Security of Supply of Electricity in the UK: Transmission and Distribution.

Prepared By

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

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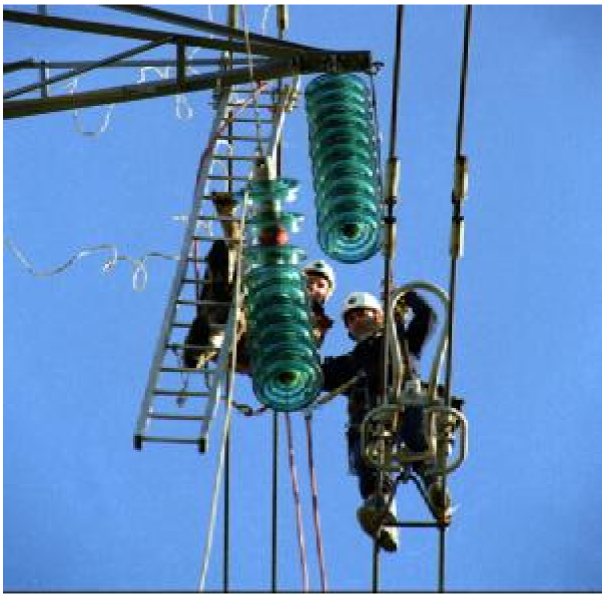

PROFESSOR JOHN H GITTUS.

John Gittus was elected Regents' Professor at the University of California in Los Angeles in 1990. He is Visiting Professor of Nuclear Engineering at the University of Plymouth, England. He was a Director of the United Kingdom Atomic Energy Authority (later AEA Technology) and is now a Consultant to Governments and private industry on nuclear matters world-wide. His recent clients include BNFL Plc, The UK Government's Department of Trade and Industry, Serco Plc, The Sumitomo Corporation, the French nuclear company COGEMA, Amersham Plc the radio pharmaceutical company, Cox Insurance Plc, the world's largest commercial insurer of nuclear risks, Chaucer Insurance Holdings and ESKOM, the South African utility.

Professor Gittus is a Fellow of the Royal Academy of Engineering (Britain's top 1,000 engineers) and has Doctor of Science degrees from the Universities of London and Stockholm. He has held over 30 patents and published over 100 papers in learned Journals describing his personal research. He invented Nimonic 115, the strongest of the early creep-resistant alloys used for the hottest turbine blades in jet engines and went on to develop a theory of creep that forms the basis of many of his papers to the Royal Society and the Philosophical Magazine. He used this theory to develop one of the world's first computer models of nuclear fuel elements, with which he forecast that some of the fuel element designs then extant would fail as their lives were extended in a quest for cheaper power. He was able to model the failure processes and deduced remedies that have been applied throughout the world. Fuel element failures are now rare, due in part to this early work.

He held a series of senior posts in the UKAEA, where he headed the late Lord Marshall's Task Force at Harwell and produced the UK's first nuclear-reactor Probabilistic Risk Assessment, for Sizewell B. He became Director of the R&D programme that underpinned the design details of Sizewell B, then Director of Safety and Director of Communications. He left the UKAEA to become the first Director General of the British Nuclear Industry Forum, where he helped with the restructuring of the UK nuclear industry, a process that is still going on. When his term of office there was complete he became a consultant, first to his successor and then, quickly, to other nuclear companies at home and overseas. On the death of Lord Marshall of Goring, Professor Gittus was appointed to succeed him at Cox Insurance Holdings Plc, advising on the insurance of the world's nuclear power stations and other nuclear installations. Since January 2003 Professor Gittus and Mr Michael Dawson have led Syndicate 1176, the biggest commercial nuclear insurer in the world and Lloyds of London's most profitable syndicate.

Amongst his published papers are two communicated to the Royal Society by P.A.M. Dirac and describing Professor Gittus's solution of a problem with the structure of matter which Dirac said he himself had been unable to solve.

Entry From Who's Who

Name
GITTUS, John Henry.

Awards
DSc. DTech; FREng 1989.

Positions
Consultant, Amersham Plc, since 1999. Consultant, Cox Power Holdings, since 1997; Consultant, Serco Plc (formerly AEA Technology) since 1993; Senior Partner, NUSYS Consultants, Paris.

Personal Details
Born 25 July 1930; *son* of Henry Gittus and Amy Gittus; *married* 1953, Rosemary Ann Geeves; one *son* two *daughters*.

Education
BSc 1st Honours Mathematics London 1952; DSc Phys London 1976. DTech Metall Stockholm 1975. CEng, FIMechE, FIS, FIM.FREng

Work
British Cast Iron Res. Assoc., 1947-1955; Mond Nickel Co., R&D Labs, Birmingham, 1955-1960 (develt Nimonic series high temp. super alloys for aircraft gas turbine engines); United Kingdom Atomic Energy Authority, 1960-1989: Research Manager, Springfields; Head, Water Reactor fuel develt; Head, Atomic Energy Tech. Br., Harwell; Director: Water Reactor Safety Research; Safety and Reliability Directorate, Culcheth; Communication and Information; Dir Gen., British Nuclear Forum, 1990-1993. Consultant: Argonne Nat. Lab., USA, 1968; Oak Ridge Nat. Lab., 1969. Visiting Professor: Ecole Polytechnique Fédérale, Lausanne, 1976; Univ. de Nancy, 1984; Regents' Prof., UCLA, 1990-1991; Prof. of Risk Mgt, Plymouth Univ., 1997-. Editor-in-Chief, Res Mechanica, 1980-1991.

Publications
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.

Recreations
Old houses, old motor cars, old friends.

Address
(office) 22 Buckingham Gate, SW1E 6LB. *Telephone:* +44 7775 898 449.

Clubs
Royal Society of Medicine, Institute of Directors.

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Figure 1: Interruptions to UK National Grid. Forecasts.

Source of Interruption.	Days: Duration of Consequent Interruption	Per Year: Likelihood	$ Maximum Insurable Amount	mean % of power lost	Million Disconnection.days
Storm	20	0.001	2E+08	25	100
Storm	5	0.01	2E+08	10	10
Storm	3	0.05	2E+08	8	4.8
Surge on west coast	10	0.001	2E+08	5	10
	5	0.01	2E+08	1	1
Surge on east coast	10	0.001	2E+08	5	10
	5	0.01	2E+08	1	1
Tornado	10	0.001	1E+08	5	10
Seismic	70	0.0002	1E+08	5	70
Hail	5	0.0003	1E+08	2	2
Terrorist Action	10	0.03	0	1	2
Control software or hardware failure	3	0.03	2E+08	10	6
Plane crash	5	0.001	2E+08	2	2
BLEVE	10	0.001	2E+08	2	4

Figure 2: The UK National Grid.

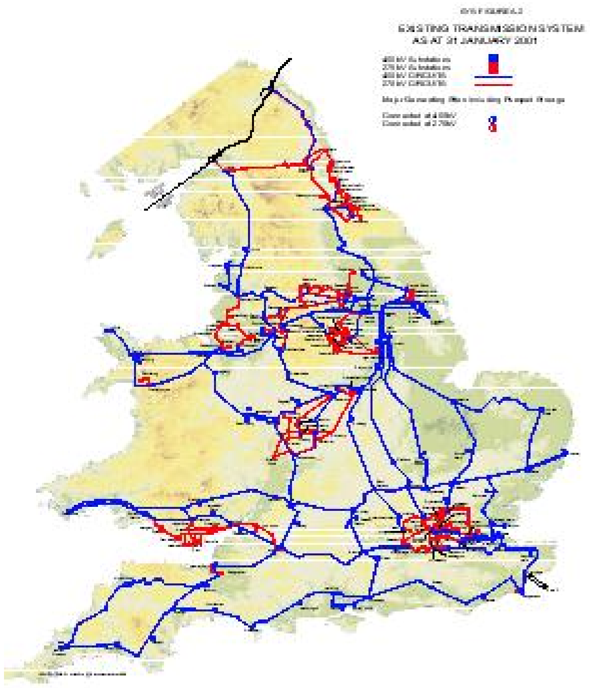
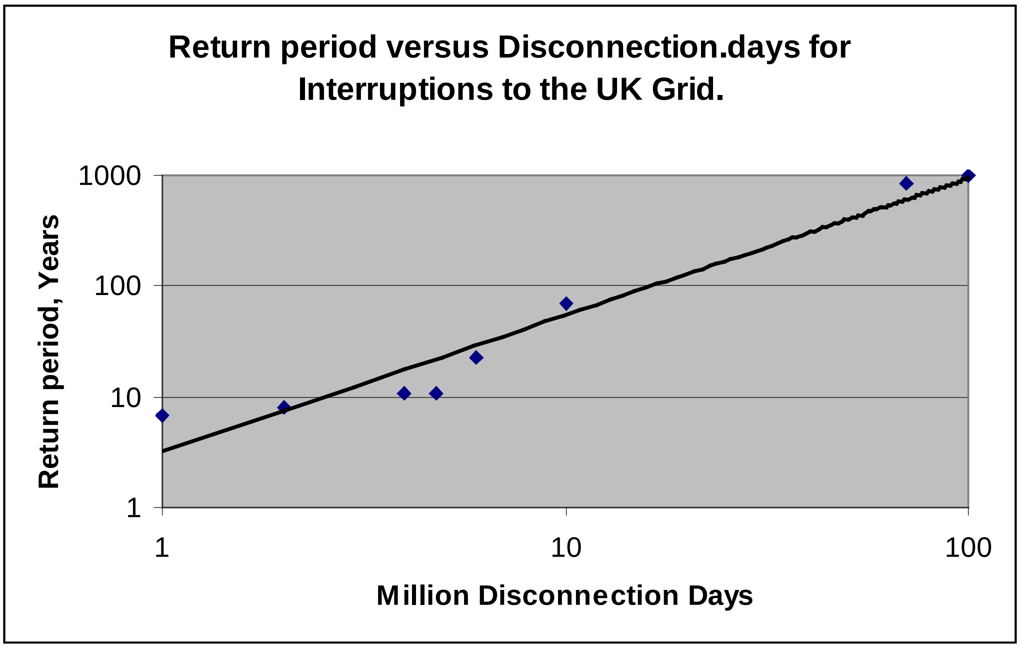


Figure 3: Return Period versus Disconnection.Days for Interruptions to the UK Electricity Grid.



Introduction.

My approach, in this analysis, is to start with a series of storms that produced widespread disconnections of the French transmission and distribution systems and then deduce from that the frequency and extent of the disconnections that severe storms will produce in the UK.

To the effects of storms are then added those of other events such as earthquakes.

Interruptions to French Electricity Supplies by Lothar and Martin Storms.

The French electricity grid was hit hard by storms on December 27 1999: about 180 high-voltage towers broke down and nine million people found themselves cut off from the grid. The estimated damage to EDF was about US$3 billion. From 25 to 28 December 1999 a series of four intensive storms developed rapidly over the Atlantic and moved into West Europe and then further east. Two of the four storms, Lothar and Martin, caused extensive damage over west and central Europe, primarily due to extremely strong winds. Extreme winds were produced by these three cyclones. For some of the recording stations, the observed gust wind speeds were of record-breaking intensity. For each event, there was a band of extremely high baroclinicity near the cyclone track over the Eastern North Atlantic and extending partly into Europe. High equivalent potential temperatures were observed south of the track. These large scale characteristics are common to European storm events, though the details of the synoptic development are rather different.

From a satellite meteorology point of view, the events were extraordinary as all of these storms are examples of the Conceptual Model "Rapid Cyclogenesis" but with different intensities. Two storms, named "Lothar" (25 - 26 December) and "Martin" (26 - 27 December) can be regarded (with some differences) as ideal examples of "rapid cyclogenesis". A third storm (called "Lothar successor") initially had the potential for rapid cyclogenesis but eventually, developed somewhat less.

Nuclear Generation was Interrupted by the Storms.

The waters of the Gironde were pushed by the winds over the protective dike around Blayais, which houses four reactors. Units 2 and 4 were stopped in the evening of December 27, unit 1 around 12.00 on December 28; unit 3 was already shut for maintenance. Invading the site through underground service tunnels, the waters flooded the pumps of unit's 1 Essential Service Water System (ESWS). This disabled the residual heat removal system, which is necessary to cool the reactors. Shortly afterwards the flood waters reached the spent fuel buildings for units 1 and 2, knocking out their safety inspection system and containment spray system too. After the internal emergency was declared, firefighters from nearby town Blaye assisted Blayais' own flood-fighting team. On December 30, the ESWS resumed operation and Blayais-4 was restarted. Electricité de France (EDF) needed its power badly to power the southern grid, which was no longer connected to the north because of the storm damage to the transmission system.

EDF said that the level of the Gironde river during the storm had been higher than the millennial level against which the dike around Blayais was designed. The French national safety agency DSIN allowed EDF to repair provisionally the pumps, motors and valves of the safety inspection system and the containment spray system of units

1 and 2. Since the incident, the two reactors had been cooled through their steam generators. After the provisional repair, EDF brought units 1 & 2 to cold shutdown, to allow installation and qualification of the new equipment and the repair of the safety systems. EDF first planned to restart units 1 & 2 by early January. But plant management later declared that other piping and concrete structures were being checked.

According to Quintin of the regional inspectorate and Goelnner, assistant director of DSIN, the dike was inadequate, the service tunnels were not protected against flooding.

The main reason why the national electricity grid was hit so hard by the storm is that the masts of the grid were not designed to withstand such heavy storms but also because the middle-voltage grid lines are mainly aboveground and thus very vulnerable. In other countries a larger part of the lines are underground. EDF will do research into the possibility of putting more power lines underground, but to put high tension lines underground is ten to twenty times more expensive than above-ground lines. The research is expected to take some ten years.

One Quarter of France’s Grid Interrupted by the Storms.

The passage of Lothar and Martin across France caused the greatest devastation to an electricity supply network ever seen in a developed country. EDF did not restore power to all homes before the new year.

Following Lothar, more than 120 high-voltage transmission pylons were toppled, 36 high-tension transmission lines were lost (a quarter of the total lines in France), and all electricity links with Germany were severed. Two million homes and businesses were left without power, and up to 1.6 million domestic customers had no water due to the lack of pumping capacity. After Martin, all the main electricity connections between northern and southern France had been severed, the number of toppled high-voltage pylons had risen to 280, and the total number of homes and businesses without power had risen to 3.5 million, affecting 10 million people. Worst affected was Charente-Maritime, where 30 high-tension transmission pylons were down, along with 1,000 middle-voltage distribution towers. In La Rochelle, two hundred 20,000-volt pylons and thirty 100,000 to 200,000-volt pylons were blown down or damaged by falling trees. A day after the storm, 90% of people in the departments of Correze and Dordogne and 80% of people in Cantal were without power. The lack of electricity deprived 360,000 telephone subscribers of phone service as of December 27th. By December 28th the number was one million-many batteries that France Telecom was using for backup had reached the end of their useful lives.

The state-owned Electricité de France (EDF) recovery effort was military in scale, expanding day by day until it involved up to 50,000 EDF employees, with 45,000 subcontractors and 6,000 soldiers.A total of 400 helicopters were in operation, and having exhausted all supplies in France, 650 km (400 mi) of spare cable had to be air-lifted on 14 transport planes from Italy. After a week, the number without power had fallen to 500,000 and power was completely restored within 20 days. On December 30, EDF offered any domestic customers who were not reconnected by the evening of the 31st free electricity for the year 2000. Compensation for power cuts to farmers was negotiated region by region, based on a 1987 national agreement. In February of 2000, EDF estimated its losses from the storms at € 1.5 billion ($1.5 billion). By December, the company estimated that future investments to upgrade their network could be as high as € 7.6 billion ($7.7 billion).

The Passage of the Storms into France.

The windfields from the two storms covered more than half of France and extended into Switzerland and Germany. Between them, these windstorms produced over € 14.2 billion ($14.4 billion) in economic damage, approximately € 7.7 billion ($7.8 billion) of which was insured. This ranks as the third largest insurance loss ever, after Hurricane Andrew in 1992 and the 1994 Northridge Earthquake. Windstorm Lothar alone represents the largest monetary insurance loss in European history. The storms caught Europe by surprise. Meteorological forecasts failed to predict Lothar's dramatic inland intensification. Modern infrastructure such as electrical distribution systems, transportation, and communication lines were hit particularly hard, leading to several very large insured and uninsured losses throughout the industrial and public sectors. Observed damage to residential structures was in line with previous experience, however the total damage from Lothar and Martin covered an exceptionally large area leading to higher overall losses. The French insurance industry also was not prepared for losses of this magnitude. Common risk transfer practice in France was for insurers to buy cover based on the level of losses in the 1990 storms Daria and Herta. These covers proved inadequate, because windspeeds in the 1990 storms were almost 20% lower than those experienced in Lothar and Martin. In addition, the occurrence of two storms within the typical 72-hour interval for reinsured events tested reinsurance contract definitions and previous assumptions.

Windstorm Lothar first developed east of Newfoundland early on December 25.The storm was swept along by an exceptional jet stream early in the morning of the 26th, at forward speeds of up to 130 km/h (80 mph). As Lothar reached the coast of northern France, the speed of the storm slowed to 97 km/h (60 mph) and the system began a rapid phase of intensification --the pressure falling an almost unprecedented 32 millibars (mb) in 8 hours, reaching 960 mb as the storm hit Paris. Although Windstorm Lothar was only 300 km (190 mi) in diameter, far smaller than most extra-tropical cyclones, the dramatic intensification resulted in internal pressure gradients comparable to those found in a strong Category 2 hurricane. Unlike a hurricane, however, the system did not weaken after landfall, but continued to intensify as it travelled inland. High winds were located in a 150-km (90-mi) wide band immediately to the south of the track. The winds on the ground reached more than 180 km/h (112 mph) on the coast, and inland up to 172 km/h (107 mph) at Orly Airport to the south of Paris, where the storm was at its most intense. Even before Lothar had dissipated, a new westerly moving disturbance was developing close to where Lothar was born. Tracking 200 km (125 mi) south of the first storm,Windstorm Martin reached its lowest recorded pressure (964 mb) and highest windspeeds as it crossed the French coast on the evening of December 27.Windspeeds were comparable to those of Lothar --up to 190 km/h (119 mph) at the coast and 158 km/h (98 mph) inland.

On the night of December 24-25, 1999, a vast counterclockwise circulation associated with a depression over England brought Arctic air from northeastern Greenland down to interact with tropical air circulating around the Bermuda High. Lothar developed along the cold front where these airmasses met. The location and strength of the jet stream that ran above this front turned a small vortex disturbance into the most intense cyclonic depression to make landfall in western Europe in a decade. There was a marked boundary to the south, with warm moist air raised into the upper atmosphere by the intense convective activity over the Caribbean during December. At 9-km (6-mi) elevation on Christmas Day, the jet stream reached 400 km/h (250 mph), evidenced by Christmas Day flights from New York to London that arrived 90 minutes early.

Storm Forecasts.

Windstorm Lothar was not well predicted. One meteorologist later claimed that forecasts could be split into those that were poor and those that were very poor. This was a symptom of the extreme instability in the atmosphere: according to some forecasts, the storm was predicted to pass through the U.K., while others failed to predict significant intensification at all. However, the strong jet stream that was the chief cause of the instability was well predicted by the European Centre for Medium-Range Weather Forecasting (ECMWF) 9 days earlier. Approximately 24 hours before the storm hit France, Météo-France issued a warning of a strong storm with the correct path, but two hours before the storm hit Paris, inland windspeeds were still predicted to be between 90-130 km/h (56-81 mph), rather than the 125-175 km/h (80-110 mph) range actually experienced. After Lothar, forecasters debated whether additional offshore data could have improved the warning, or whether the storm's dramatic intensification remained beyond the present generation and scale of Numerical Weather Prediction (NWP) models. It is clear that situations of very high instability (such as the unusually straight jet stream) inevitably imply low predictability. A similarly straight and strong jet stream existed the day before the arrival of the October 15-16, 1987 (1987J) storm, which impacted northwestern France and southeastern England, resulting in € 1.88 billion ($1.9 billion) in insured losses.

Residential Sector.

Of the 3 million claims received in France, 2.5 million came from the residential sector, accounting for 50% of the total insured losses. According to the Fédération Française des Sociétés d'Assurances (FFSA), claims were received from about 10% of residential policies, four times greater than the combined losses from 1990 Windstorms Daria and Herta. The average residential claim was approximately € 1,525 ($1,545), only marginally higher than the € 1,250 ($1,270) average in 1990. Windstorm Lothar affected residential buildings from Ouessant to Strasbourg, showering the streets with broken tiles. In the town of Saint-Pierre-sur-Dives in Calvados (population 4,000), 90% of properties were affected, and 50% made an insurance claim. In and around Paris, an estimated 60% of roofs experienced some damage. Trees were often agents of damage to both buildings and cars, even in city centres. Every town in the path of the storms was affected. More than 6,000 trees (of a total of 173,000) were blown down in Paris, over 1,000 street trees fell in Versailles, and around 300 trees fell in the city of Bordeaux. In a national survey of low-value local authority housing (HLM), 17% of 270,000 respondents (out of 3.5 million housing units) had made a claim, with an average claim size of approximately € 1,525 ($1,545). Approximately 1,100 people (out of a total of 16 million residents) were rehoused. Roofs accounted for 95% of the principal damage, although 35% of building fronts were affected, as well as antennae, shutters, windows, and trees. RMS field surveys identified four principal factors influencing the level of residential building damage: * Rural versus urban location: Damage was generally worse in rural areas due to a combination of higher windspeeds in areas of low surface roughness and higher building vulnerability. For example, in the village of Presles in southwest Calvados, 19 out of 20 farms were damaged.

Period of construction:

RMS surveys in towns in eastern France immediately after the passage of Lothar showed damage patterns that varied according to the age of the building. Broken roof tiles from very old houses were scattered throughout town centres. In addition, buildings constructed during the late 1980s and early 1990s were widely affected while housing of the 1960s and 1970s in the same locations suffered low levels of damage. A similar pattern was observed in eastern regions of Paris and new housing developments north of Paris. * Architectural elements: The tall, slender chimneys typical of older buildings in central Paris were particularly vulnerable to damage in the high winds, and many toppled over, causing additional damage to roofs. Buildings with modern high-pitched roofs also performed poorly.

Level of maintenance:

Poorly maintained roofs showed higher levels of failure. This was particularly apparent among older buildings. For example, a row of mid-19th century Hausmann era buildings of the same age and style in western Paris showed varying levels of damage. Interviews with companies making repairs confirmed that the level of maintenance and renovation was a primary factor in the relative performance of the roofs. Commercial Sector

Commercial and Industrial Losses.

Commercial and industrial facilities experienced € 2 billion ($2 billion) of losses due to Windstorms Lothar and Martin. The average commercial and industrial claim was € 5,790 ($5,870), significantly higher than in 1990. This was in part a consequence of `warranty' extensions to basic coverages put in place during the 1990s by insurers seeking to preserve or increase their market share. The average was also dominated by a handful of very large industrial losses, the largest of which was over € 150 million ($152 million). The worst affected location for commercial and industrial losses was the port at La Rochelle/Pallice in Charente-Maritime, a principal center of cereal exports. A container crane was blown into the Charente River, and two others were damaged. Commercial properties sustained widespread damage to lightweight roofs commonly used for warehouses, causing water spoilage to stored goods and equipment. Warehouses and manufacturing facilities were hit hard in other regions as well, particularly around Paris. An RMS survey of a major auto manufacturing facility in Poissy south of Paris revealed that 40% of the total insured losses of € 1.8 million ($1.9 million) was from roofing damage. This is typical of industrial complexes in the path of the storm. Other commercial buildings suffered damage, particularly to glass curtain walls in office blocks. Buildings in most business parks around Paris were also affected.

Among public facilities of commercial construction, schools were the worst affected. Of France's 11,400 schools, 935 (8%) sustained damage in the storms and a number had to be closed for repairs. Across the path of Windstorm Lothar, from Brittany to Lorraine, the proportion of schools and colleges affected varied from 50% to as high as 60% in Ile de France around Paris and 80% in the Champagne region to the east. Average damage in the worst affected departments was close to € 150,900 ($152,900) per school. The worst damage was found in schools built in the 1960s/70s and during the 1990s and was associated with the use of lightweight architectural elements of metal, plastic, and glass in walls and roofs.

Business Interruption Losses.

In terms of business interruption impacts, the storms could not have been more fortuitously timed. By the time most people had returned to work on January 3 (eight days after Lothar), the number of electricity disconnection-days had fallen to around 10% of the total, and most of the damaged roofs had gained a temporary covering. Insured losses were further mitigated by the fact that policies for small businesses did not cover business interruption, while other larger commercial policies specifically excluded losses caused by an interruption in the supply of electricity or other lifelines. While Windstorm Lothar was responsible for the majority of losses across France, some of the most severe damage was observed where Windstorm Martin made landfall in the open terrain of the Charente- Maritime and Gironde departments.

Storm Surge.

However, the most dramatic impact of Martin was associated with the storm surge caused by onshore winds that were at their climax when the storm made landfall. The small town of Port-des-Barques (1,750 people), located on the outer estuary of the Charente River, was overwhelmed by waves, and at La Rochelle 500 boats were smashed or sunk. Worst affected was the Gironde estuary, where water accumulated in the funnel of the bay causing a 2.5-m (8-ft) storm surge. On the evening of December 27, the quays along the Garonne River in Bordeaux flooded, forming a lake approximately 50 cm (1.6 ft) deep that immobilized large numbers of parked cars. Further north, the entire peninsula where the Garonne and Dordogne rivers meet was converted into an island. At 21hrs on December 27, the majority of houses in the town of Ambès were inundated with water, mud, and debris. Nearby, the 1,800 inhabitants of the village of Saint-Louis de Montferrand were flooded when the surge overwhelmed dykes that were never repaired following a storm surge in February 1996. More than 2,000 people had to be evacuated --41 of them by helicopter after a dyke ruptured. The water remained for a few hours and then fell with the tide during the night of the 27th-28th.

Effects on Telecommunications.

Transmission and distribution is controlled by electronic means. In this context it is important to be aware that Lothar and Martin had spectacular effects on France's telecommunications infrastructure. The country's modern telecommunications network was tested for the first time in storms of this intensity, resulting in the largest single insured loss of over €152 million ($154 million) to France Télécom.

The telephone system was progressively brought down by the loss of electricity, and the emergency batteries in handsets only lasted for three days. By December 30, more than 1 million subscribers were without telephone services.

Even mobile phone users did not escape. In Charente-Maritime, 60% of mobile phone relay stations were out of action. Across the whole of France, cellular network providers lost between 8-16% of their nationwide mobile phone relay stations.

Effects on Transport.

Transportation systems were also impacted, sustaining losses over € 300 million ($305 million). Owing to the number of trees and power lines that fell on the track, the railway system was completely halted across much of eastern and northern

France after Lothar, as well as the whole of southwest France after Martin. Trees brought down overhead lines at more than 220 places. A total of 10,500 passengers were trapped in the Gironde, as well as another 700 passengers at Poitiers. Even 10 days after the storm, three major railway lines through central France had not yet been reopened.

The rail operator SNCF estimated its total losses at € 78 million ($79 million), including € 30 million ($31 million) for business interruption. After Lothar, 80% of secondary roads to the north of the Loire were blocked. Many autoroutes were also interrupted, including the A4 and A35 in eastern France. The A13 in the heights of Marly remained closed for 4 days, as 200 fallen trees had to be cleared. All the roads over the Vosges mountains were also impassable. As late as the 30th of December, 4,300 km (2,700 mi) of secondary roads remained blocked in Charente-Maritime. Four airports were closed as a result of Lothar, including both Paris airports. At Orly West, a 50-m (165-ft) long glass and metal roof collapsed at the entrance to the arrival gates.The airport at Clermont- Ferrand had its control tower damaged, and the roof of the airport at Metz also needed repairs.

Insured Losses.

Windstorms Lothar and Martin caused the largest insured catastrophe loss since 1992, when Hurricane Andrew generated € 15.2 billion ($15.4 billion) in insured losses. Official estimates from the Fédération Française des Sociétés d'Assurances (FFSA) put insured losses from all natural events in France during 1999 at € 6.9 billion ($7 billion), of which € 6.5 billion ($6.6 billion) was attributed to Windstorms Lothar and Martin. Five insurance groups paid approximately 60% of these losses. Across Europe the storms caused additional losses of about € 700 million ($710 million) in Germany and € 500 million ($510 million) in Switzerland. Due to the lack of historical precedent, market participants were surprised by the level of loss across all insurance sectors.

For example, residential losses were € 3.4 billion ($3.5 billion), substantially higher than the € 1.1 billion ($1.1 billion) loss experienced in the 1990 storms Daria and Herta, which have been used as the primary catastrophe benchmark event for the last decade. Windstorm events impacting western Europe can cause a greater number of claims than almost any other type of natural catastrophe due to large event footprints and a high population density. In France, windstorm is a covered peril in all fire insurance policies, so the majority of property losses were insured.

In the weeks immediately following Lothar and Martin, insurers were overwhelmed with nearly 3 million claims, resulting in bottlenecks for claims adjusters.To help manage the problem, some insurers initially publicized `no-claims assessor' thresholds as high as € 7,620 ($7,725) The magnitude of damage constituted about three months `French Roofing GDP'. Inflation in the days following the storm was rampant. In some of the worst affected areas close to Paris, the price of tiles increased more than 300%, and repairers' labor rates surged. A week after the storm, there were stories in the press of tree clearing quoted at € 305 ($310) per hour, and replacing 20 tiles on a roof cost up to € 1,220 ($1,240).

Reinsured Losses.

In terms of catastrophe reinsurance protection, the French market had not anticipated a loss of this magnitude. The French market bought cover totaling € 2 billion ($2 billion) in 1998 and € 2.1 billion ($2.1 billion) in 1999, using the 1990 storms as the benchmark for reinsurance purchasing. Companies who took the seemingly conservative stance of buying protection based on 1990 losses plus 20-30%, found these programs wiped out by Lothar alone. Reinsurers were also heavily impacted. Very soon after the storms, reinsurers agreed to consider the two storms as separate events for the purpose of reinsurance recoveries, despite the fact that the storms happened within the critical 72-hour period. The final bill for reinsurance companies was nearly € 3.6 billion ($3.7 billion), representing about 55% of total insured losses. This experience calls into question previous patterns of reinsurance purchasing and raises new questions for reinsurers about the implications of the 72-hour clause.

The experience of Windstorms Lothar and Martin challenges previous market practices and rates for both insurers and reinsurers in France. Pricing for additional catastrophe covers doubled immediately following the storms, and insurers remained under pressure for 2001 renewals as companies revised their reinsurance limits to equal or exceed their losses from Lothar. Increases of 50% for the lower tranches of reinsurance and as much as 300% for the highest layers were reported, aggravated by a continuation of tight capacity in the retrocessional market.These reinsurance rate increases and capacity constraints revived interest in alternative risk transfer. Primary insurance rates were also expected to increase, but at a much more modest pace. Several French companies decided not to increase their residential rates in 2001. Reported increases in auto rates are in the region of 3%, while the industrial rate increases of 15% publicized in September 2000 were revised down to about 5%.

The Implications of multiple Storms.

The prospect for grouping losses from two windstorms that occur in 72 hours into a single reinsurance recovery remains not only in France but also in all European countries. Such `twin storms' are quite common. Over the previous decade, the losses from Windstorms Vivian and Wiebke in Germany in 1990 and the December 24-25, 1997 storms in the U.K. were effectively inseparable. Twin storms typically have parallel tracks, often compounding damages from the first storm.

Historical Precedents.

Lothar is the most damaging storm to have affected France for more than 200 years. The northeasterly heading 1987J windstorm, with similar windspeeds and size, only affected the northwest corner of France, and the majority of its windfield was offshore. However, Lothar had a majority of its windfield over land and made a direct hit on Paris, the highest concentration of exposure in France. RMS analyzed over 100 geographic `relocations' of Lothar's footprint, and found only two scenarios that generated higher losses for France than those observed using Lothar's actual track.

Forest damage can be used as a proxy for assessing the relative impact of windstorms in western Europe over the past 150 years. Normalizing treefall as years of timber-harvest lost provides a consistent metric comparable to percent industry insurance loss. Lothar and Martin blew down 3 years of timber harvest in France, 2.7 years in Switzerland, and 0.75 years in Germany. This compares with 1990 windstorm losses of 0.3 years in France, 1.2 years in Switzerland, and 2 years in Germany. In France and Switzerland, forest damage from the storms in 1999 was more than twice that of any previous year out of the past 150. The Company known as RMS has made historical research and storm reconstructions covering the last 500 years of history. These show two storms similar to Lothar passing through northeastern France in 1581 and 1800, with tracks slightly further to the north. However, no storm of this intensity has passed directly over Paris.

Although Lothar represented a relatively extreme loss for France, for Europe as a whole RMS estimates the return period for a `Lothar-sized' loss at approximately 15 years. A Lothar-like storm passing directly over London would cause industry insured losses in excess of € 11.8 billion ($12 billion). However the return period for this is not 15 years: it is a much longer period as only a small percentage of the severe storms that hit Europe will actually damage London. The vast majority will affect some other geographical sector of Europe.

Modelling the Storms that Will interrupt Transmission and Distribution of Electricity in the UK.

In the previous section we established that storms can seriously interrupt the transmission and distribution of electricity. The storms Lothar and Martin, which produced the most severe interruptions ever experienced in a developed country, demonstrated the proportion of a European country’s transmission system that has been so interrupted and the period of interruption.

The country in question was France, but it could have been the UK had the path of the storm been more northerly.

What then is the return frequency of such storms for the UK, and how severe must they be in order to interrupt the transmission and distribution of electricity in the UK? These are the questions that will now be addressed and answered.

Historical and Stochastic Methods: the “Virtual Database”.

History is a poor guide to the future effects of storms. Detailed records have not been kept for a sufficiently long period of time. However historical storms can be analysed and the component parts of the evolution of a storm can then be used to generate numerical simulations of storms that could have occurred, but which in the event never have occurred.

In this way many simulated storms can be developed and incorporated into a database—a “Virtual Database”. Then from the virtual database the return period of storms of varying intensity can be calculated, for the UK (or another country, if so desired).

The characteristics of the limited database of actual storms can then be compared with those of the storms in the virtual database as a way of demonstrating that the latter are indeed realistic. The comparison will have to be made for the whole of the European landmass because it is only for this large area that significant historic storm data are available.

Providing that there proves to be a good correlation between the historic European storms and the virtual ones, we can have confidence in the virtual storms constructed to the UK, both in terms of their severity and their duration.

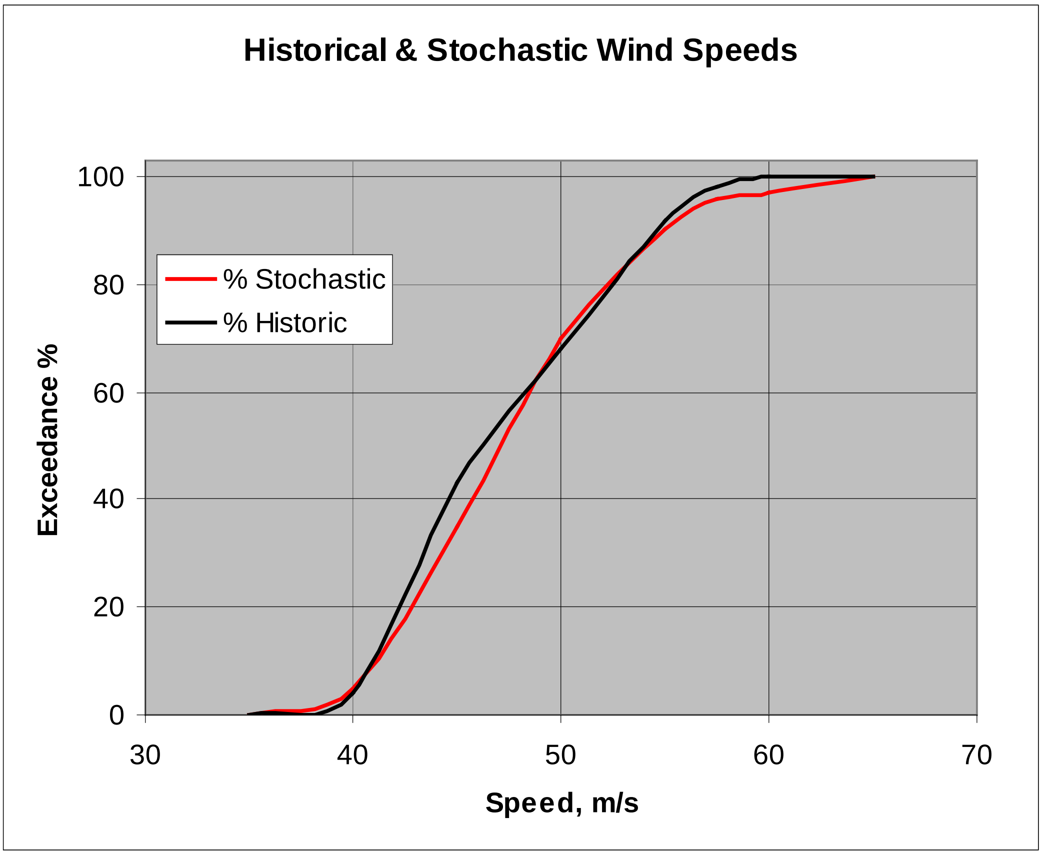
Numerical Weather Prediction, NWP.

Traditionally, the potential costs of catastrophic risk, including those presented by extreme weather events, have been transferred, or dispersed, through various insurance instruments. This is true for both corporate interests and individuals. Understandably, the insurance industry has been interested in catastrophic event. risk modeling and loss mitigation for a long time. On the other hand, costs arising from regional climate anomalies have been borne by businesses under operational expenses. Recently, weather risk of this kind has begun to be addressed using financial instruments called Weather Derivatives, especially for the energy sector in the US. As energy markets have been deregulated, use of these instruments has increased. Weather derivatives are also beginning to emerge in other countries, especially in Europe. Numerical Weather Prediction (NWP) models have played an important role in public safety and damage mitigation for extreme weather events for years.

Comparison of Wind Speeds.

The following Figure compares historical wind speeds with those forecast from virtual storms. The latter are termed “stochastic” windspeeds. This comparison is taken from published work describing the development and properties of models developed by the Company AIR. It will be seen that there is good agreement, giving confidence in the storms that form the virtual database in the case of these particular models.

Figure 4: Comparison of Historical and Stochastic Wind Speeds [1]



Comparison of Modelled and Actual Losses.

The actual and modelled losses have been compared for recent European storms and a representative example of these comparisons in shown in the following figure, which is for Herta (1990) Good agreement is found, as is the case for all the half-dozen or so storms for which such comparisons have been made.

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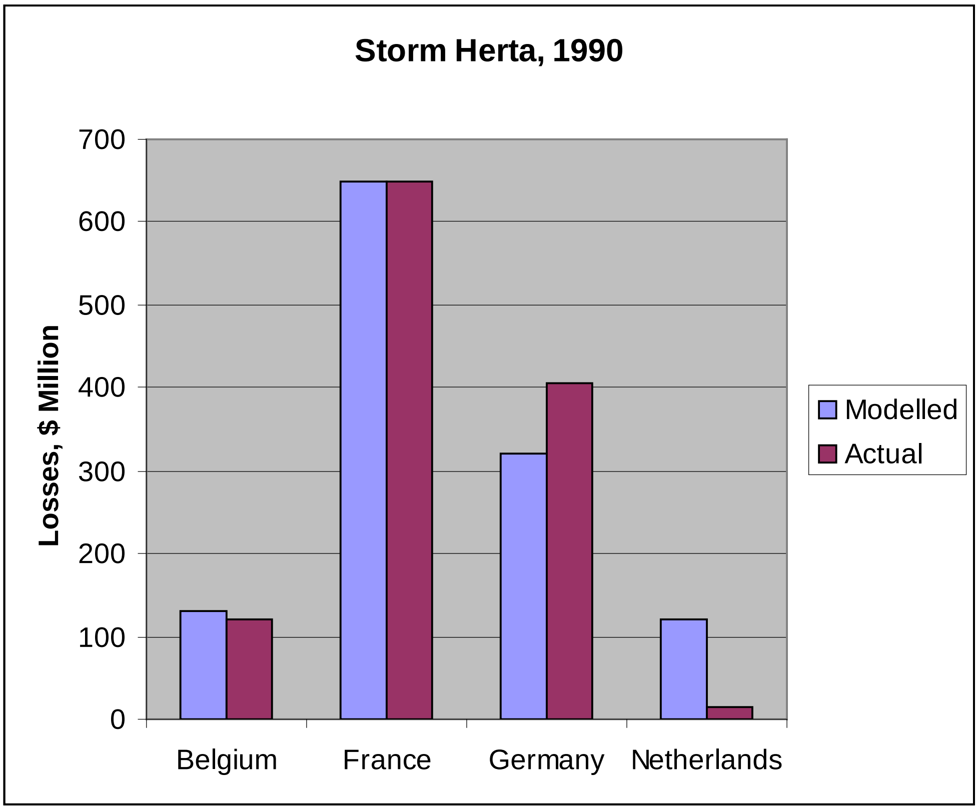
[1] From published work on the AIR model. Corresponding author address: John L. Keller, Applied Insurance Research, Inc., 101 Huntington Ave., Boston, MA 02199, jkeller@air-worldwide.com.

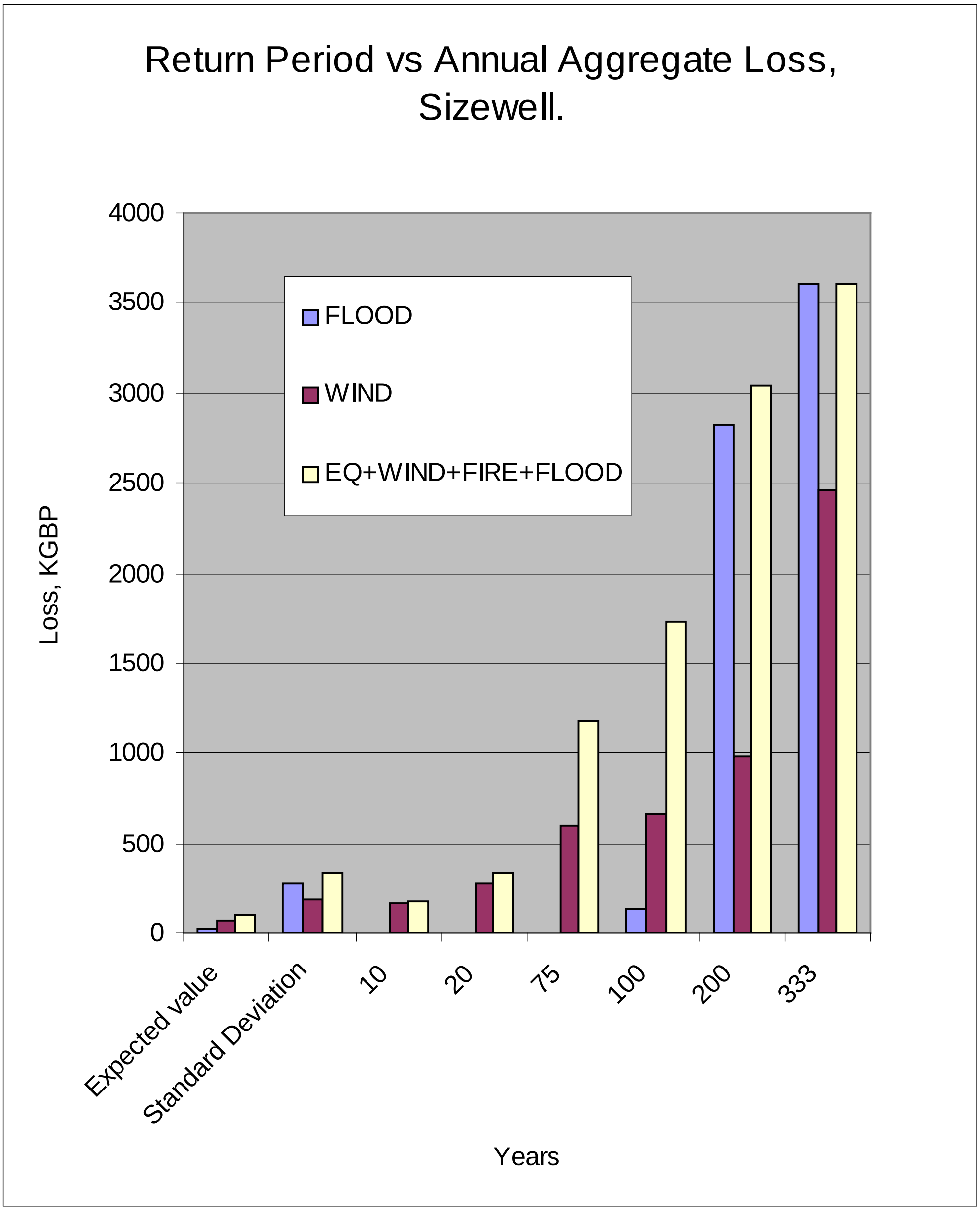
Figure 5: Comparison of Modelled and Actual Losses for Storm Herta, 1990



Forecasts.

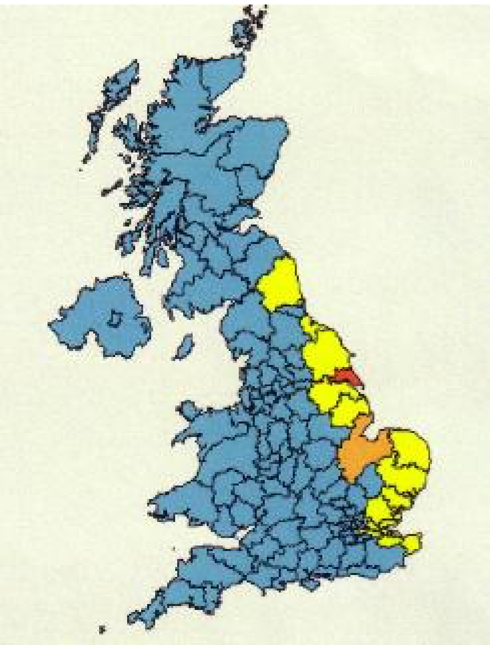
An example of a forecast arrived at from the virtual database in given in the following figure, which is for the Sizewell B nuclear power station. Here the return periods extend to only 333 years and the losses do not involve any release of radioactivity: they are simply due to damage to office and similar buildings.

Figure 6: Forecast Losses at Sizewell.



The next Figure shows the forecast Storm losses for Sizewell should the flood occur that has a return period of 100 years. Also shown are the losses sustained in surrounding parts of the UK.

Figure 7: Forecast Storm Losses, Sizewell, 100 year Flood. Red = 1 BNGBP Loss.

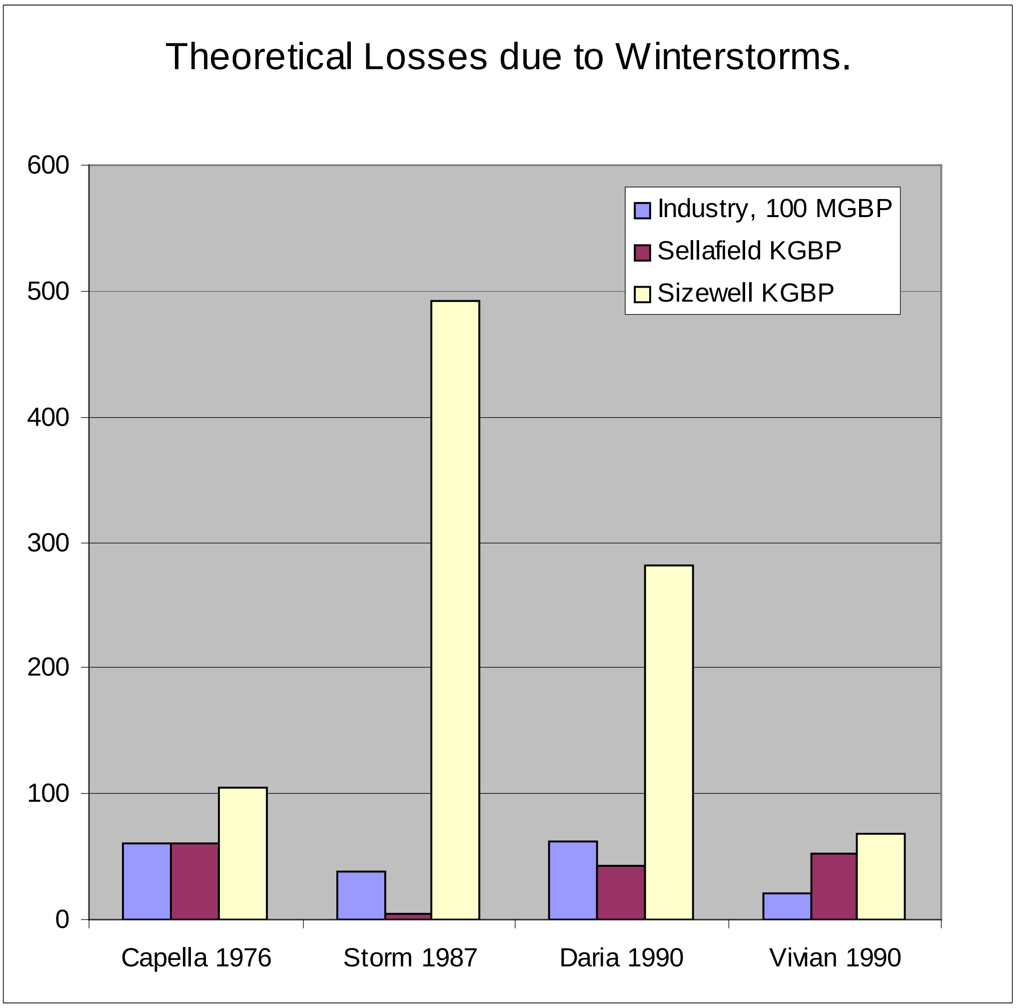


The following Figure shows the theoretical losses due to historic winter storms.

The industry-wide losses shown in this figure correlated well with those that actually occurred.

The theoretical losses at Sellafield and Sizewell do not involve damage sufficiently severe to cause any release of radioactivity. These losses are instead those that might be anticipated from damage to office and similar buildings.

Figure 8: Theoretical Losses due to Historic Winter storms.

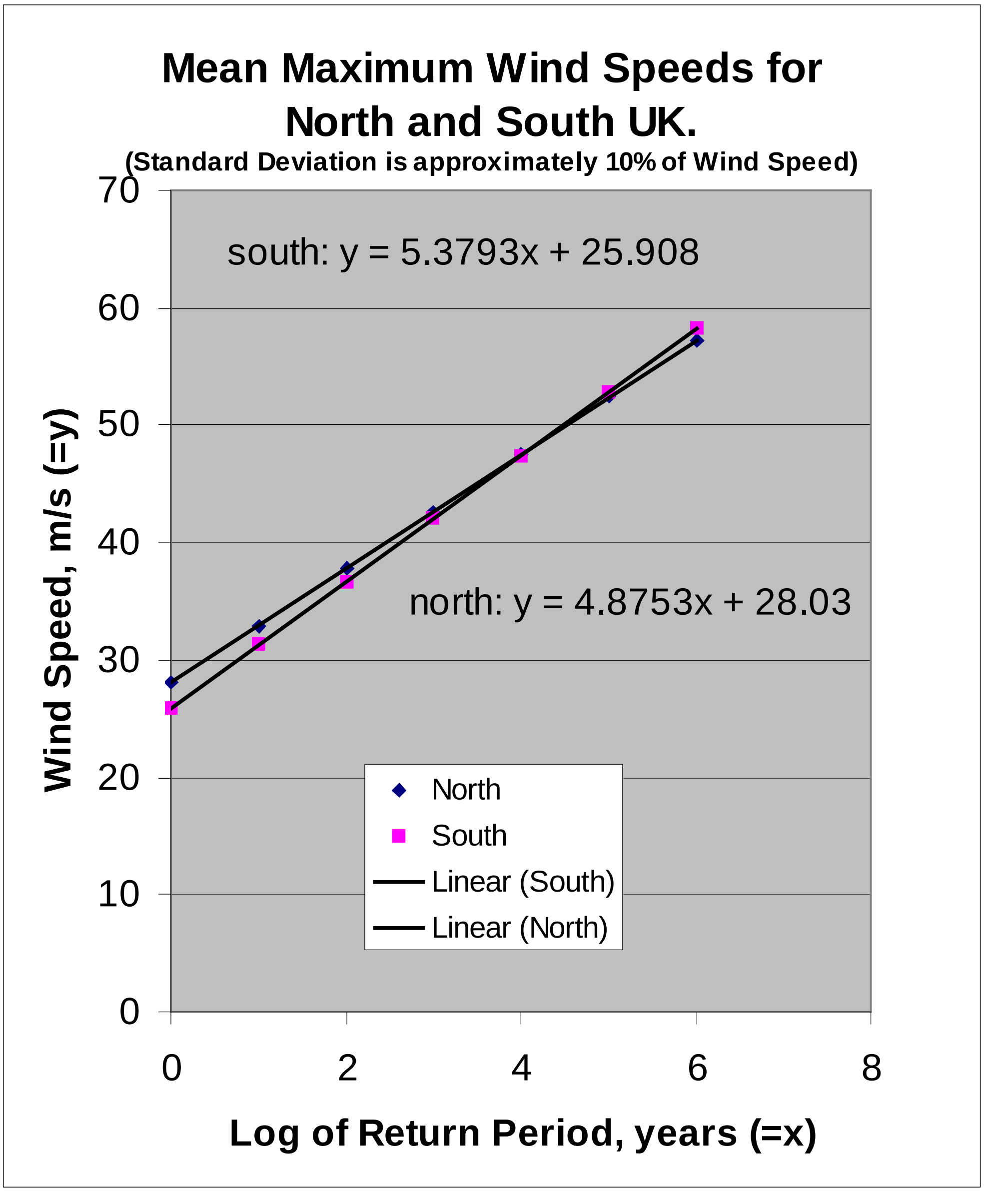


Forecast of Interruptions due to Wind Storms.

Forecast Windspeeds.

The following Figure summarizes my forecasts of the (log to the base ten of Return Period) for Wind Speeds in North and South regions of the UK.

Figure 9: Forecast Mean Maximum Wind Speeds for North and South UK.



These are the mean maximum wind speeds and gusts of substantially higher velocities are to be expected, Figure 10. Tornados, with which I deal separately, produce much higher wind speeds, albeit for brief periods and over limited areas of land or sea.

Figure 10: The Highest Wind speeds Recorded in the UK.

Low-level site:	**123 knots**	**Fraserburgh, Aberdeenshire, 13 February 1989**
High-level site:	**150 knots**	**Cairngorm (1,245 m AMSL), 20 March 1986**

In the UK, the storms that generate these localised wind speeds cover areas equal to or greater than that of the whole country. They last on average for an entire day.

UK versus France: Storms 1987J, Lothar and Martin.

The storms Lothar, Martin and 1987J are here used to estimate the interruption to transmission and distribution that storms in general will produce in the UK:

Windstorm 1987J caused 2.3 million disconnection-days in the UK and affected an area which was one fifth of the area of France that was affected by Lothar. Had it affected as big an area of the UK as Lothar did of France, therefore, it would have produced 11.5 million disconnection-days, supposing that the UK transmission and distribution systems have the same resistance to storm-damage. In fact Lothar caused 12.6 million disconnection-days in France, which is near to the figure of 11.5 million disconnection days.

We may therefore conclude that, if Lothar had centred on the UK instead of France, it would have caused the same number of disconnection-days at did Lothar in France: of the order of 12 million disconnection-days.

Lothar and 1987J produced mean maximum windspeeds of about 40 m/s. Figure 9 shows that such windspeeds have a return period of order 100 years in the UK. Consistent with that conclusion is the fact that Lothar is the most damaging storm to have affected France for more than 200 years.

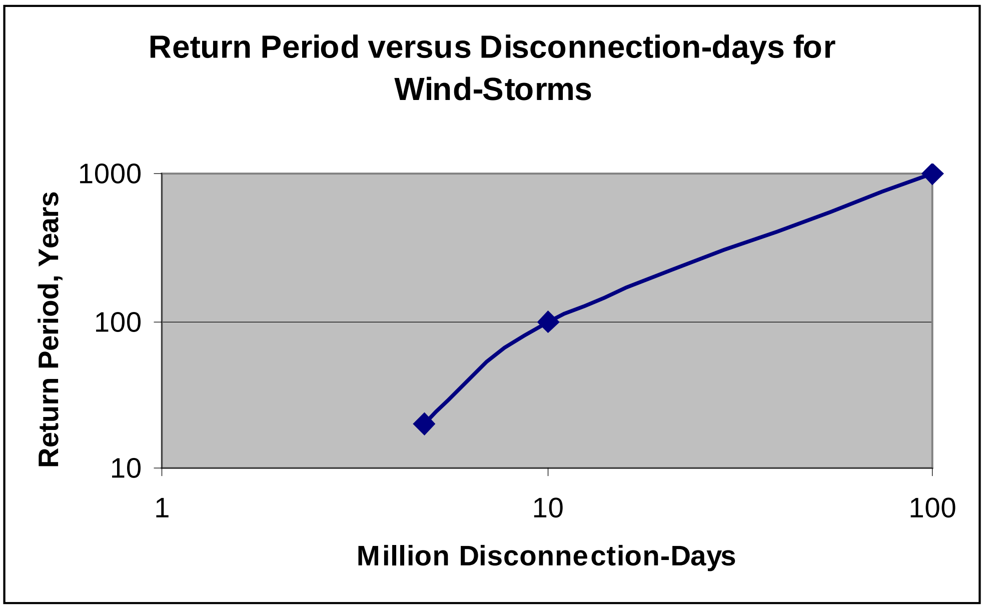
Forecasts for a Lothar-like Storm in the UK.

From the data on Lothar, Martin and 1987J summarized in the earlier part of this Report, it is deduced that storms having a return period of 100years will cause a loss of an average of 10% of electric-power to UK consumers for a period of 5 days, leading to 10 million disconnection-days.

Forecasts for Other Wind Storms in the UK.

Similar considerations lead to the forecasts for more frequent and less frequent windstorms. The following Figure shows the relationship between Return Period and Disconnection days for Windstorms:

Figure 11: Forecast Return Period versus Disconnection-Days in the UK: Wind Storms.



Surge.

The enormous mechanical forces of high waves have a colossal destructive potential, which can lead to the destruction of even solid steel and concrete structures, such as offshore installations like oil rigs and loading bays. The rise in sea levels will increase the storm surge hazard even further and may result in the interruption of transmission and distribution systems that are near to the coast. The majority of coastal areas remain very flat even far into the hinterland. The water streaming in from the sea may therefore flood large areas, especially because even if a dam breaks, the water level in the sea - unlike in a river - does not go down and the volume of water there is virtually unlimited. In the vicinity of a breach, the rapid flow of water causes total losses, whereas some distance away damage is caused by the water level slowly rising, which on account of the corrosive quality of the salt water is more serious than the damage caused by freshwater floods.

The 1953 UK Storm Surge Caused One Million Disconnection-Days.

On 31 January 1953, one of the strongest North Sea windstorms of the 20th century produced the highest storm surge ever recorded along much of the eastern coast of England. As the tide rose that evening, water levels reached heights not seen during at least the previous 250 years. The storm that caused the surge began to develop around midday on Thursday, 29 January as a low-pressure system located to the southwest of Iceland, with a central pressure of 1003 mb. The system proceeded to move to the northeast over the following 30 hours, deepening rapidly by 24 mb and was located to the northwest of Scotland by 6 pm GMT on Friday, 30 January. Instead of continuing on the same path, the system became influenced by the circulation around a strong anticyclone located to the west of Ireland and turned to the southeast. It entered the North Sea during the morning of 31 January, where it attained its lowest pressure of around 966 mb. The contrast in pressures between the low-pressure system and the anticyclone led to very high winds to the southwest of the storm centre, and a gust of 125 mph (56 m/s) was recorded at Costa Hill (altitude 15 m) in Orkney, the highest recorded land windspeed in the U.K. to that date. The winds caused significant damage to property and the destruction of forests in northeast Scotland, felling more trees than the annual timber-harvest.

As the storm system moved down the North Sea during the remainder of Saturday 31, high pressure continued to build over the eastern North Atlantic. Although the system was filling at the time, encroachment of the high pressure increased the pressure gradient over the North Sea, effectively squeezing the system and tightening the isobars. The strong winds pushed water into the North Sea from the Atlantic and southwards, generating the surge. The water was driven on-shore as the coasts of eastern England and the Netherlands funnel together and the sea becomes shallower, amplifying the surge along the east coast of England and then against the southwest coast of the Netherlands where it arrived during the early hours of Sunday, 1 February. The storm crossed the North Sea just two days after the full Moon, interacting with the spring tides (when the gravitational pull of the Sun and Moon combines to create the highest tide of the lunar cycle).

The high water levels and accompanying waves overwhelmed and broke through flood defences and walls all along the east coast of England during the night of Saturday 31 January.

On Saturday 31 in the morning, the storm claimed its first casualties when the Princess Victoria ferry, on passage from Stranraer in Scotland to Larne in Ireland, sank with the loss of 133 lives. Flood warnings for the east coast were issued late that morning, however there was no national coordinated system for distributing these warnings at the time. The danger mark on the Norfolk coast of 2.5 m (8 feet) above mean sea level was surpassed at 6 pm and within half an hour the sea level had risen a further 1 m (3 feet), giving a surge-height of 3.6 m. The sea level rose up to 0.6 m (2 feet) higher than recorded during the previous 80 years and for many sections of coast it remains the highest recorded surge in the North Sea.

This gives us an estimate of 100 years as the return period for a surge of height 3.5 m.

A government inquiry into the causes of the floods identified that along the 1,600 km (1,000 miles) of east coast affected there were 1,200 flood defence breaches, 647 square kilometres (160,000 acres) of land flooded, 307 people died and 24,000 houses were damaged, of which 500 were totally destroyed. Around 200 industrial facilities were also damaged by floodwater.

Among the worst affected areas was the low-lying Canvey Island in the Thames Estuary, which was completely inundated; the death toll was later confirmed at 58. Water flooded up to 8 km (4 miles) inland around Cley on the north Norfolk coast, and to a depth of 1.8 m (6 feet) in the town centre of Kings Lynn. It was not just coastal communities that were at risk, as the surge travelled inland from The Wash along the Rivers Ouse and Nene, causing both rivers to overflow and break their banks. Along the south bank of the River Thames defences were breached, and the floodwater reached the top of embankments in the City and through Westminster.

The overall financial cost of the disaster at the time is difficult to quantify, as accurate records were not collated. A month after the flood, the Home Secretary, Sir David Maxwell Fyfe, estimated the material cost of the damage to be £40 - £50 million: equivalent to around £1 billion in 2003 values. However this does not include the impact of interrupted business activity or the costs of relocation. Flood was not a general insurance coverage at the time, and therefore the proportion of costs repaid by insurance was very small.

The spectre of a major storm surge flood in London led to the construction of the Thames Flood Barrier near Woolwich, which became operational in 1982. The barrier was initially designed to protect against extreme tidal surge events with a return period of up to 1 in 1,000 years until 2030.

Three hundred miles, or 45% of the dikes in southwest Netherlands were damaged. The floodwaters inundated 47,300 buildings, of which 9,215 were destroyed. A large quantity of livestock was killed, and infrastructure was severely disrupted with many roads submerged and damaged. Damage in the Netherlands was estimated at the time to be 1 billion guilders (250 million Euro), with 350 million guilders (90 million Euro) damage caused to the flood defences.

U.K. Storm Surge probabilistic catastrophe analysis model.

The analysis upon which I base the forecasts for the effects of Surges of greater severity derives from a range of alternative combinations of tides arriving with the surge. It derives from the RMS U.K. Storm Surge model, which treats failures probabilistically according to surge height and wave action, using fragility curves appropriate to the construction type, height, and quality of each structure. By combining synthesised scenarios of varying probability, estimates of possible flood event losses are derived, each with their associated relative probabilities.

Figure 12 shows that it is the East Coast of England and Scotland together with the Welsh Coast of the Irish Sea that are the sectors subject to surge.

Figure 12: Storm Surge Coastal Areas, UK and Nearby Continental Europe. (dotted lines along coasts}.

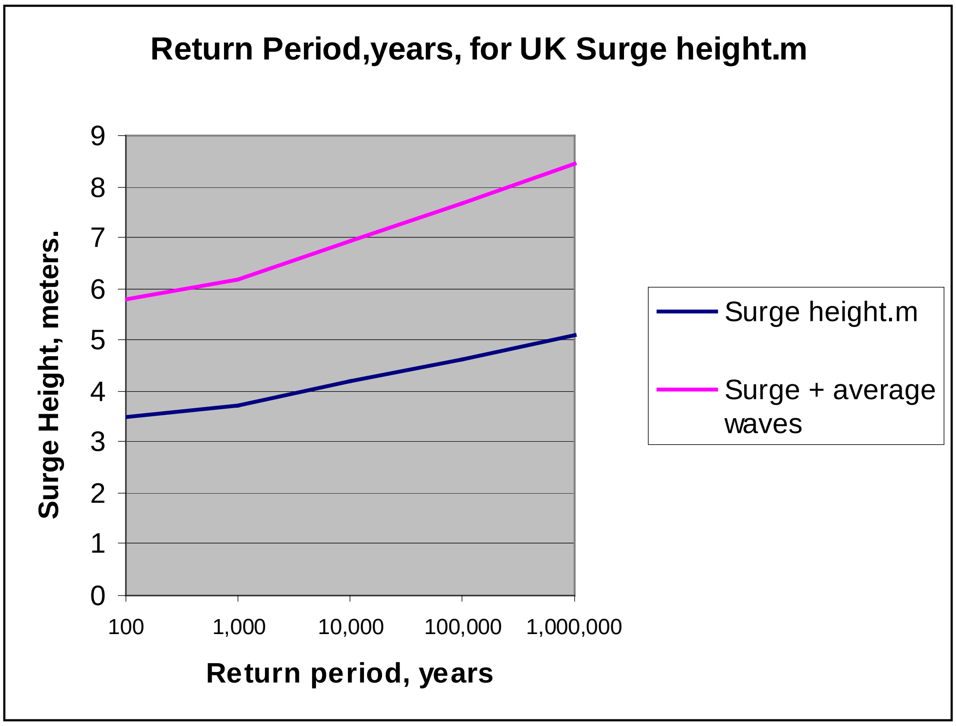
For surges with a return period of 100 years we use the outcome of the 1958 surge, described above: There have been four major surges in Europe in 20th century of which the 1953 surge was one.

Electrical supplies were interrupted by the 1953 surge. There were 1 million disconnection-days.

This coupled with the figures given above, leads us to the estimate included in the Summary Table at the beginning of this Report.

This surge is included in the forecasts given in Figure 13, which gives our forecasts of the height of surges as a function of return period.

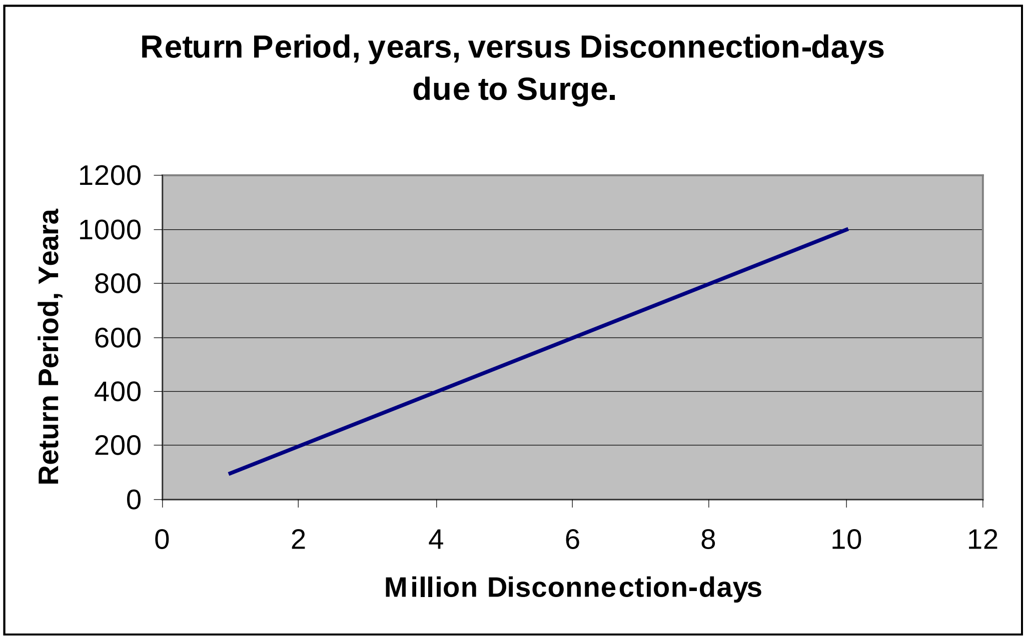
Figure 13: Return Period for UK Storm Surge.



The forecasts of insured property loss from all these possible scenarios, involving different states of tide and failure scenarios, range from £5 million to more than £2 billion. The probability-weighted average `expected' loss is £470 million with a return period of 40 years. This represents a significant reduction from the return period of loss reconstructed from the 1953 flood footprint, which is 750 years. However, rising sea-levels and continued subsidence of the southeast corner of England, together with the sea bed on which the offshore wind generators will be situated, which is associated with the recovery of land-levels after the Ice Age, act to increase the risk of high level storm surge year on year.

The next Figure shows the Return Period for various numbers of Disconnection-days.

Figure 14: Return Period versus Disconnection-days due to Surge.



In the Summary Table at the beginning of this Report figures are given for the disconnections that surges will produce with Return Periods of 100 years (i.e. data from the 1953 surge) and 1,000 years.

Tornado.

A tornado is a violently-rotating column of air which is usually in contact with the parent thunderstorm - although as many as a third occur without thunder. In the centre of a tornado, winds are actually very light and may descend towards the ground - just like the eye of a hurricane.

A tornado will typically last for a few minutes, track across the land for 2 to 5 kilometres (roughly 1 to 3 miles) and will have a diameter of 20 to 100 metres (roughly 20 to 100 yards). Windspeeds are in the order of 72 to 113 miles per hour - that is, T2 or T3 on the Tornado Intensity Scale. At the more extreme end, some tornadoes track for over 100 kilometres, are over 1 kilometre wide and have winds in access of 300 miles per hour (T10) - such tornadoes are extremely rare, anywhere in the world.

In contrast, a hurricane is an intense area of low pressure that only forms in the tropics where the sea surface temperature is at least 27 degrees Celsius. A hurricane has a diameter of around 100 miles, has mean windspeeds which must average at least 73 mph (by definition), and can last for several days - but will rapidly decay on making landfall.

The largest tornado outbreak in Britain is also the largest tornado outbreak known anywhere in Europe. On November 21, 1981, a cold front spawned 105 tornadoes in the space of 5.25 hours. Excepting Derbyshire, every county in a triangular area from Gwynedd to Humberside to Essex was hit by at least one tornado, while Norfolk was hit by at least 13. Very fortunately most tornadoes were short-lived and also weak (the strongest was around T5 on the TORRO Tornado Scale) and no deaths occurred. The UK suffers more Tornados per square mile than any other country in the world.

On December 28, 1879, all 74 lives were lost when a passenger train plunged from the Tay Bridge (Tayside) into the Tay Estuary, when the middle section of the bridge collapsed. Although the bridge was poorly constructed and had already been weakened in earlier gales (including the pre-existing winds at the time of the tragedy), the ultimate failure is believed to have been caused by two or three waterspouts, that is to say tornados over the water, which were sighted close to the bridge immediately before the accident.[2]

Measuring Tornado Intensity

The Fujita Scale, or simply FScale, classifies tornadoes based on their rotational wind speeds and on the damage caused both to man-made structures and to vegetation. The index ranges from F0, representing tornadoes that result in only minimal damage, to F5, the most severe category of tornado causing "incredible" damage. A tornado's intensity will typically change during its brief life. Along a single tornado's path, then, it is not unusual to observe F2 damage at one point, F3 at another, and just F1 at a third. Because tornadoes generally last only minutes and, more often than not, occur out of the range of weather stations or anemometers (instruments used to measure wind speeds), assigning an Fscale classification is often an inexact science.

A similar measure, the Tornado Intensity Scale ranges from T0 to T10, with each point representing a range of windspeed, just like the Beaufort Scale (in fact, the Tornado Intensity Scale is based directly on the Beaufort Scale). T0 to T3 are weak tornadoes, T4 to T7 are strong tornadoes and T8 to T10 are violent tornadoes. T10 = F5.

On average, 33 tornadoes are reported each year in the United Kingdom. This average is based on a 30 year period, though in reality the actual yearly figures may vary dramatically from year to year.

Most tornado reports are from the Western Midlands, Eastern Midlands, Central-Southern England, South-Eastern England and East Anglia. Some occur in South-Western England, North-Western England, North-Eastern England and Wales. Tornadoes are rare in Northern Ireland and Scotland, Figure 15.

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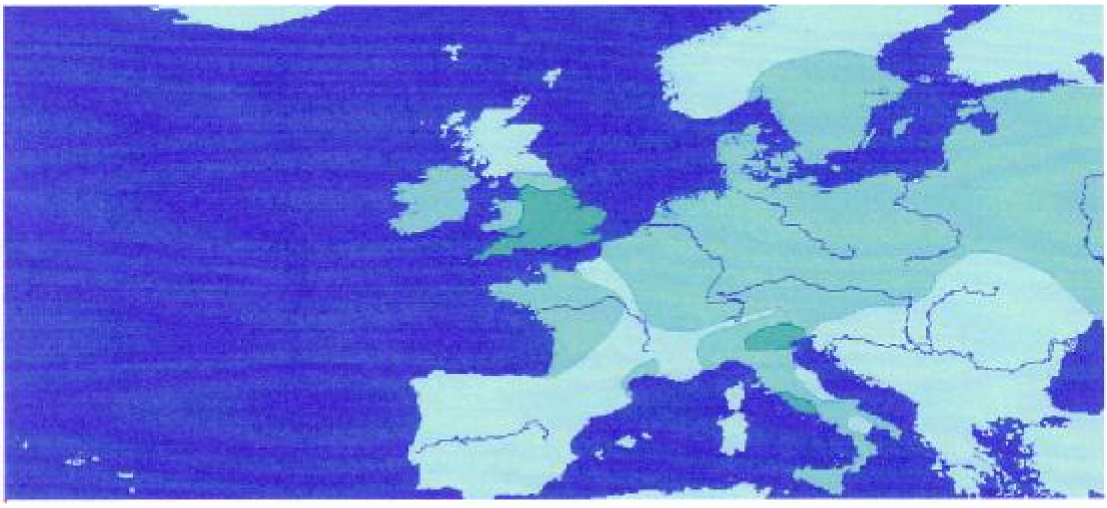
[2] Tornado and Storm Research Organisation. Head of TORRO:- Prof. Derek M. Elsom.Geography Dept.Oxford Brookes University.Gypsy Lane.Headington.Oxford. Oxfordshire OX3 OBP.

Figure 15. Tornado intensity in UK and Continental Europe: The darker the colour the greater the intensity.



Characteristics of UK Tornados.

From the RMS and AIR models, coupled with historical information, I have estimated the velocity and intensity of UK Tornados. Results are typified by Figure 16, Figure 17 and Figure 18. In the latter I have compared windspeed in a storm with the speed of wind in a tornado, showing the much higher, though briefer and more localized windspeed in a tornado than in a winter storm.

Figure 16: Percentage of UK Tornados Forecast to have the stated velocity or less.

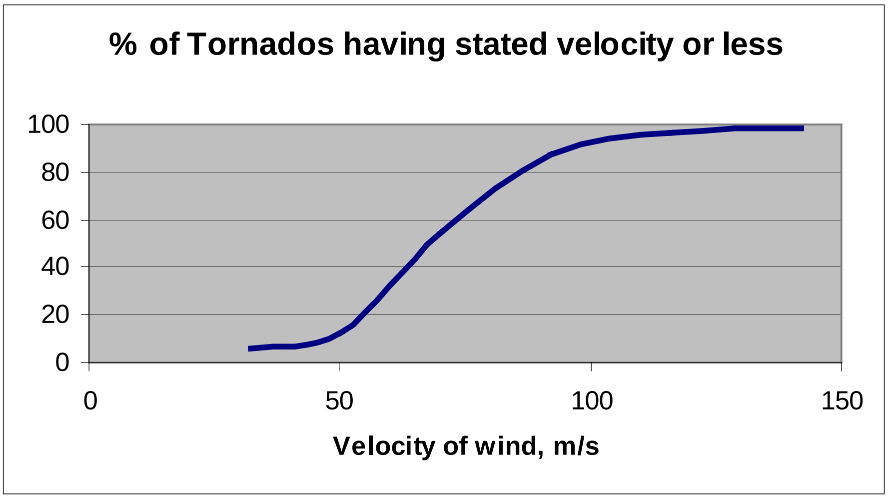


Figure 17: Percentage of UK Tornados Forecast to have the stated Intensity or Less.

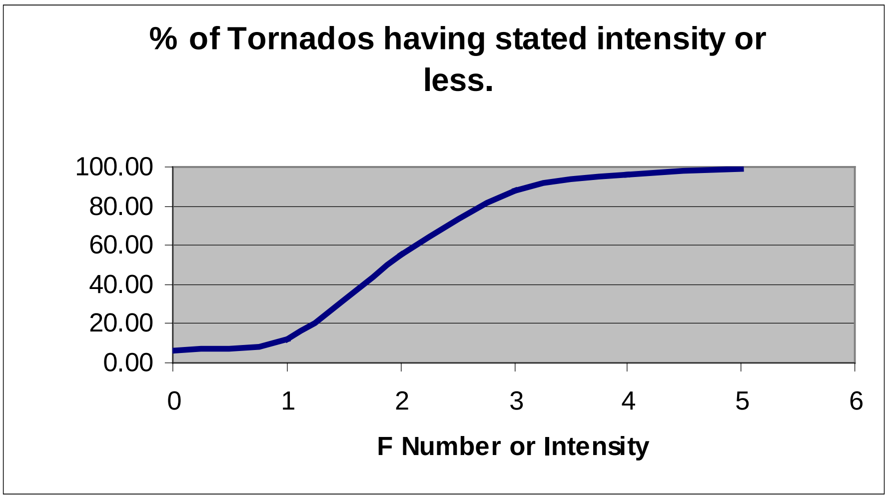
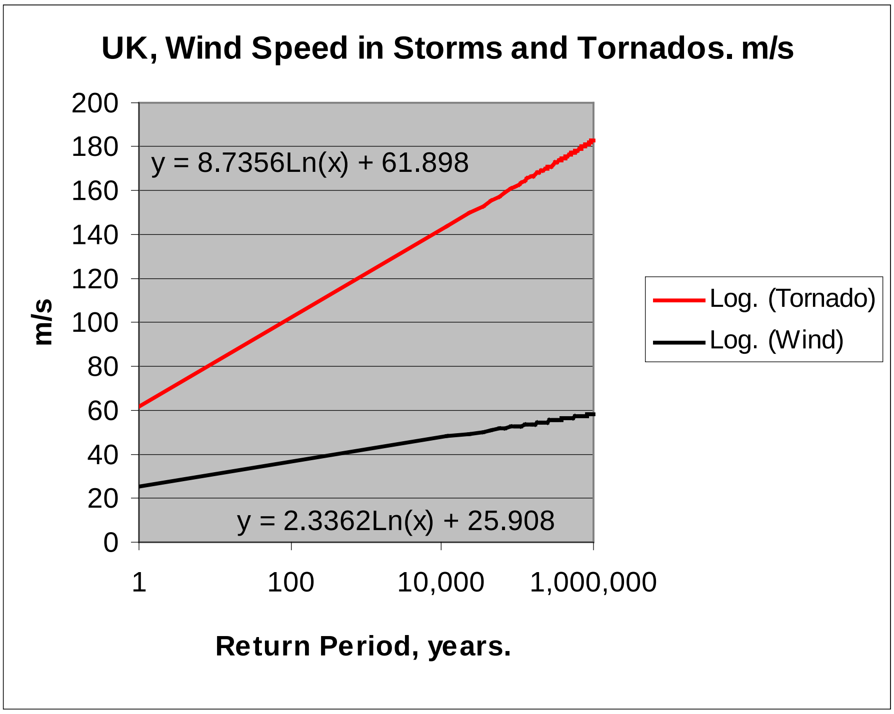


Figure 18: UK, Wind Speed in Storms and Tornados, m/s.



Predicting the Damage due to Tornados

Within cyclones, wind speeds generally increase with height. The air spirals upward to the central core of the tornado to merge with the airflow in the parent cloud at the top. Structural failures occur even in well-engineered commercial structures. Structures also sustain damage from airborne debris that acts as missiles. These are usually pieces of already damaged structures that are picked up by the force of wind and carried sometimes-great distances. The high-speed rotating winds of a tornado can turn almost anything into a missile. To estimate the damage and associated losses from these perils, models use damageability relationships, or damage functions, which have been developed over a period of many years. Post-disaster field surveys provide first-hand data on how structures perform when subjected to such extreme weather conditions. These data are incorporated into the modes through the subsequent calibration and testing of the damageability relationships.

My estimates for the effects of tornados on the reliability of transmission and distribution systems the UK, summarized in the first table in this Report, were arrived at by the same methods as for the effects of storms. Even the most up-to-date building codes do not require that buildings and structures such as grid-towers and distribution-poles be able to withstand the extreme winds of violent tornadoes. Accordingly it is clear that tornados capable of damaging towers or poles occur somewhere in the UK every year. The frequencies with which transmission is interrupted by tornados are therefore dominated by the fact that the area affected by a tornado is small. The likelihood that one of the damaging tornados that occur in a given year will occur where there is a major grid line is therefore low.

Hail.

The area most frequently affected by hail damage extends from Lancashire, Greater Manchester, and Merseyside, south-eastwards to the counties in and around the Thames Valley (Berkshire, Bedfordshire, Buckinghamshire, Hertfordshire, Oxfordshire) and Greater London, and to parts of East Anglia (Cambridgeshire, Essex and Suffolk).

The earliest known severe hailstorm in Britain occurred at Wellesbourne in Warwickshire in May 1141 and was at least H3 in intensity. However, there are believed to have been one or more fatalities caused by hail - which would infer very large stones and hence a much higher intensity rating.

Figure 19 shows that the intensity of the risk presented by Hail, in the UK, is greatest in the southern part.

For the recent period from 1981 to 2000 potentially damaging hail (TORRO intensity of H1 or more on a scale of 1 to 10) was reported on between 6 and 28 days each year with an average annual frequency of 15 days in Great Britain .Analysis of TORRO's database of more than 800 hailstorms which reached an intensity of H3 or more reveals that the early summer experiences the highest proportion of such storms, with more than half (52%) occurring in June or July. Around three-quarters of all these hailstorms (77%) occurred between May and August, with June experiencing the peak monthly frequency (29%).

On September 22, 1935, an H6 hailstorm tracked 335 km from the west-south-west from Newport (Gwent) to Mundesley (Norfolk). It is likely that the true length was longer still, as the storm probably tracked along the Bristol Channel for some distance before reaching Newport, as well as continuing over the North Sea after Mundesley. Several hailstorms have reached H7 in Britain, but only one H8 has been recorded. On May 15, 1697, a H8 hailstorm tracked from Hitchin to Great Offley (Hertfordshire) - although this makes a track length of only 5 km, the true hail swathe must have been much longer.

The heaviest hailstone recorded in Britain fell from the H7 storm which tracked 150 km from West Wittering (West Sussex) to Maldon (Essex) on September 5, 1958 - the stone, which fell on Horsham (Sussex), weighed 141 g. However, descriptions from older accounts which do not usually quote weights clearly indicate that significantly heavier stones have fallen in Britain (even when suspected exaggeration is taken in to account).[3]

Figure 19: Hail. Purple Shading.

Figure 20 shows my Forecasts for the Intensity of Hail Storms in the UK and Figure 21 shows the frequency with which hail storms of the stated intensity will strike switchyards, potentially causing interruptions to the supply of electricity over an area of the UK.

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[3] For further details see Webb, J. D. C, Elsom, D. M, and Reynolds, D. J (2001) Climatology of severe hailstorms in Great Britain, Atmospheric Research 56, pp 291-308

Figure 20: Intensity, H, of Hail Storms in the UK.

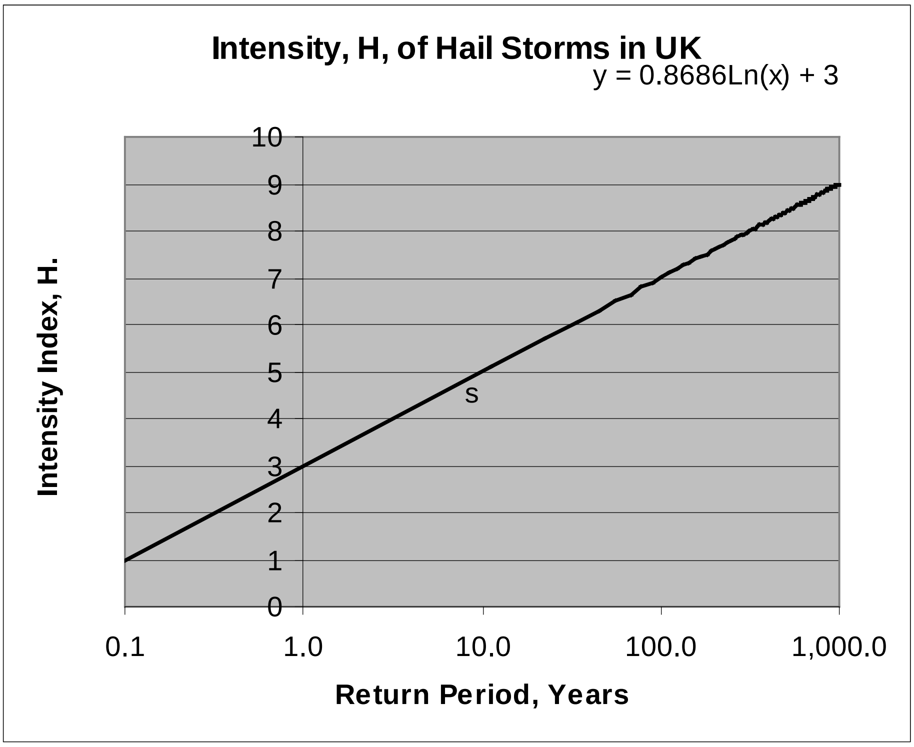
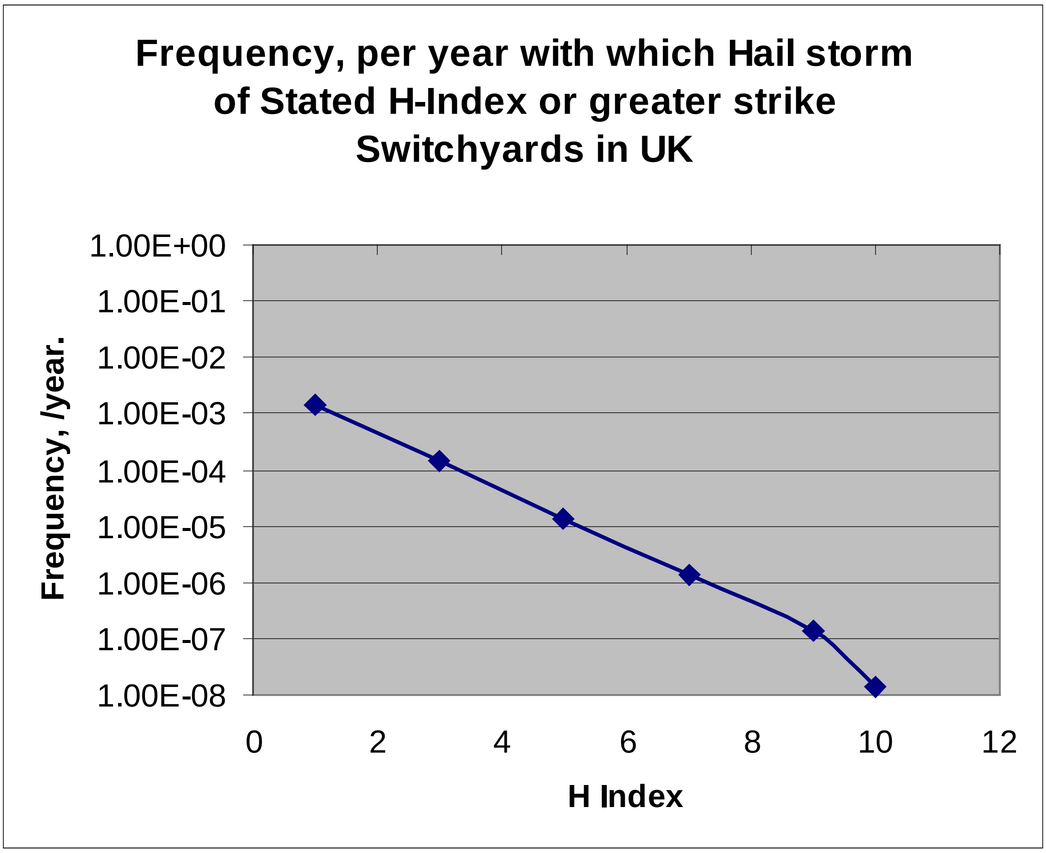


Figure 21: Frequency with which Hail storms of various intensities will strike switchyards in the UK.



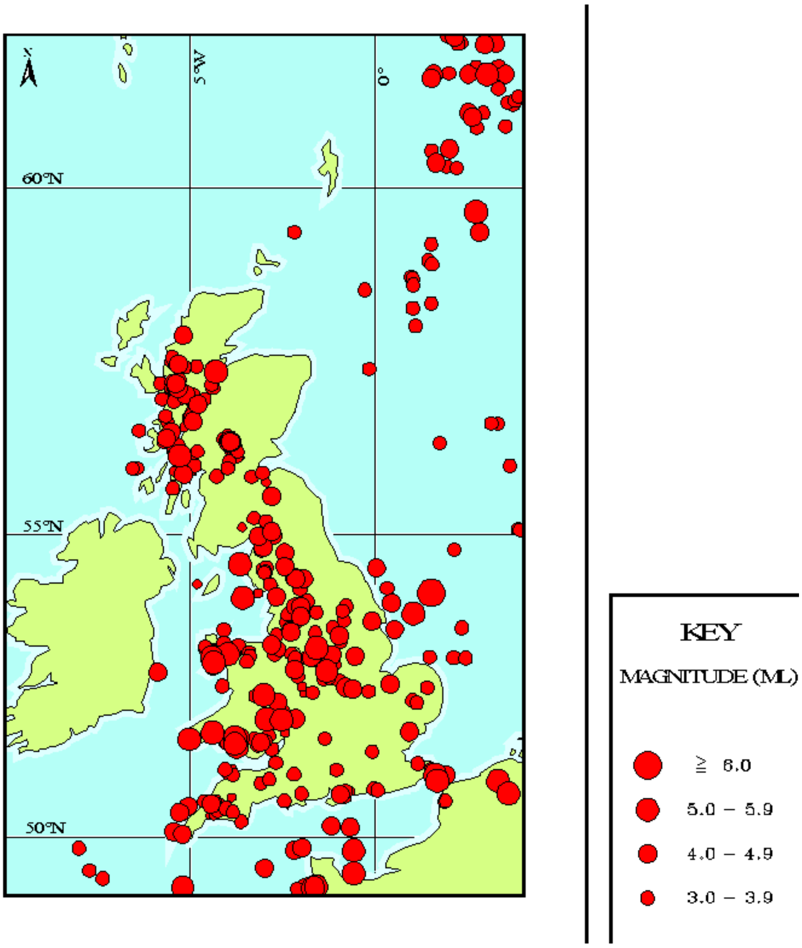
From these calculations and historic data the frequency with which hail will interrupt supplies of electricity in the UK has been calculated and is given in the first table in this Report.

Earthquake

The UK is not a country generally associated in the public mind with earthquakes. However, while the UK is nowhere near in the same league as high seismicity areas such as California and Japan, it nevertheless has a moderate rate of seismicity, sufficiently high to pose a potential hazard to sensitive installations such as dams, gridlines, switchyards and chemical plants.

Figure 22: Regions of Raised Seismic Intensity, UK and Continent, The darker the yellow colour, the more seismically active the zone.

Figure 23: Earthquakes in the UK and its coastal waters.



The whole of Ireland is practically free of earthquakes. This is clearly a real phenomenon and not a product of reporting - as Ware, as early as the 17th century, remarks in describing an earthquake (probably Welsh) felt in Dublin in 1534, *"... qui casus adeo rarus est in Hibernia, ut quando contingit, inter prodigia habeatur"* [loosely, which is such a rare thing in Ireland that when it happens it is considered a wonder].

Certain centres can be identified as showing typical patterns of activity. For example, the Caernarvon area of north-west Wales is one of the most seismically active places in the whole UK. Both large and small earthquakes, usually accompanied by many aftershocks, occur at regular intervals. The most recent of these larger events was the earthquake of 19 July 1984 (5.4 ML), which was one of the largest ever UK earthquakes to have an epicentre on land and had a very protracted aftershock sequence. Two further felt earthquakes have occurred there since, on 29 July 1992 (3.5 ML) and 10 February 1994 (2.9 ML). It is tempting to ascribe several early earthquakes of unknown epicentre (eg that of 20 February 1247) to this area just because it seems to be such a favoured site for large earthquakes.

In South Wales, on the other hand, although a line of epicentres of significant events can be traced from Pembroke (an earthquake in 1892) to Newport (active in 1974), only the Swansea area shows consistent recurrence, with significant earthquakes occurring in 1727, 1775, 1832, 1868 and 1906. (Given this periodicity it may be that a further earthquake in this area is due in the near future.) The Hereford-Shropshire area has also produced large earthquakes in 1863, 1896, 1926 and 1990, but none of these share a common epicentre.

The area of the Dover Straits is particularly significant because of the occurrence there of two of the largest British earthquakes in 1382 and 1580 (both of magnitude about 5¾ ML). Since 1580 the only earthquakes there have been much smaller, raising the question of whether there is a danger of another 1580-style earthquake in the near future. The area may be structurally continuous with a zone of activity running east through Belgium, in which case it could be argued that stress in this area since 1580 has been released further east. This does not rule out another 1580-type earthquake in the future, but it is impossible to estimate how soon it might occur.

In the north of England seismic activity occurs over a more or less continuous area from Leicester to Carlisle. The most prominent centres of repeating activity here are the upper end of Wensleydale (with significant earthquakes in 1768, 1780, 1871, 1933 and 1970) and to a lesser extent the Skipton area.
What is remarkable is the lack of correlation between this pattern and the structural geology of the UK.

The boundaries between areas of moderate or high seismicity and areas of very low seismicity do not correspond to any major structural feature; for instance the sharp dividing line running SE from Inverness. And the major boundaries are not clearly reflected in the pattern of seismicity either as dividing lines between zones of differing rates of seismicity nor as lineations marked by earthquakes. It seems likely that the pattern of seismicity may be influenced by the distribution of ice during the last glaciation - certainly for Scotland this appears to be the case.

The distribution of British earthquakes in time

Earthquakes are not rare in the UK, as Figure 24 shows there were ten in March 2003.

Figure 24:This map created at Tuesday March 25 08:42:25 GMT 2003

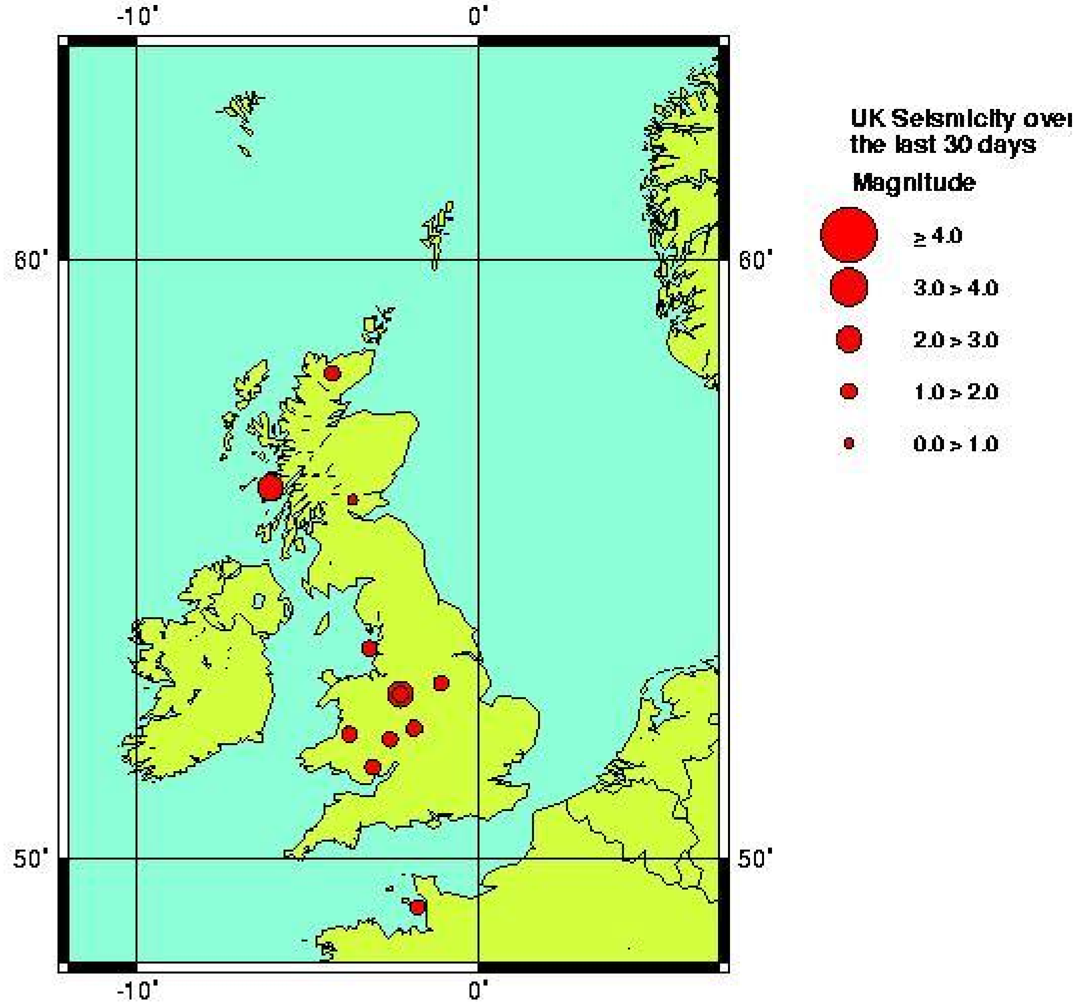
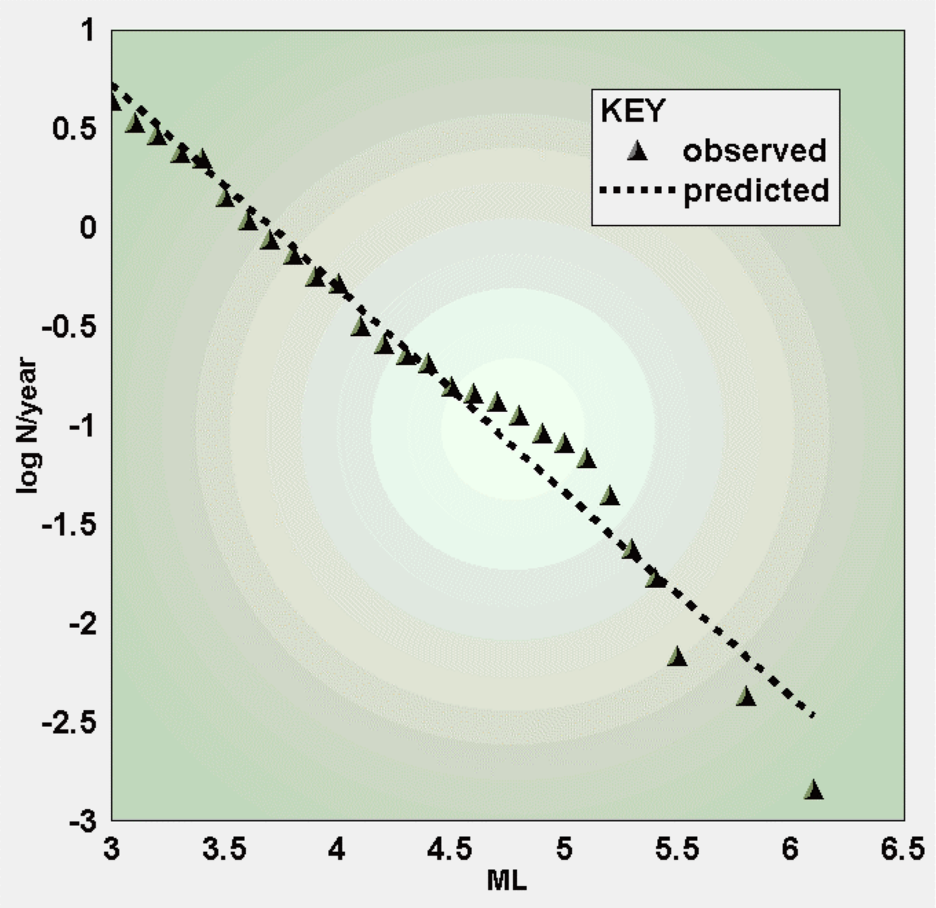


Figure 25: Frequency of Exceedance Versus UK Earthquake Intensity.



It has long been realised that larger earthquakes occur less frequently than smaller earthquakes, the relationship being exponential, ie roughly ten times as many earthquakes larger than 4 ML occur in a particular time period than earthquakes larger than magnitude 5 ML. This can be expressed by the Gutenberg-Richter formula

$$\log N = a - b M$$

where N is the number of earthquakes per year exceeding a given magnitude M. The constant a reflects the absolute level of seismicity in an area, and the value of b has generally been found to be consistently close to 1.0.

This holds true for the UK for the area 10o W to 2o E and 49o N to 59o N. This deliberately excludes the northern North Sea area which is of high seismicity and completely under-represented in the catalogue before 1970 because of the impossibility of detecting smaller events in this area before that date. A least-squares regression to the UK data of Figure 25 gives the relationship

$$\log N = 3.82 - 1.03\ M$$

One can therefore draw the following conclusions about average recurrence - the UK may expect:

- an earthquake of 3.7 ML or larger every 1 year
- an earthquake of 4.7 ML or larger every 10 years
- an earthquake of 5.6 ML or larger every 100 years.

Seismic hazard calculations

The intensity attenuation model used here is expressed by the formula

$$I = 3.32 + 1.44\ ML - 3.34 \log R$$

where ML is local magnitude and R is hypocentral distance in kilometres. The data that I have used to produce this formula are found in Musson [4] .

Seismic hazard studies in the UK in the past have been mostly single-site studies for particular installations. The first attempt to look at hazard for the UK as a whole using the PSHA methodology was conducted by Ove Arup around 1991. This study calculated hazard at eleven representative sites in the UK. Following this, a study to produce contour maps of UK seismic hazard was commissioned by the Department of Trade and Industry. In this study the computer code SUNMIC was used, which allows a "logic tree" model to be applied to the hazard, by which uncertainty in input parameters can be modelled by the inclusion of multiple choices each with a weighting value).

One of the innovations used in this study was the approach taken to source zone modelling. If several significantly different source zone models are included in a logic tree model without regard for their combined effect, the result tends to be that the conflicting source zones smear one another out into a semi-uniform distribution of hazard; meaningfulness is lost. In this study, two mutually supportive zone models were constructed; one consisted of relatively broad zones based chiefly on the general regional trends observed in the seismicity data. The second consisted of much smaller

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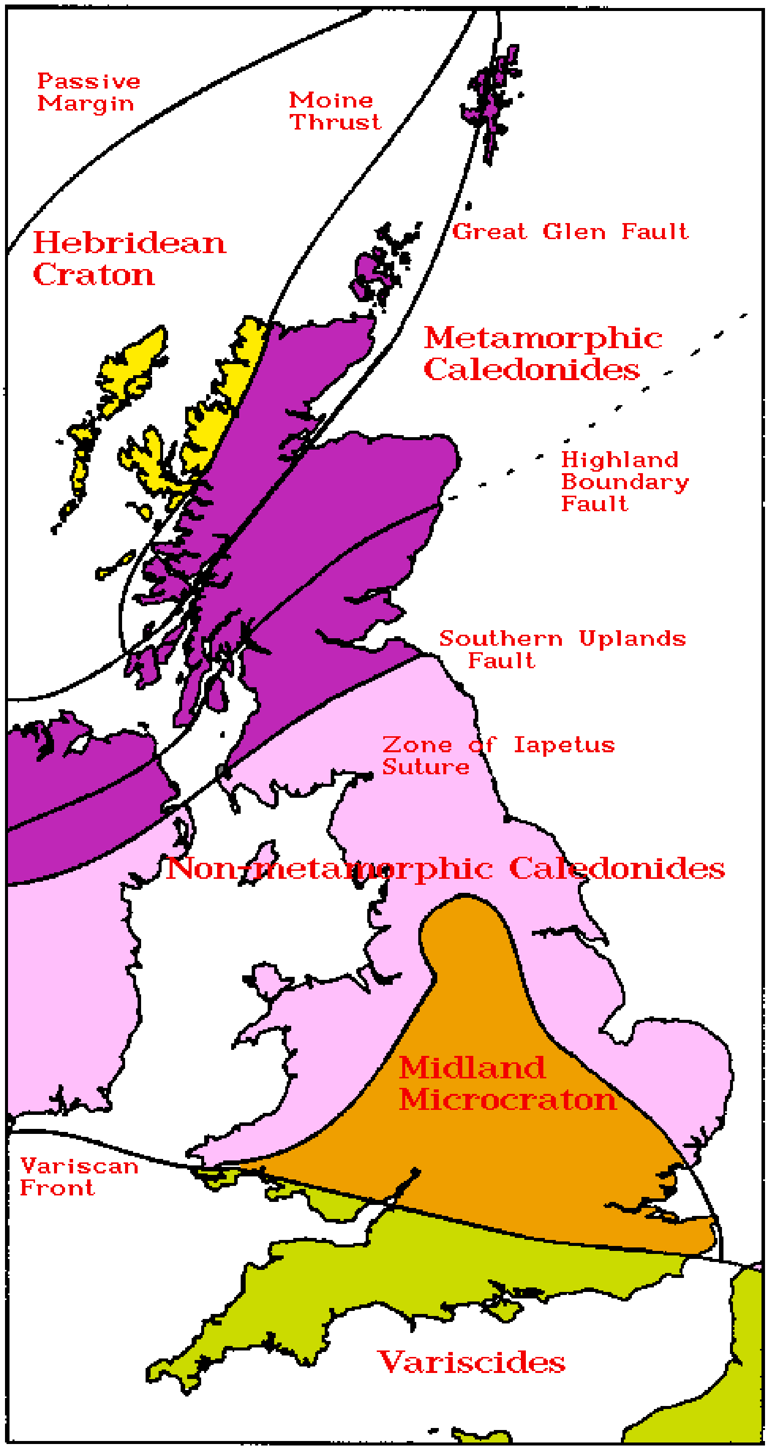
[4] Musson, R.M.W., 1994a. A catalogue of British earthquakes, BGS Technical Report No WL/94/04.

zones closely placed around sites of known large earthquakes, the size of these zones being roughly related to the degree of uncertainty in the epicentral location. The result of the combination of these two models was a hazard map in which the general areas where earthquakes might be expected to occur would have higher hazard, but within these, spots where such earthquakes had occurred in the past were picked out as having locally higher hazard values.

Seismic hazard results

Figure 26 Seismic Hazard Map of the UK.

Figure 27: Tectonic Map of the UK, for comparison with Seismic Hazard Map.



A sample hazard map of the UK is shown in Figure 26.

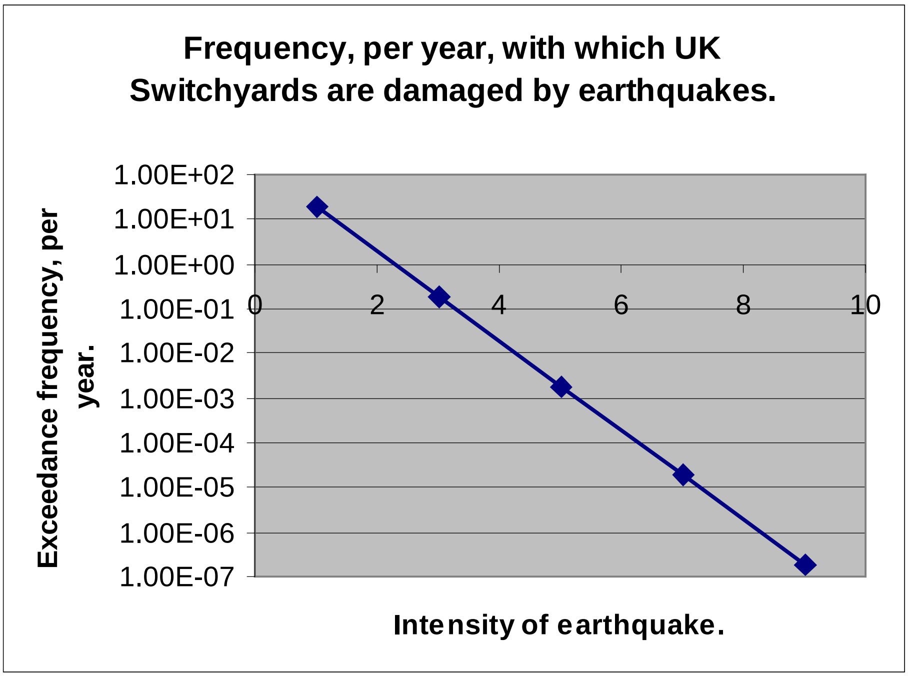
The map shows intensities that are 90% likely not to be exceeded in 50 years - equivalent to a return period of 475 years.

As might be expected, the areas of highest hazard parallel the areas where earthquakes have been most common in the past, but particularly those places where repeated earthquake activity has been highly localised - this localisation has a pronounced effect on the hazard calculations compared to areas where the seismicity, while high, is more diffuse and less repetitive. The zones where hazard is higher than average encompass the W Highlands of Scotland, an arc running from Carlisle to Pembroke, NW Wales and W Cornwall. The places in the UK with lowest seismic hazard are Northern Ireland (especially the western counties) and outlying parts of Scotland, including the Orkneys and Outer Hebrides.

The actual values of hazard are not particularly high, since the predicted intensity for the higher zones is only 6 EMS. In other words, even in areas of relatively high exposure to earthquakes in the UK, if a facility has a life of 50 years there is only a 10% chance that it will experience shaking equivalent to intensity 6. Moving briefly from hazard to risk, if we take as a guideline that probably less than 5% of buildings of normal construction (eg conventional brick houses) will be damaged in a place when the intensity there is 6, the probability of damage for a single house in 50 years is therefore less than 0.5%.

The Exceedance frequency with which UK Switchyards and other transmission-structures are forecast to suffer earthquakes of various intensities is shown in Figure 28. The resultant interruption to UK electricity supplies is summarized in the Table at the commencement of this Report.

Figure 28: Exceedance Frequency with which UK Switchyards will suffer earthquakes of stated intensity.



Terrorist Attack.

The most likely form that will be taken by a terrorist attack that damages the transmission system is the disconnection of the grid from a nuclear power station. The emergency equipment on a nuclear power station is powered either from the station, from the national grid or from diesel generators. If the grid is disconnected from the station by terrorist activity then the station automatically shuts down, leaving the diesels to power the equipment that must function in order safely to remove radioactive decay heat. If the diesels too are sabotaged then there is a prospect of a severe accident with resulting release of radioactivity.

Should terrorists, for example, dynamite several of the grid towers near to a nuclear power station, then not only will the station shut down but also the grid will be interrupted. Then a percentage of consumers will become disconnected from electricity supplies.

I have elsewhere calculated the effects of terrorist attack on the UK nuclear power stations themselves. Here I deal only with the disconnection of consumers from the grid due to terrorist activity near nuclear power stations. This forms an extension to an analysis that I have performed on behalf of the UK Department of Trade and Industry.

Methodology of Terrorism Assessment.

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 section 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 11th, 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.

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.

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.

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 11th 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:

- 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.
- 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 11th 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 Figure 29, where it is termed the distribution of ***Prior Probabilities***.

Figure 29. Probability of Frequency of Core Damage due to Terrorist Attack, Before and After September 11th 2001

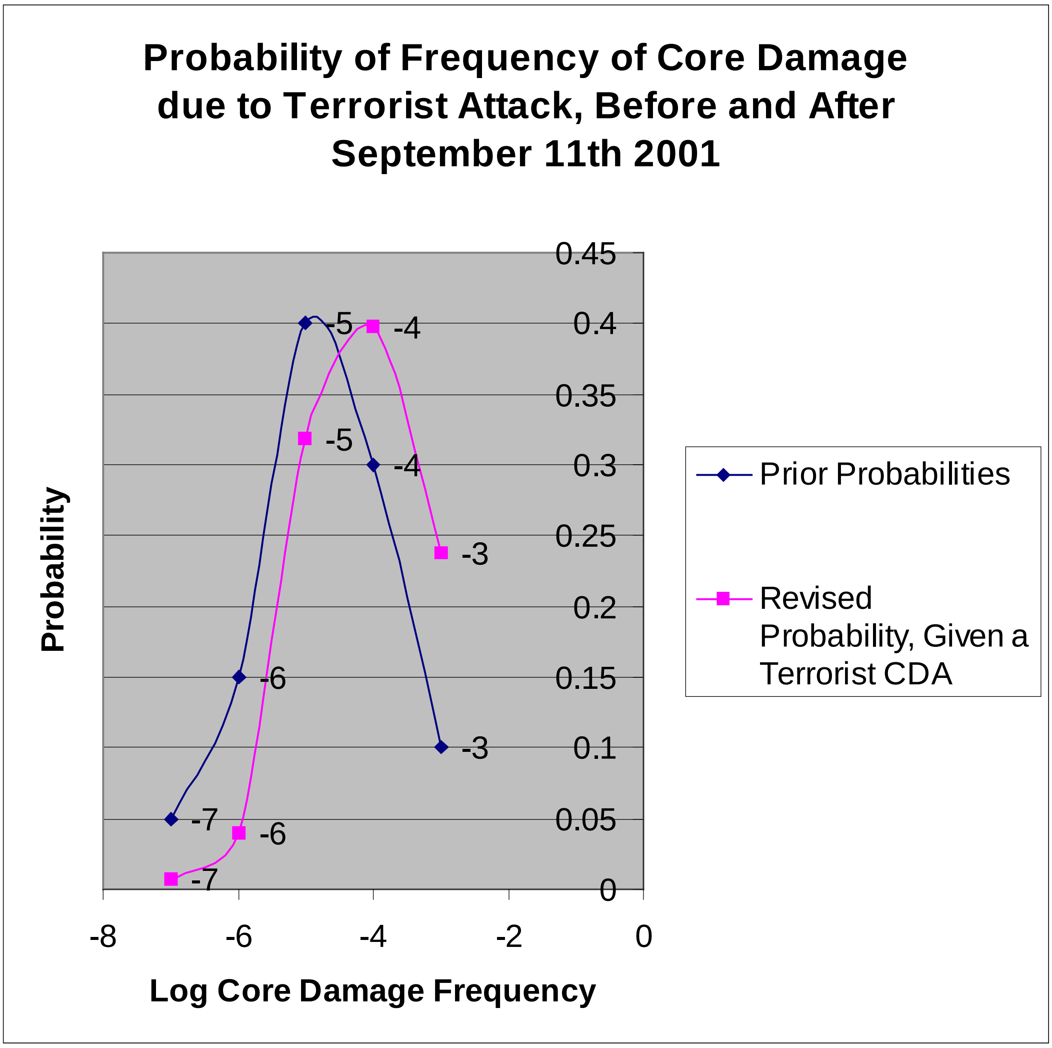


Figure 29 also shows a curve for the ***Revised Probability***, given that the WTC attack occurred. Here we take the elementary view that the WTC event might equally have included an attack on TMI. This follows directly from our argument that TMI and the WTC are members of the same class of World Terrorism 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 11th 2001.

Conclusion on Al Qaeda.

It is concluded that the Terrorist strike on September 11th 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.

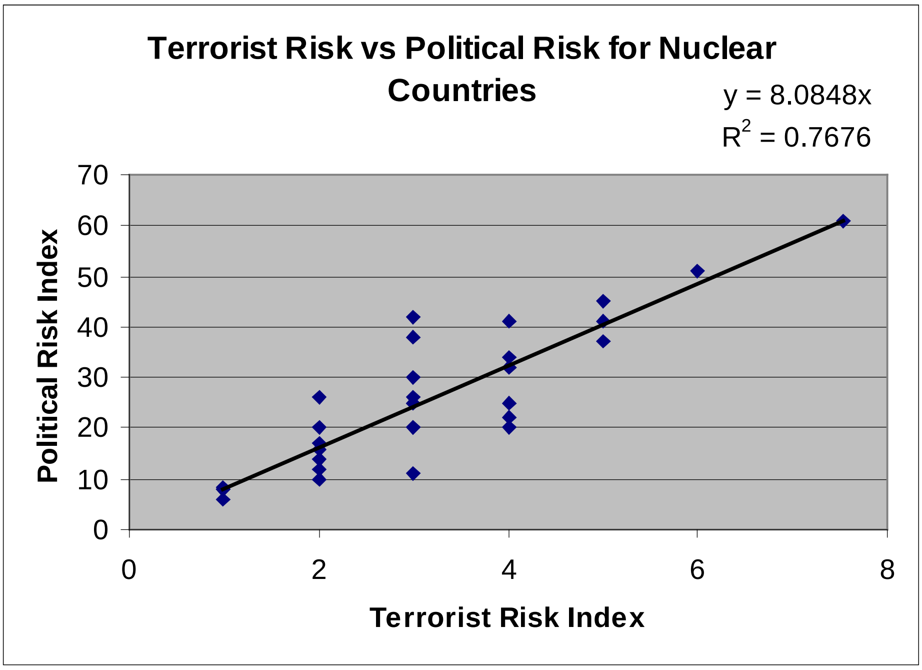
We have forecast that the risk due to terrorism is now actually an order of magnitude higher. That is our estimate has increased from R/10 to R. The non-terrorist risk remains at 0.9R and so the total risk is not R (as we previously thought) but 1.9R.

Implication of the War on Iraq.

To the added risk due to Al Qaeda we must now add the risk presented by Iraq. This I have estimated in my second Report to the DTI. As there has been no terrorist strike associated with the Iraq war, it is necessary to use other information in order to estimate the likelihood of such an attack.

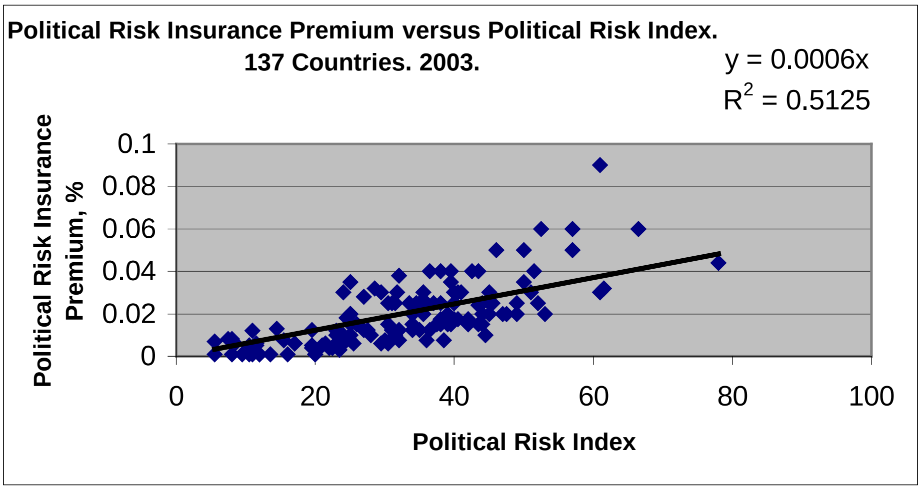
Three data bases were used in this work. One contains, for various countries including Iraq and the UK, Political Risk Insurance Premiums. The second comprises Business Risk Indices. The third contains Indices of Terrorist Risk within each country. There are as yet no definitive data bases for the Terrorist Risk presented to one country by others. I have discovered, however, that these three data bases exhibit certain correlations. This is exemplified by Figure 30, which shows the correlation between the Terrorist Risk indices and the Political or Business Risk Indices for the countries that have nuclear power programmes, and one or two other countries such as Iraq.

Figure 30. Terrorist Risk Index versus Political Risk Index for Countries having Nuclear Programmes.



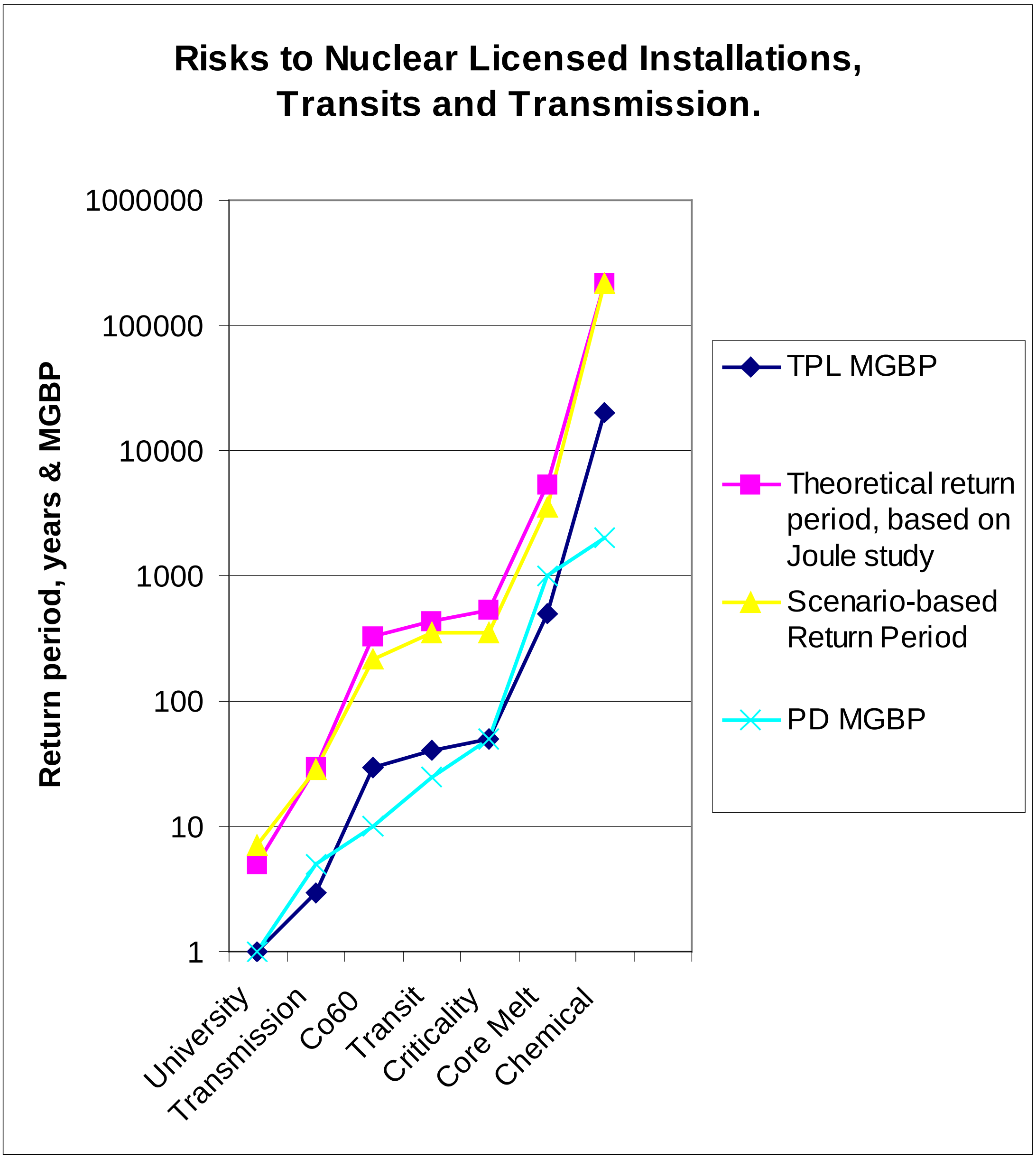
Similarly there is a correlation between the Political Risk insurance premium and the Political or business risk index, Figure 31.

Figure 31 Correlation between the Political Risk insurance premium and the Political or business risk index.



I have in this manner defined a ***vector*** that expresses the terrorist threat presented by one country to another. The forecasts of the terrorist threat to the UK presented by Al Qaeda ***and*** Iraqi terrorists are so arrived at. Figure 32 summarizes the forecasts so arrived at and the consequences for the transmission of electricity in the UK are summarized in the first table in this report.

Figure 32: Risks to Nuclear Licensed Installations, Transits and Transmission in the UK.



Control Software.

Transmission and distribution is controlled by electronic means. In this context it is important to be aware that the storms Lothar and Martin had spectacular effects on France's telecommunications infrastructure. The country's modern telecommunications network was tested for the first time in storms of this intensity, resulting in the largest single insured loss of over €152 million ($154 million) to France Télécom.

If a storm interrupts the transmission and distribution of electricity by damaging the electronic systems that control the grid and allied equipment, then I have already included this in the effects of such storms. There will however be breakdowns in the hardware and software that are not the consequence of storms or any of the other factors dealt with in this Report. Indeed such “crashes” of microprocessor-based systems are frequent, and the systems are designed with redundancy and diversity of hardware and software so as to reduce their effects to some target level of unreliability. From knowledge of these targets for various sectors and the frequency with which they are currently being met I have calculated the forecast in the first table in this Report.

Plane Crash.

Here I have used the database on plane-crash that is used in the PRA of UK nuclear power stations, coupled with the map of the UK national grid, to estimate the frequency with which a crashing plane will interrupt the grid.

To a first approximation, the databases show that the return period of major plane-crashes in the UK is of order 30 years, that there is a 3% chance that there will be severance of the national grid when such a crash occurs and that 2% of consumers will so be disconnected for 5 days. The first Table in this Report reflects these findings.

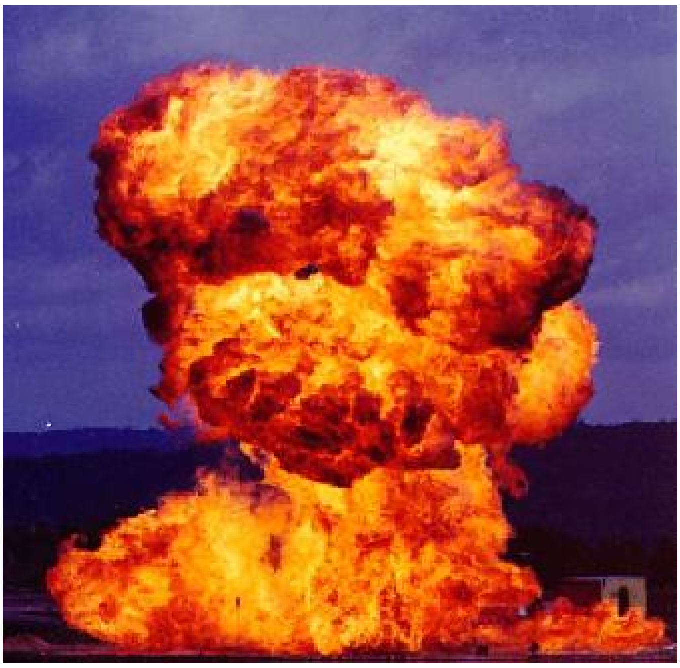
Boiling Liquid Vapour Explosion, BLEVE.

The *Boiling Liquid Expanding Vapour Explosion (BLEVE)* effect depends crucially on a phase change from liquid to vapour that might occur during a loss of containment.

If a sample of water is placed in an evacuated chamber then the water will boil even at room temperature. To be more precise, the *vapour pressure* describes the pressure that a vapour-filled void will have when in equilibrium with a liquid. An important subtlety is that the vapour pressure is a property associated with the liquid rather than the vapour itself. To appreciate this subtlety, consider an open container of water (at room temperature) that is placed inside a larger sealed chamber so that a void exists above the water. Now, imagine that the chamber is suddenly evacuated. Under these circumstances the room-temperature water will start to boil (ie., vaporize) and continue to do so until the pressure in the chamber matches the vapour pressure of the water. If the pressure in the chamber is maintained below the vapour pressure of the water (say, by connecting the vacuum pump directly to the chamber) then the water will continue to boil until no liquid remains. This does not require any increase in temperature.

This is what happens in a BLEVE of a high pressure vessel filled with water -- such a BLEVE is just a very fast episode of the process described in the above paragraph. The time scale of a catastrophic failure can be on the order of milliseconds. Such a rapid loss of containment generates a transient bubble-like outward propagating pressure disturbance (ie., a shock wave) inside of which the pressure drops below the water's vapour pressure. A small fraction of the water inside this bubble instantly vaporizes and very rapidly expands to approximately 1600 times its initial volume. This rapid expansion is the explosion referred to in a ``BLEVE" and it represents a violent conversion of internal energy into kinetic energy.

Figure 33: BLEVE.



If a tanker of LPG accidentally collides with some vehicle or building then a rolling cloud of escaping gas can engulf, for example, a neighbouring switchyard and there ignite explosively. There have been a number of such BLEVE events. The fire and explosion have the capacity to disconnect supplies from the switchyard and I have estimated the frequency and magnitude of such disconnections from historic data on BLEVE events.

A BLEVE can have damaging effects over a radius of a kilometre (Figure 34 and Figure 35)

Part of the BLEVE data base is given in the Annex: BLEVE’S and other Examples of some disasters in the chemical process industries.

Figure 34: Magnitude of BLEVE versus Litres of LPG.

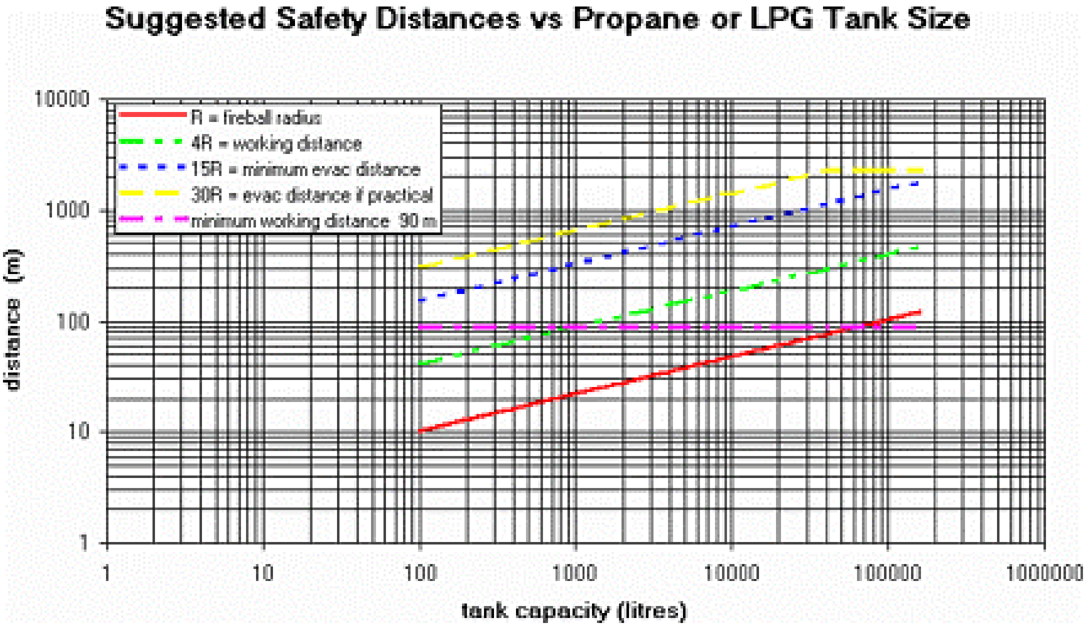
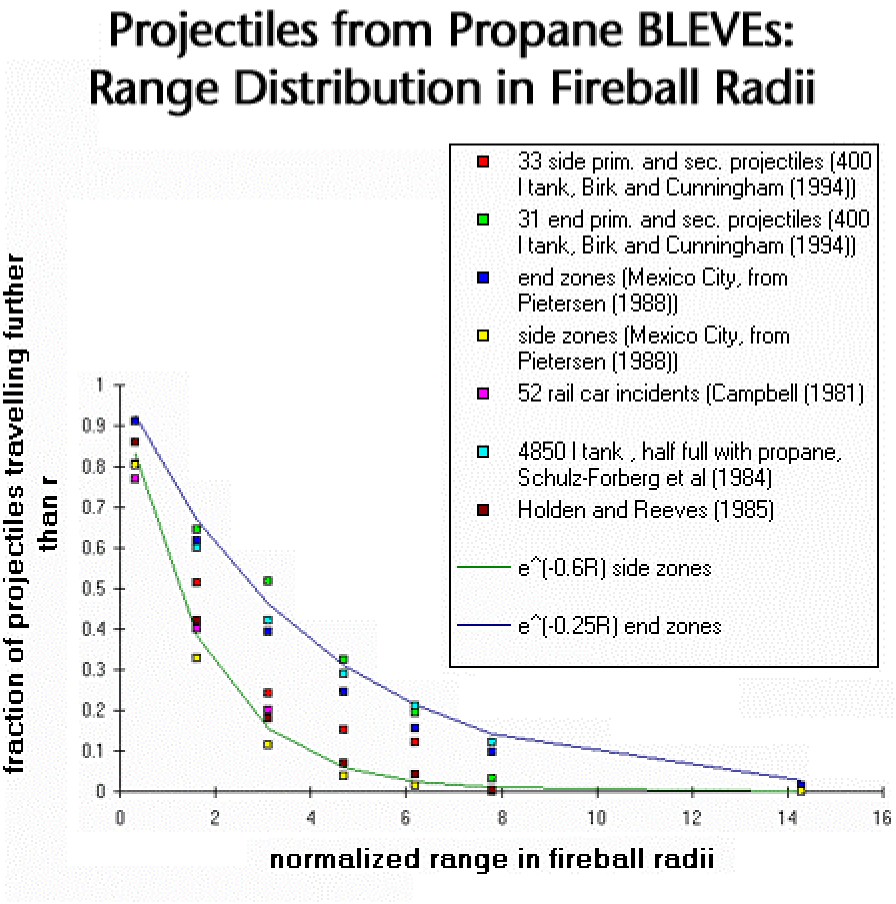


Figure 35: Projectiles from Propane BLEVE's, Range Distribution.



Annex: BLEVE'S and other Examples of some disasters in the chemical process industries

No	Place	Date	Substance involved	Event	Loss			Plant unit involved
					Killed	Injured	Financial [$]	
1.	Texas City, TX, USA	16.04. 1947	ammonium nitrate	f, ex	552	~3000	-	two ships
2.	Signal Hill, CA, USA	22.05. 1958	oil froth	f	2	18	54,300,000	tank farm
3.	Feyzin, France A B	04.01. 1966	propane	bleve	18	81	87,000,000	storage vessel
4.	Lake, Charles, LA, USA	08.08. 1967	isobutylene	vcex	7	13	79,800,000	alkylation unit
5.	Pernis, Netherlands	21.01. 1968	oil slops	vcex	2	85	123,600,000,	slop tanks
6.	Linden, NJ, USA	05.12. 1970	$C_{10}HC$	vcex	-	40	135,400,000	refinery reactor
7.	Flixborough, UK A B	01.06. 1974	cyclohex-ane	vcex	28	104	635,900,000	caprolactam plant
8.	Antwerp, Belgium	10.02. 1975	ethylene	vcex	6	13	90,100,000	polyethylene plant
9.	Beek, Holland A	07.11. 1975	propylene	vcex	14	-	114,700,000	petrochemical plant
10.	Umm Said, Qatar	03.04. 1977	LPG	f	7	13	210,800,000	gas plant
11.	Abqaiq, Saudi Arabia	11.05. 1977	crude oil	f	-	-	125,500,000	pipeline
12.	Abqaiq, Saudi Arabia	15.04. 1978	methane(1) LPG(2)	f(1), vcex(2)	-	-	148,900,000	gas plant
13.	Texas City, TX, USA	30.05. 1978	LPG	bleve	7	10	145,800,000	storage vessel

14.	Deer Park, TX, USA	01.09. 1979	distillate	ex	-	-	165,600,000	tankship *Chevron Hawaii*
15.	St. Joseph, MO, USA	21.04. 1980	grain	dex	1	4	4,400,000	shipping bin
16.	Ohama, NE, USA	12.11. 1980	grain	dex	none	none	3,300,000	head house
17.	Corpus Christi, TX, USA	07.04. 1981	grain	dex	9	30	59,300,000	bucket elevator
18.	Bellwood, NE, USA	07.04. 1981	grain	dex	2	1	6,400,000	bucket elevator
19.	Caracas, Venezuela	19.12. 1982	oil froth	f	150	>500	74,500,000	storage tank
20.	Romeoville, IL, USA	23.07. 1984	propane	vcex	15	22	200,000,000	absorption column
21.	Fort McMurray Alberto, Canada	15 08 1984	HCs	vcf	-	-	120,700,000	coking unit
22.	San Juan Ixuatepec, Mexico A B C D	19.11. 1984	LPG	vcf, bleve	650	6400	31,300,000	terminal
23.	Bhopal, India	03.12. 1984	methyl isocyanate	tox	~4000	-	-	storage tank
24.	Las Piedros, Venezuela	13.12. 1984	oil	f	-	-	97,700,000	hydro-desul-phurizer
25.	Pride, Italy	19.05. 1985	HCs	f	-	-	98,100,000	ethylene plant
26.	Pampa, TX, USA	14.11. 1987	-	f, ex	-	-	308,000,000	reactor
27.	Grange-mouth, UK	22.03. 1987	hydrogen	f	-	-	111,200,000	separator vessel
28.	Norco, LA, USA	05.05. 1988	C_3HCs	vcex	7	28	413,600,000	cat cracker
29.	Alpha Piper, North Sea A B	06.07. 1988	gas, oil	ex, f	167	-	1,860,000,000 8,850,000,000*	compression unit, drilling platform

30.	**Antwerp, Belgium**	**07.03. 1989**	**ethylene oxide**	**ex**	**-**	**-**	**101,300,000**	**distillation column**
31.	**Richmond, CA, USA**	**10.04. 1989**	**hydrogen**	**f**	**-**	**-**	**118,400,000**	**refinery**
32.	**Pasadena, TX, USA** **A** **B**	**23.10. 1989**	**isobuthane**	**vcex**	**23**	**~103**	**>623,500,000** **1,770,000,000***	**polyethylene plant**
33.	**Sterlington, LA, USA**	**01.05. 1991**	**-**	**Ex**	**-**	**-**	**126,000,000**	**nitroparaffin unit**
34.	**Coatzacoale, Mexico**	**11.03. 1991**	**-**	**Ex**	**-**	**-**	**180,000,000**	**chlorine plant**
35.	**Munich, Germany**	**23.05. 1993**	**peroxide**	**f, ex**	**2**	**-**	**3,600,000,000**	**cleaning of peroxide installation of pilot plant**

Event	
Bleve	**Boiling liquid expanding vapour explosion**
Dex	**Dust explosion**
Ex	**Explosion**
F	**Fire**
Tox	**Toxic release**
Vcex	**Vapour cloud explosion**
Vcf	**Vapour cloud fire**
*	**‘cash flow’ situation cost**