# Nuclear installations abroad - the accident risks and their potential consequences for Ireland

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## Introduction

All countries, even those without nuclear installations, but especially those in the northern hemisphere are vulnerable to the effects of severe nuclear accidents The purpose of this paper is to examine Ireland's vulnerability to damage from accidents at civil nuclear installations and draw some conclusions.

## The Threat

Ireland is threatened in two ways: firstly, by accidents and, secondly, by the day to day chronic leakages of small amounts of activity (often referred to as routine discharges) from nuclear installations. This paper focuses on the threat from accidents. The effect of routine discharges is the subject of a separate paper at this seminar.

One of the many lessons learnt from the Chernobyl accident was the need to report accidents promptly. This need led to the establishment of "The International Nuclear Event Scale" which could be used in an effective and unambiguous way to communicate promptly the gravity of an accident. The scale is illustrated in Figure 1. It will be seen that accidents at levels 5, 6 and 7, often referred to as "severe accidents" are by definition the only ones by which we in Ireland could be affected.

During the 50 years, or so, history of nuclear power there have been four accidents at these levels (see Figure 2) two of which have been at civil nuclear installations, the reactors at Chernobyl and Three Mile Island, and two at military nuclear installations namely, the Windscale Pile (1957) and Kysthym Storage Tank (1957). Accidents at lower levels are relatively common but decrease with increasing level on the scale. For example in 1995, 17 events were reported at level 1 of the scale, 8 at level 2, 1 at level 3 and none at the higher levels. Using reported figures for events at levels, 1, 2 and 3 over the past years it is easy to forecast with confidence their frequency in years ahead. This cannot be done, in the case of severe accidents because they are rare events, however alternative methods of forecasting their frequency exist which will be discussed later.

In order to assess the threat it is necessary to determine both the probability and the consequence of severe accidents and then take into consideration both distance of the accident from Ireland and the probability of unfavourable weather conditions carrying the radioactive material to Ireland. The following simplified mathematical expression may help understanding:

$$T \ \alpha \ Ps.Pw.Q.D^{-n}$$

| | | |
|---|---|---|
| Where | $T$ | is the threat of nuclear damage |
| | $Ps$ | is the probability of a severe accident |
| | $Pw$ | is the probability of unfavourable weather |

| | |
|---|---|
| Q | is the size and character of the accidental release of radioactivity |
| D | is the distance from the accident |
| n | is exponent which depends on weather, height of release, particle size and other factors |

## The Importance of Distance

The above expression may be used to help indicate those reactors which present the greatest threat to Ireland. The main question to be answered is are the reactors of Eastern Europe and beyond a greater threat than the safer reactors of Western Europe, particularly those in the UK?

The Eastern reactors are believed to be less safe than nearby UK reactors by a factor of about ten. So by inserting some typical figures in the above expression and using $T_{uk}$ and $T_{ee}$ to represent the threat from UK and Eastern European reactors respectively one gets

$$\frac{T_{uk}}{T_{ee}} = \frac{10^{-5} \times 10^{-1} \times Q \times 200^{-n}}{10^{-4} \times 10^{-1} \times Q \times 3000^{-n}} = 1.5 \text{ when } n=1$$

The values for Pw and Q are assumed to be the same in both cases. The result is very much dependant on the value of n which lies generally between 1 and 2. Assuming a value of 1, the UK reactors, at approximately 200 kilometres distance, present the greater threat but only just: however, as the value of n increases towards 2 so also does the threat from the UK reactors.

## Sources of Threat

Having defined the threat and emphasised the importance of distance it is now necessary to identify the types of nuclear installations which are the source of the threat. By definition a civil nuclear installation means any installation in the civil nuclear fuel cycle (see Figure 3). This consists of three parts: that before the reactor known as the "front end", the reactor itself and lastly the "back end". The front end is not a likely source of severe accidents because the processes involved do not entail high working temperatures and pressures and the uranium itself is not very radiotoxic - the finished product can be safely handled with gloved hands. Moreover, there is no history of severe accidents at these plants.

The reactor itself and the on-site interim storage of spent fuel are clearly sources of threat but so also are parts of the "back end" such as spent fuel storages at reprocessing plants, the plants themselves, and the on-site high level liquid waste storage tanks. The radioactive material in this part of the fuel cycle is highly radiotoxic and continues to produce heat which must be removed if safety is to be maintained.

## Measuring the Threat

Having identified severe accidents at nuclear installations in the back end of the nuclear fuel cycle as the source of threat the next step is to consider how the probability and consequence of such accidents can be measured.

It has long been recognised that accidents, whether they be initiated by man or nature, seem to obey a certain relationship between frequency and consequence i.e. high frequency accompanies low consequences and vice versa (see Figure 4). In the 1960s Professor Farmer of the UKAEA proposed a safety criterion for regulators which recognised this relationship and declared a limit for the frequency of accidental releases of radioactive material from reactors. At the time this was accepted as good theory but not practical because of the difficulty of measuring the likelihood of occurrence of large releases.

In the 1970s much effort was put into the development of methods of measuring the probability of nuclear accidents involving large releases of radioactive materials into the environment - i.e. rare events. This work was most advanced in the UK and the US where the WASH-1400 Report [USNRC, 1975] (or "Rasmussen Report" by which it is more commonly known) on the safety of nuclear reactors, published in 1975, used a method then called Probability Risk Assessment (PRA) to estimate the frequency and consequences of severe accidents. The report estimated the frequency of core melting in US pressurised water reactors (PWRs) and boiling water reactors (BWRs) at about $10^{-4}$ per reactor year. The accident in 1979 at TMI was such an accident but happened earlier than Rasmussen predicted. Nevertheless, his method had identified the type of accident and was accurate within a factor of about three on frequency.

The PRA method now known (more optimistically) as Probability Safety Assessment (PSA) is widely used not only by nuclear regulators but also by designers and operators of nuclear and large chemical plants. It is, however, a very time consuming and expensive process which needs access to fine detail of plant design and to component reliability data banks. It is not therefore a matter of picking up an instrument and measuring an effect - which can be done in the case of routine discharges - rather it is a tool that can be only used by those with large resources and an intimate knowledge of the plant in question. The US has led the world in the application of PSA both at the design and operational stages of reactor life with Western Europe not far behind, however, details of such studies are not readily available. In the absence of such information for UK installations there is little alternative but to revert to the regulator's criterion mentioned previously and proposed for use by UK regulators in the Royal Commission's Report on Environmental Pollution [RCEP, 1976]. Figure 5, taken from the Commission's Report, illustrates the criterion which indicates those nuclear risks which are not acceptable and those which are tolerable. It is the basis of the principles used today by the Nuclear Installations Inspectorate (NII) in their treatment of severe accidents in the regulatory process [HSE, 1992].

For the purpose of this paper two accidents, one supposedly at Calder Hall (a Magnox type reactor on the Sellafield site) and another at one of the Advanced Gas Reactors at Heysham are chosen with frequencies and releases of radioactive iodine and other radioisotopes to the environment which are considered tolerable by the criterion. Their positions on the diagram are (Figure 5) are indicated. Although the criterion illustrated is for reactors, similar criteria exist for other sources of hazard in the nuclear fuel cycle where radioactive iodine is not the primary radiotoxicant. The third supposed accident is at a high level liquid waste storage tank at Sellafield reprocessing plant. The expected frequency and associated release of radioactive material to the environment is again in accordance with the idea of "tolerable risk". It has a higher consequence and a lower probability than the other two.

## The Guinea Pig Installations

The particulars of the nearby nuclear installations chosen for the purpose of determining the consequences/damage in Ireland in the event of severe accidents in the UK are:

> Calder Hall Unit A, an early Magnox type nuclear reactor at Sellafield, 39 years old, 60 Mega watts electrical power, 205 km distant from Dundalk, 220 km from Dublin;

Heysham 2, unit A, Advanced Gas Reactor (AGR) at Heysham, Lancashire, 7 years old, 680 Mega watts electrical power, 235 km distant from Dundalk and Dublin;

High Active Waste Tanks at Sellafield, the oldest are about 25 years, each hold about 140 $m^3$ of concentrated high active liquid waste from about 15 reactors cores. There are about 20 tanks some of which are kept empty on standby, ready to receive the contents of a faulty tank. Distances to Dundalk and Dublin are 205 and 220 km respectively.

## Calculation of Atmospheric Dispersion

The pathway to Ireland of releases from nuclear accidents will be in the atmosphere rather than the sea as is the case for most routine discharges. Large releases into the aquatic environment are not considered in this report because the likely effect on Ireland would be small in comparison with atmospheric releases and the probability of large aquatic release is very much lower.

The material released into the atmosphere will be both gaseous and solid: the latter will be in very fine particulate form with maximum dimension of a few millionths of a metre (microns). The solid material will eventually come down to earth; in the long term in the form of a dry deposit or in the shorter term as a wet deposit, "washed" out of the atmosphere by precipitation. The gases will mix intimately in the atmosphere and remain there until they decay into non-radioactive solid substances and eventually come down to earth also (see Figure 6). Dispersion is difficult to model. Existing models have large uncertainties and results therefore must be treated with caution. A computer code has been used to calculate the doses to the most exposed members of the public under the most unfavourable weather conditions i.e. those giving the largest doses. When these raw results are tempered by:

a. comparison with the actual effects of the 1957 accident at Windscale [Crick and Linsley, 1982] in the UK (it released 33% more radioactive material than that assumed in this case for Calder Hall).

b. giving credit for emergency response in Ireland and "accident management" in the UK.

c. uncertainties in modelling.

d. a degree of technical judgement.

It is concluded that the accident at Calder Hall with a probability of about 6.6 x $10^{-5}$ per year would cause less harm in Ireland than did Chernobyl [Cunningham *et al.*, 1987], while the Heysham supposed accident would be approximately the same (the probability in this case being about $10^{-6}$ per year). Finally, the supposed accident in the storage tanks at Sellafield would be expected to exceed the harmful effects of Chernobyl (the probability being less than about $10^{-7}$ per year). No deaths would be expected in the immediate aftermath of the accident however an increase in cancers over a period of about 25 years or so would be expected assuming that present day models for the effects of low level radiation are valid. The probabilities of the three supposed accidents might be described as being highly unlikely, improbable and highly improbable respectively. Unfortunately, however, they cannot be described as being impossible just as a meteor strike on this country killing 10 people cannot be ruled out - it is calculated to be as probable as the supposed accident at the Calder Hall Reactor.

The threat to Ireland is real and necessitates the maintenance of an emergency response system. This is actively encouraged by international agencies and is a requirement for parties to the Nuclear Safety Convention including those, like Ireland, without nuclear programmes.

## Conclusions

1. The dominant threat to Ireland from the civil nuclear power programme worldwide is due to potential atmospheric releases from nearby installations in the UK despite the fact that reactors in Central Europe and further east are less safe. The main focus therefore of our emergency preparedness must be directed at the UK installations because of their proximity.

2. Accidents at INES levels 1, 2, 3 and 4 will not affect Ireland.

3. Severe accidents at UK installations would not cause deaths in Ireland in the immediate aftermath of the accident nor would evacuation be necessary.

4. Doses in excess of those experienced in the aftermath of Chernobyl accident could be suffered: they could exceed 1 mSv in the year following initial exposure i.e. they could exceed the annual dose limit for members of the public.

5. Favourable weather conditions and/or distance from a severe nuclear accident may mean that Ireland would avoid any effects. Winds are mainly from the north to south west sector and are frequently strong: both factors help to preserve Ireland from atmospheric contamination originating from the east.

## References

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Cunningham, J.D., MacNeill, G., Pollard, D., 1987. **Chernobyl its effect on Ireland.** Dublin: Nuclear Energy Board.

Health and Safety Executive, 1992. **Safety assessment principles for nuclear plants**. United Kingdom: HMSO.

Royal Commission on Environmental Pollution, 1976. **Sixth report. Nuclear power and the environment**. London: HMSO.

United States Nuclear Regulatory Commission, 1975. **Reactor safety study. An assessment of accident risks in US commercial nuclear power plants**. WASH-1400. United States: USNRC.

Figure 1.

## The International Nuclear Event Scale

For prompt communication of safety significance

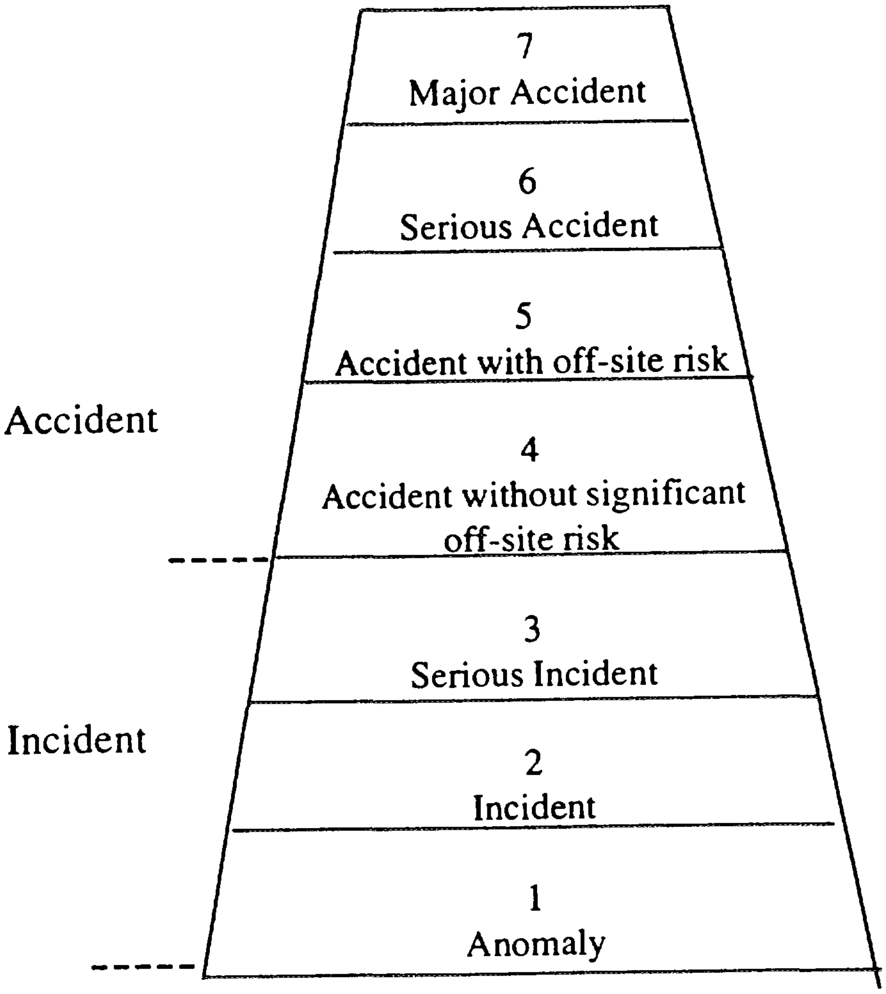


Figure 2.

## Past Severe Accidents

| Site | Level | Date | Type |
|---|---|---|---|
| TMI (USA) | 5 | 1979 | Reactor (PWR) |
| Windscale | 5 | 1957 | Plutonium Production Pile |
| Kysthym (USSR) | 6 | 1957 | Storage Tank at Reprocessing Facility |
| Chemobyl (USSR) | 7 | 1986 | Reactor (RBMK) |

Figure 3

**Nuclear Fuel Cycle**

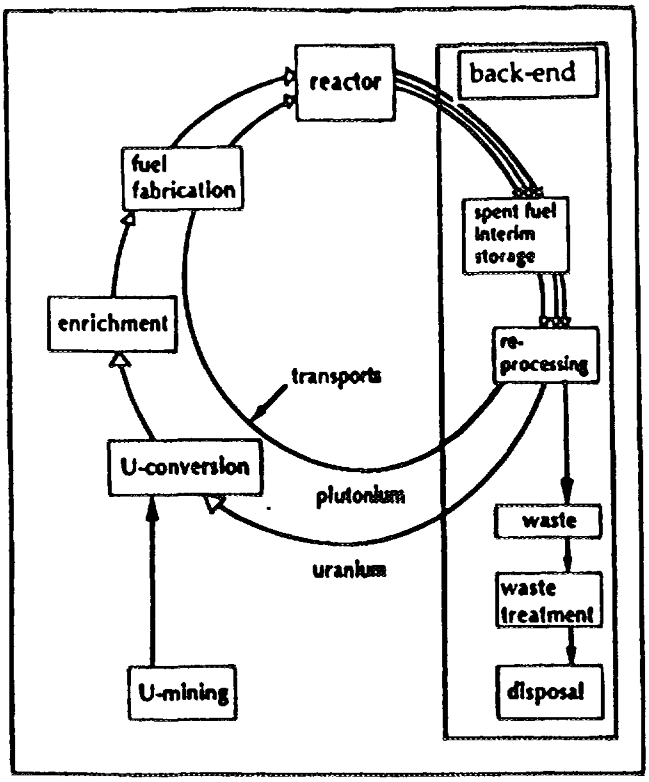


Figure 4

**Incidence of natural disasters ( in the USA)**

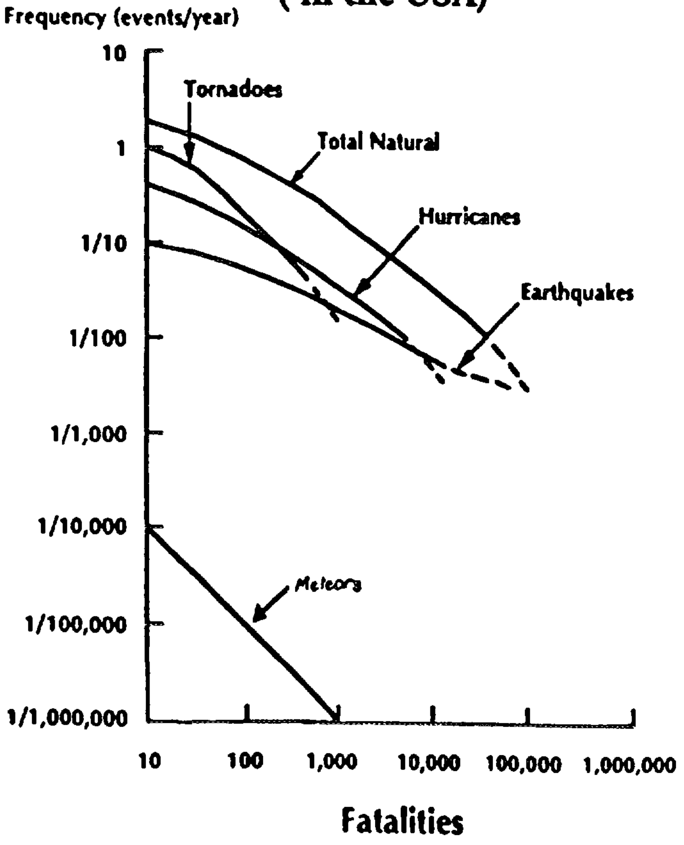
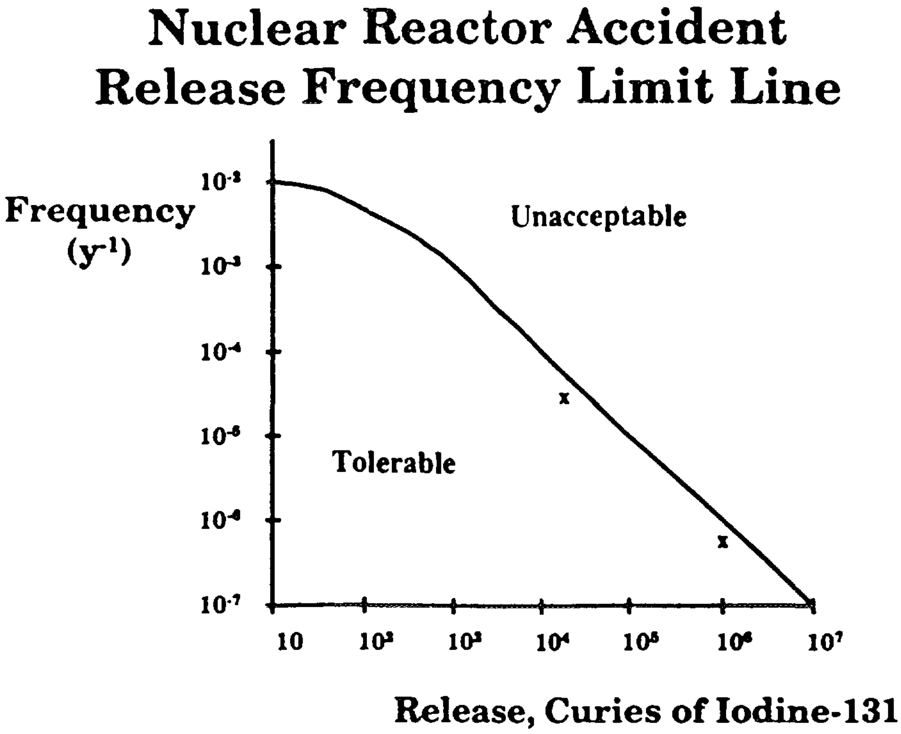
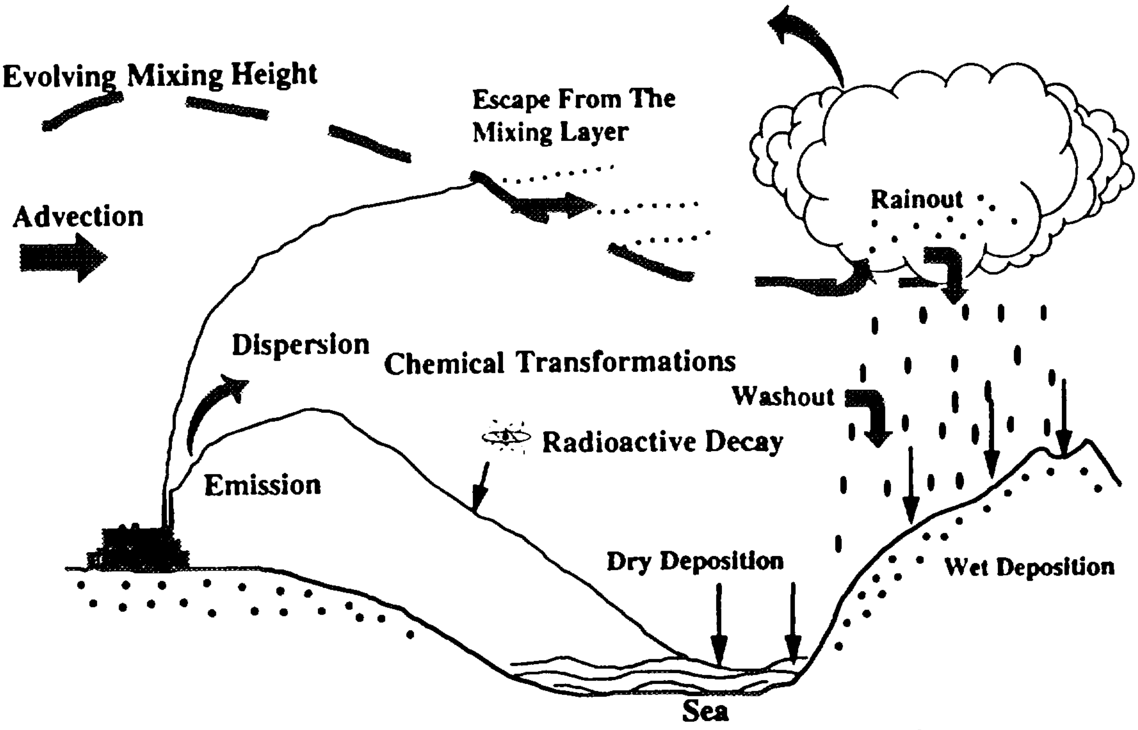


Figure 5



"x" marks the position of supposed reactor accidents

Figure 6



Some Processes Affecting Airborne Pollution