Nuclear and Non-Nuclear Accident Consequences

by J R THOMSON

Introduction

Before April 1986, one of the first questions in any conversation about nuclear safety was "But what happens if . . . ?" Post-Chernobyl, the answer to that question is known to all, at least in a filtered form, via the news media. It is perhaps now an opportune time to reconsider nuclear accident consequences, and to compare them with the consequences of other man-caused accidents.

Prior to Chernobyl, the nuclear industry tended to sidestep the conditional question "What happens if?" and instead answered more complex questions concerning societal risk. However, it is the contention of this article that nuclear accident consequences are at worst no more severe than other man-caused accidents, at least in terms of mortality. This contention can be supported by empirical evidence, but should not necessarily be regarded as a defence of nuclear power. Two (or more) wrongs do not make a right.

A further question that is often asked concerns the risk to an individual from living close to a nuclear accident. This article therefore addresses the question of calculated individual risk, conditional on being directly downwind of an accident, for both nuclear and chemical accidents.

The following is intended as a personal view and is subject to assumptions which are sometimes implicit. Care should be taken when using any conclusions out of context. It is also noted that data relating to source terms and collective doses from reactor accidents are estimates, and that alternative references to those cited here might lead one to slightly different conclusions.

Empirical data

Actuarial data for chemical and nuclear accidents

V C Marshall of Bradford University wrote an article in 1977 entitled "How dangerous are explosions and toxic escapes?" (1). The article was prefaced with a quotation from Tennyson which is worth recalling:

"Oh yet we trust that somewhow good will be the final goal of ill."

Marshall presented data for mortality in chemical plant accidents in the form of a graph of "mortality index" (deaths per tonne) plotted against the mass of explosive or gaseous toxic escape. His results are shown in Fig 1, to which the data for the Bhopal accident have been added. For accidental explosions, he concludes that the relationship between mortality index M_I (deaths/tonne) and mass of explosive m is

$$M_I = 4\,m^{-1/2} \qquad (1)$$

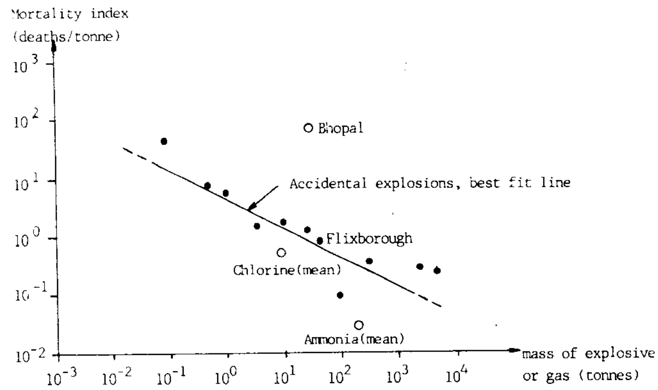

FIGURE 1
Mortality index (deaths per tonne) as a function of the magnitude of the accident for explosions and gas release accidents (Marshall 1977)

where m is in tonnes. For toxic escapes, mean results only are given, due to the paucity of the data.

A similar approach for analysing the consequences of nuclear accidents yields interesting results. An equivalent diagram to Fig 1, but for reactor accidents, can be produced by considering the assessed collective effective dose equivalents and source terms for the Windscale fire in 1957, the TMI accident in 1979 and the Chernobyl accident in 1986.

Source terms (S) have been described solely in terms of iodine^{131} release, since this single isotope contributed a significant fraction to the collective effective dose equivalent in all three cases. A "dose index" (D_I) has then been calculated as follows:

$$D_I = \frac{\text{collective effective dose equivalent (man-Sv)}}{\text{source term (TBq } I^{131})} \qquad (2)$$

A graph of dose index against source term is presented in Fig 2. Data were taken from the NRPB analysis of the Windscale fire (2), the Kemeny Commission report on the TMI accident (3), the UKAEA report on the Chernobyl accident (4) and (5) (See Table 1).

Whilst the danger of reaching misleading conclusions from three points on a log-log plot must be remembered, these results suggest an empirical relationship between dose index (in man-Sv/TBq) and source term of the following form:

$$D_I = 50\,S^{-0.33} \qquad (3)$$

It should be noted that local population density is not a particularly significant factor in assessing collective dose, particularly for large releases; the 135,000 evacuees from Chernobyl received less than 5% of the total collective dose. Hence the above relationship

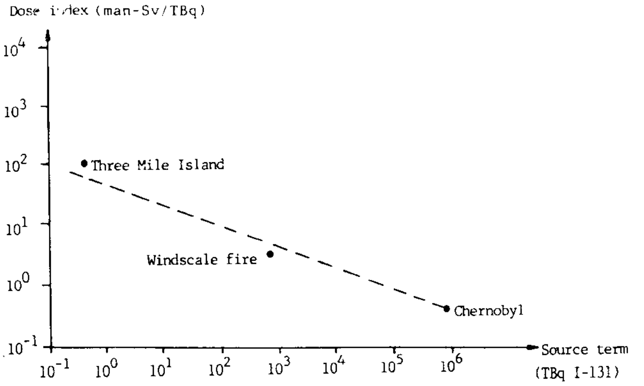

FIGURE 2
Dose index (collective effective dose equivalent (man/Sv)/ source term (TBq I-131)) as a function of the source term.

should not be particularly affected by local demographic conditions. However, this method of presentation makes no allowance for variation of the relative amounts of other fission products in the source term, or for climatic conditions. These factors may have caused inaccuracy in the above relationship, although it is nevertheless proposed as a rule-of-thumb for assessing the consequences of reactor accidents.

TABLE 1

Source terms, collective effective dose-equivalents (CEDE) and dose indices (D_I) for reactor accidents

(All source terms and CEDEs are approximate)

	Source term (TBq I^{131})	CEDE (man-Sv)	D_I (= CEDE/ source term)
TMI	0.55	56	102
Windscale	740	2000	2.7
Chernobyl	850000	500000	0.59

There is no theoretical justification for the functional form of equation (3). The calculation of collective dose is well-known to be extremely complicated, requiring the consideration of the effects of cloudshine, inhalation and ingestion, for each of a large number of isotopes all having differing toxicities. This complexity makes it impossible to derive theoretically any simple relationship between collective dose and source term. Nevertheless an approximate relationship of the form $D_I = aS^{-b}$ is what one might reasonably expect from considerations of plume dilution, depletion and decay. Buoyant plume rise will also play a significant role in reducing the dose index in large releases, where the releases will inevitably be at high temperature.

Putative cancer mortality in nuclear accidents is assessed by multiplying the collective effective dose equivalent by the ICRP risk coefficient, 1.25×10^{-2} (man-sV)$^{-1}$. This coefficient is likely to be revised upwards to approximately 3×10^{-2} (man-Sv)$^{-1}$ (9), although the relevance of the linear dose-risk hypothesis at low individual doses remains questionable. Ref 10 contains a recent review of "radiation hormesis", the name given to the effect, observed by some investigators, whereby low individual doses are found to exert a beneficial influence on health.

Non-nuclear man-caused accidents

Table 2 presents a list of all man-caused accidents (that is, excluding deliberate wartime activities) within the last century, which have caused death-tolls in excess of 1,000, of which the author is aware. This table leaves out any putative cancer mortalities due to fossil fuel combustion or the Chernobyl accident. Sources include Jay Nash's "Darkest Hours" (6) and the Guinness Book of Records. The latter book suggests that 25 million people had been killed in road accidents worldwide by 1975, a toll which makes other accidental causes of death look insignificant and exceeds the total death toll of World War One by a factor of greater than two. It is

TABLE 2

Non-military man-caused catastrophes which have caused more than 1,000 deaths 1887-1987

Year	*Event and location*	*Death toll*
1889	Dam failure, Pennsylvania	c.2,200
1904	Liner 'General Slocum' fire, New York	1,020
1912	'Titanic' sinking	1,502
1912	Steamer 'Kichemaru' sinking off Japan	c.1,000
1914	Liner 'Empress of Ireland' sinking	1,370
1916	Steamer 'Hsin Yu' sinking off China	c.1,000
1917	Munitions ship explosion, Nova Scotia	1,963
1921	Steamer 'Hong Kong' sinking off China	c.1,000
1931-35	Hydroelectric tunnel construction, West Virginia (deaths due to silicosis)	c.2,500
1935	Arsenal explosion, Lanchow, China	c.2,000
1942	Colliery coal dust explosion, Hinkeiko, China	1,572
1948	Refugee ship 'Kiangya' sinking, off China	c.1,100
1951	Smog, London	3,000-4,000+
1953	Dyke failure, Holland	1,487
1954	Ferry 'Toya Maru' sinking off Japan	1,172
1963	Dam failure, north Italy	c.1,800
1979	Dam failure, Gujarat, India	5,000-15,000
1982	Petrol tanker explosion in tunnel, Afghanistan (possible military involvement)	1,100-2,700
1984	Methylisocyanate release, Bhopal	c.2,500
1987	Ferry 'Dona Paz' sinking off Philippines	c.1,500

also noted that the destruction of the Yangtze Kiang dam by the Japanese in 1938 is reputed to have caused 900,000 deaths (sic), and is therefore the most catastrophic single act of war.

Individual Risk Downwind of Chemical and Nuclear Accidents

Although the subject of theoretical risk to individuals living close to the sites of chemical or nuclear accidents has often been addressed previously, the author is unaware of any attempt to compare one with the other. The results of such a comparison are shown in Fig 3, which shows theoretical individual risk downwind of hypothetical instantaneous, neutrally-buoyant, ground-level discharges of chlorine and radioactivity, normalized to give 1% risk at 2 kilometres downwind. The calculations assume that the individual is in the open and does not attempt to seek shelter or escape the plume.

The dose-risk relationship for chlorine is a fairly complex one; dose is normally taken to be the time integral of $(\text{concentration})^{2.75}$, and the relationship between dose and risk is assessed by probit analysis. (See, for example, (7)). The curve in Fig 3 corresponds to a chlorine release of about 3.3 tonnes. Worldwide, there were 29 toxic release accidents of greater magnitude than this in the period 1914-1977 (11).

For the radioactive plume calculation, ICRP data have been used. This curve represents the risk due to the cloudshine from 15 x 10^6 TBq of krypton-85m (corresponding to about 14% of the gaseous gamma activity in a 3,000 MWth reactor), or else the risk due to inhalation from a plume of 0.11 x 10^6 TBq of iodine^{131} (neglecting deposition, and corresponding to about 3% of the I^{131} inventory of a 3,000 MWth reactor); the curve shapes are similar for both species. Hence, and more realistically, the curve will correspond to appropriate proportions of the two isotopes. From Table 2, the only accident to have occurred which is more severe than this is the Chernobyl accident.

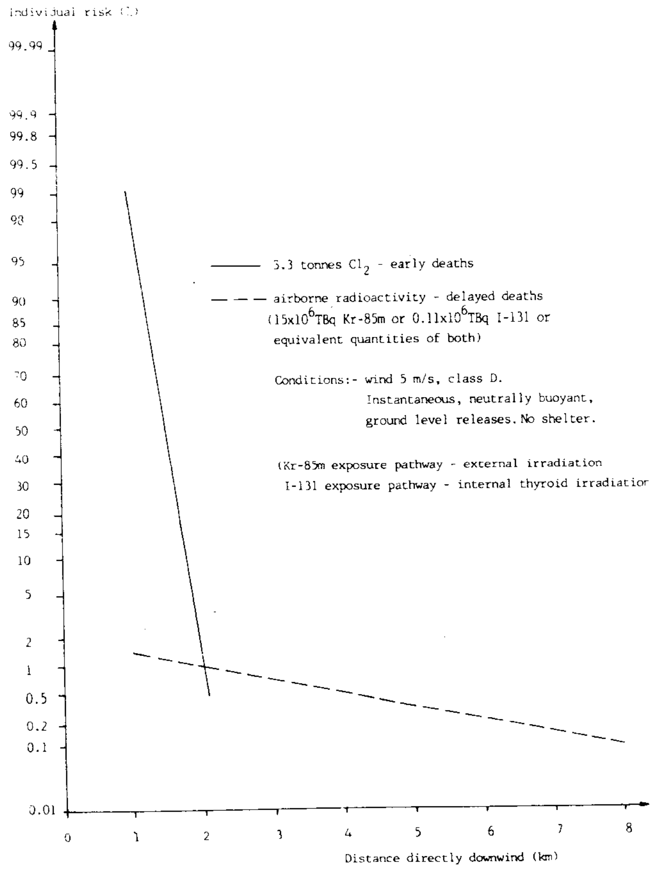

FIGURE 3
Probability plot of individual risk downwind of chemical and nuclear accidents. Source terms are selected to yield 1% theoretical risk at 2 km downwind. (Author's calculation based on Ref 8)

The above assumptions pessimise any likely accident consequences, but the shapes of the two curves in Fig 3 highlight the differing natures of chemical and radioactive toxicity.

Who gets the blame?

As a final comment, there are a number of interesting parallels between the Chernobyl and Zeebrugge ferry accidents. In both cases the accidents arose because of designs which did not exclude failure modes which were sudden and catastrophic. In both cases it was assumed that the risk of these recognized failure modes could be minimized by administrative and managerial controls. In both cases, the designs had been approved by the relevant regulatory authorities. However, in both cases, the legal blame has been placed on those who were operating the plant at the time of the accident, and other similar plant has been allowed to continue to operate, albeit with further administrative controls and improvements to sub-systems. One possible conclusion might be this: we should be wary of any temptation to criticize the Soviet nuclear regulatory authorities — similar mistakes are still being made elsewhere. Another possible conclusion is that, in the UK at least, other hazardous industries could learn from the vaunted "safety culture" of the nuclear industry.

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