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Short Communication

THE RELATIVE RISK FROM MATERIALS IN STORAGE AND IN PROCESS

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In accounts of hazards in the oil and chemical industries it is frequently suggested that the risk from materials in storage is in some sense less than that from those in process. This distinction is made in the industrial comment on the risk analysis carried out on the hazardous installations in the Rijnmond area for the Rijnmond Public Authority by Cremer and Warner [1].

Here an attempt is made to cross-check the risk assessment by estimating from the annual fatality rate in the process industries in the Netherlands the annual fatality rate attributable to the six storage installations studied. It is stated that there are approximately 4 deaths per year in the Dutch process industries and that, if it is assumed that 50% of these are due to technological accidents and that 20% of these latter involve multiple fatalities, then the annual fatality rate attributable to multiple fatality technological accidents is $4 \times 0.5 \times 0.2 = 0.4$ deaths per year. Then, taking the number of process and storage installations in the country as approximately 500 for each and not distinguishing between them, the annual fatality rate for multiple fatality accidents attributable to the six storages is $0.4 \times 6/(500 + 500) = 2.4 \times 10^{-3}$/y. It is suggested, however, that "the hazard potential of operating a production unit is about a 100 times higher than that of storages", so that taking this factor into account the annual fatality rate for multiple fatality accidents for the six storages becomes $0.4 \times 6 \times (1/100)/(500 + 500/(1/100)) = 4.8 \times 10^{-5}$/y.

The distinction between process and storage has also recently found expression in the EC Directive on Major Accident Hazards [2], which specifies for the application of control measures different quantities in process or associated storage from those in isolated storage.

The hazard potential of storage is a function of the nature of the material (whether flammable or toxic), its normal boiling point, the storage conditions and the quantity held. The quantity of material tends to be very much higher in storage than in process. If the material is a liquified gas, whether held under pressure or fully refrigerated, it is liable on release to form a vapour cloud. Thus on account both of the quantity of the material and of the conditions under which it is held the hazard potential of storage can be high.

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The risk of escapes from storage is usually held to be less than that of those from process. As a general proposition this is almost certainly true, although it does not appear to have been demonstrated across the whole range of leak sizes. If consideration is restricted to large multiple fatality accidents, however, it appears that the proportion of releases from fixed installations which occurs from storage is by no means negligible.

A list of major accidents, including many which are well known by name, has been given by Lees [3]. This list is not exhaustive, but it is believed to be unbiased as far as the ratio of process to storage accidents is concerned. Table 1 is an abstract from this list giving all those accidents involving 10 or more deaths and indicating whether the source was process or storage. Accidents involving explosives, including ammonium nitrate, and transport,

TABLE 1

Some major accidents involving ten or more deaths in the oil and chemical industries (after Lees [3])

Date	Location	Deaths	Process/ storage
1926	St Auban	19	storage
1928	Hamburg	10	storage
1939	Zarnesti	ca. 60	storage
1944	Cleveland	128	storage
1944	Denison	10	storage[a]
1947	Rauma	19	storage
1950	Poza Rica	22	process
1959	Ube	11	process
1960	Kingsport	15	process
1962	Toledo	10	process[b]
1965	Louisville	12	process[c]
1966	Feyzin	18	storage
	LaSalle	11	process[d]
1968	E. Germany	24	process[e]
1972	Brazil	37	storage[f]
	Weirton	10	process
1973	Potchefstroom	18	storage
1974	Czechoslovakia	14	process[f]
	Flixborough	28	process
1975	Beek	14	process
	Scunthorpe	11	process
1976	Chalmette	13	process[g]
1977	Columbia	30	process[h]

[a] Gugan [4].
[b] Chementator [5].
[c] Chementator [6].
[d] Chementator [7].
[e] Assumed.
[f] Davenport [8].
[g] Chementator [9].
[h] Anon. [10].

TABLE 2

Some other major accidents involving storage in the oil and chemical industries (after Lees [3] and other sources)

Date	Location	Deaths
A. Accidents involving fatalities		
1967	Lake Charles	7
1968	Pernis	2
1972	Jakarta	72[a]
1977	Umm Said	6[b]
1982	Caracas	> 100[c]
B. Accidents not involving fatalities		
1970	Blair	
1976	Baton Rouge	

[a] Anon. [11].
[b] Anon. [12].
[c] Anon. [13].

including pipelines, have been excluded. The table shows process and storage as the source of 14 and 9 accidents, respectively, making the latter 39% of the total.

Table 2 lists some other well-known major accidents which have involved storage. Lake Charles and Pernis were large unconfined vapour cloud explosions and Blair and Baton Rouge large toxic releases of ammonia and chlorine, respectively. Umm Said was a fire and explosion. Jakarta and Caracas have been less well reported.

It is possible that the figures just quoted may overestimate the contribution of storage under modern conditions. Table 1 includes a series of storage accidents from the prewar and wartime periods when standards were not so high as they are today. If these accidents are excluded, process and storage are the source of 14 and 4 accidents, respectively, making the latter 22% of the total. With the same exclusions the contribution of storage to fatalities is 29%.

There is, therefore, a *prima facie* case that storage is perhaps rather more significant than is often allowed.

A more complete picture of the contribution of storage may be obtained by considering lesser accidents. Data on fire losses for the petroleum industry are given regularly by the American Petroleum Institute [14]. Table 3 shows data for 1977 on the number, frequency and cost of fires for refineries and natural gas plants (process) and for tank farms, bulk terminals (shore) and bulk plants (inland) (storage) for 73 participating companies. Process and storage were the source of 195 and 23 accidents, respectively, making

TABLE 3

Some fire loss data for the petroleum industry in 1977 (after American Petroleum Institute [14])

	Number of fires	Frequency of fires: fires/100 properties	Cost per fire ($)
Refineries	176	141.9	204,000
Natural gas plants	19	3.72	49,000
Tank farms	3	1.05	127,000
Bulk terminals (shore)	11	2.06	313,000
Bulk plants (inland)	9	0.97	195,000

storage 11% of the total. Storage contributed 72% of the financial loss.

Data on sources of spill material for unconfined vapour cloud explosions have been given by Davenport [8]. Process and storage were the source of 24 and 4 accidents, respectively, making the latter 14% of the total. Storage accounted for 28% of the financial loss.

Data on accidents involving 2 to 9 deaths are shown in Table 4, indicating whether the source was process or storage. These data are taken from a further collection made by the author which again is not exhaustive but is believed to be unbiased. Accidents involving general industry, explosives, petrol stations, warehouses, oil rigs, construction and transport have been excluded, though storage accidents involving loading/unloading terminals are included. The tables show that the contribution of storage rises from 13% for accidents involving 2 deaths to 36% for those involving 6—9 deaths.

TABLE 4

Some lesser accidents involving two to nine deaths in the oil and chemical industries

	No. of deaths per accident				
	2	3	4	5	6—9
Process					
No. of accidents	26	13	9	4	11
Total no. of deaths	52	39	36	20	81
Storage					
No. of accidents	4	3	3	1	5
Total no. of deaths	8	9	12	5	46
Deaths from storage (%)	13	19	25	20	36

The data in Tables 1 and 4 are based on small samples, but it is clear that there is a significant contribution from storage.

The risk assessments given in the two Canvey Reports [15, 16] also show that storage makes a significant contribution to the risk.

The modes of escape from storage are in fact quite numerous. Table 5 lists some of these modes. Section A of the table gives some of the modes for the accidents in Tables 1 and 2 and section B some other possible modes.

What the foregoing data appear to indicate is that the contribution of storage to deaths in multiple fatality accidents in the oil and chemical industries tends to increase with the number of fatalities and for accidents involving 5 or more fatalities to approach a figure of the order of 20—35%. Thus the idea that material in storage presents a much lower risk than that in process is a half-truth and cannot be accepted without qualification. As far as concerns multiple fatality accidents, and in particular large multiple fatality accidents, the contribution of storage is appreciable.

TABLE 5

Some modes of escape from storage in the oil and chemical industries

A. *Modes which have occurred (in accidents listed)*	
Overfilling/overflow	Blair
Slopover	Pernis
Overfilling/overpressure	Rauma
Brittle fracture	Cleveland, Potchefstroom, Umm Said
Internal explosion	Zarnesti, Baton Rouge
Escape from filling/offtake pipe	Lake Charles
Escape from drain/sample point	Feyzin
B. *Other possible modes*	
Rollover	
External fire	
External impact	
Maintenance/modification work	

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