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Natural events and accidents with hazardous materials

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Abstract

Based on accident case histories extracted from the data bases Mhidas (SRD) and Facts (TNO) an analysis was performed to identify relevant natural events causing accidents involving hazardous materials. A natural event is defined as an event originating from nature which initiates accidents with hazardous materials. In the analysis, the accidents from the two sources were pooled and the analysis concerns a total of 232 accidents, which were analysed with regard to specific natural cause, geographical distribution and time trend.

The analysis indicates that between 1% and 5% of accidents in industrial activities have natural events as a causative factor. Further for specific industries certain types of natural events seem to be dominating.

The most often reported natural cause of accidents is 'atmospheric phenomena' which account for 80% of the natural events found, lightning being the most common cause. Looking specifically at storage and processing activities lightning accounts for 61% of the accidents initiated by natural events.

1. Introduction

In order to prevent industrial accidents involving hazardous materials it is important to understand the causes, and much effort is undertaken to clarify these and to distribute the information to prevent similar accidents [1–3]. Accidents with hazardous materials are rarely caused by one cause, but are rather the result of a series of events. By investigation of the accident it is important to understand the chain of events rather than looking for one single root cause which in most cases does not exist.

The analysis presented in this paper falls into two parts: firstly, an analysis of all accidents identified, including transport, storage and processing is performed; secondly, the accidents concerning storage and processing are reviewed separately because of their relevance to the EC Major Accident Hazards Directive.

Accidents in industrial installations may occur due to a number of causes, which is often classified according to two main groups: technical/system failure and human/organisational error within the plant. The two groups do not exclude each other,

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e.g. a design error is both a human error (the design was wrong) and a technical failure (e.g. mechanical failure of machinery). A similar classification can be made for transport and loading/unloading accidents.

However, in some cases in initiating events fall outside these two main classes. The industrial activities in which hazardous materials are handled may be subject to external events of either technical/human origin like an aircraft crash on site or malicious damage. Another group of events are natural phenomena such as earthquake, wind, lightning, flooding or avalanches. The scope of this paper is to investigate the importance of those natural events for accidents with hazardous materials where hazardous materials are defined according to the UN classifications (excluding radioactive materials).

The accidents identified were analysed with regard to specific natural cause, geographical distribution, time trend, etc.

The analysis of the accident case histories falls into two parts: a general analysis including all accidents and a specific analysis of processing and storage accidents.

This paper first discuss the definition of natural events, followed by a statistical analysis of the accidents.

2. Natural events

In this context a natural event is defined as an event originating from nature which can initiate industrial accidents. This means that technical failures and human errors should be excluded from the category 'natural events'. The definition of 'natural events' as initiating factors for industrial accidents involving hazardous materials is fuzzy as natural phenomena may influence the *consequences* once an accident has taken place. Examples in which the importance of presence/absence of natural phenomena strongly influence the evolution of incidents are easily constructed: Release of a large amount of toxic gas. Strong wind will dilute the gas cloud fast, whereas calm conditions with an inversion layer will aggravate the situation. In this example the 'wind' would not be included in the causative factors of the accident although it clearly influenced the outcome of the event.

For the present investigation, the accident case histories were supplied from the accident data bases in TNO and SRD. The search profile was specified to the data bases as *accidents with hazardous materials initiated by natural events*, and the natural events were exemplified as weather conditions, earthquakes and land slides. The data received from TNO for the accidents contain a field where the cause of the accident is simply 'natural cause' and SRD accident descriptions have a field where the keyword is 'external cause'. For the data bases the searches were performed in these fields.

From a theoretical point of view, the natural events can be organised according to the sphere of nature that they belong to, and Table 1 shows both the classification of the causes in main and subgroups and contains the specific events identified from the data bases.

Table 1
Observed natural events

Atmospheric phenomena	Geological phenomena	Aquatic phenomena	Biological phenomena
Temperature	Earthquakes	Shoal	Beaver dam
Wind	Volcanic activity		Wasp nest
Rain	Ground subsidence		
Lightning	Landslide		
	Soil erosion		

Table 2
Rain causing secondary natural phenomena

Rain causing	Number of events
Ground settlement	1
Ground subsidence	3
Landslide	2
Flooding	8
Soil erosion	5
Earth movements	1
Total	20

The classification of the cause of accidents is not simple because the causes are sometimes interdependent. For example, the phenomena 'flooding' does not appear in Table 1 because the floodings found in the accident descriptions were due to heavy rains and in the analysis flooding is thus seen as a secondary phenomena, due to rain. Further, in some of the accident descriptions rain caused ground subsidence, landslide and soil erosion which in those cases have been classified as accidents due to rain. This illustrates very nicely the problem of finding a root cause for an accident – it depends on definition of the start of the event chain. The full list secondary natural phenomena caused by rain found in this analysis is listed in Table 2.

Further it was found difficult to distinguish between some of the geological phenomena, as the descriptions of accidents were not sufficient to allow a discrimination between the usage of the terms 'ground subsidence', 'soil erosion' and 'landslide'. Accidents belonging to these classes have therefore been grouped in one main group in the final classification. It should be noted that the data do not exclude that these phenomena were caused by rain.

The accidents supplied do all have the natural event as major contributing cause, and in some cases it seems to be the only cause. Natural events which only aggravates the accident once it has started do not seem to be registered in the data bases in a way which allows them to be found.

3. Results from all accidents with hazardous materials

Most of the accident case histories supplied were short consisting of one or two lines describing the event. The accidents came from a wide range of industrial activities including processing, storage, off-shore industry and transport. An example of the information supplied about accidents is shown in Table 3.

The accidents are arranged in Table 3 with the following format: Column 1 contains information on the date of the accident and the source of information which can be either Facts data base (TNO in the table) or Mhidas (SRD in the table). Column 2 gives the place of the accident and Column 3 the substance(s) involved as reported in the accident description. In Column 4 the quantity of substance involved and the released quantity are reported when known. In Column 5 a short description of the accident is found and in Column 6 the operation mode is shown. Column 7 contains information on the type of event (release, fire, explosion) and the natural cause of the accident. In Column 8 fatalities (f), injuries (i) and evacuees (eva) are given (if any).

In total 154 accidents were supplied from Facts and 105 from Mhidas. Of these 27 were identical accidents reported in both data bases. In the following analysis the accidents from the two sources have been pooled and the analysis therefore concerns a total of 232 accidents. The complete accident sample set has been analysed with regard to various parameters and the results are shown in tables and discussed below.

In some cases the information supplied about a common accident differed between the two data bases but this was to be expected [4]. In the present analysis of accident case histories the discrepancies were: (1) date of accident (differing one day in three cases); (2) number of injuries (one case where one data base did not mention victims, whereas the other said 300); (3) in some descriptions.

A more detailed analysis of the causes of the 27 common accidents showed one case where the codification of the data gave a very different appearance of the information even with the same background information.

The common source had the following description: oil was released after pressure of ice against an earthen supporting dock used to unload fuel barges to on-shore tanks ruptured a pipeline.

In one data base the accident was classified as caused by 'natural-cause' and 'pressure of ice' whereas the other data base classified it as caused by 'mechanical external' and 'ground temperature'.

This example illustrates the problems of coding data for input in a data base, preserving all informations and the same quality level as the source(s), in a way that is not sensitive to search profiles.

However, it was only this one case out of 27 that significant discrepancies between the designation of the causes were found. Normally only minor variations among the designated causes were found which seems to indicate that once an accident has been described as having a natural cause, this information is captured in the data bases.

As seen from Table 3 information about the consequences of the accidents is generally scarce: The amount released and the damage caused by the accident are often missing. This is a common trend in accident reporting that these informations are missing, and that the information given is relatively scarce.

Table 3
Example of accidents

Date	Place	Substance	Quantity total/released (tonnes)	Description	Operation mode	Event	Damage
2/2/82 SRD	Forcados, Nigeria	Oil		Subsidence caused a leak in main trunkline	Pipeline	Subsidence	
15/2/82 TNO	Atlantic ocean	Diesel oil, lubrication oil, aviation fuel		Rig 'Ocean Ranger' capsized and sunk during severe storm	Off-shore	Wind	84*f*
30/03/82 SRD TNO	Golden, British Colombia, Canada	Methanol	300	A rockslide caused derailment of 16 tank cars. Two tank cars fell from cliff into river spilling content	Rail transport	Release Rockslide	
22/6/82 TNO	Holland	Ethylene bisstearyl amide		Dust explosion in spray tower	Processing	Explosion Lightning	
26/6/82 TNO	Holland	Natural gas		Lightning ruptured gasline	Pipeline	Lightning	
27/6/82 SRD	Staveley, Derbyshire, UK	Sulphur trioxide, oleum		Drums of waste sulphur trioxide and oleum buried in a pit caused explosion during heavy rainfall due to chemical reaction	Waste dump	Explosion Rain	
9/7/82 TNO	Germany	Hydrochloric acid		Release from valve of tankwagon by sun radiation	Rail transport	Release Temperature	
4/8/82 TNO	Holland	Natural gas		Gas explosion in school	Pipeline	Ground Subsidence	
30/11/82 SRD	Orange, California, USA	Styrene monomer		Windstorm caused power outage that shut down refrigeration unit causing storage tank of styrene to explode	Explosion Wind	5*i* 3000 eva	

TNO and SRD informs that their data bases contain approximately 16200 (TNO) and 5500 (SRD) accidents, giving 1% and 2%, respectively, of the accidents registered in the data bases having natural events as a causative factor.

A study [5] of pipework and in-line equipment failure using accident descriptions from five international data bases estimates that 2% of the accidents are due to natural causes, though the definition of 'natural causes' was not specified. This study is also interesting from a quality point of view because of the 921 accidents reported, it was possible to find immediate and underlying causes in 502 cases only.

Another indication of the percentage of accidents caused by natural events is obtained from the USA Environmental Protection Agency (EPA). It has investigated the reasons for accidents in the period 1986–1991, the accident sample covered 103 fires and/or explosions [6]. The causes of the accidents included 'Natural Hazards' and the percentage given was 5%. Again the definition of 'Natural Hazards' was not specified in the article.

Further, the Major Accident Reporting System [7] which currently contains 121 public accident case histories reports that for these accidents five accidents or 4% a natural event was a contributing cause to the accident. The specific causes for the MARS accidents were: (a) lightning (one accident); (b) extreme ambient temperature (two accidents); (c) extreme wind intensity (two accidents).

It should be noted that the 4% are based on the total number of accidents. However, causative factors are known only in 99 cases, thus given a proportion of 5%.

The results are summarised in Table 4. The difference in level can be partly attributed to the varying completeness of accident descriptions in the data collections. For the USA and MARS data samples the effort has been concentrated on finding the cause of the accident, whereas the TNO and SRD data results from inhomogeneous quality data sources where the most important issue is the recording of the accident, not accident analysis to determine causes of the accident.

The large data samples thus show only a minor proportion ascribed to natural events. However, the accidents in the EPA study and in the MARS database generally are better described. This may account for the higher figures.

For the accidents initiated by a natural event the number of accidents in each group of natural event has been determined, see Table 5. The most interesting results are

Table 4
Proportion of accidents initiated by natural events from different data sources

Data sample	Number of accidents with natural events	Total number of accidents	Proportion of accidents with natural events as contributing causative factor
USA EPA [6]	5	103	5%
MARS [7]	5	121/99	4%/5%
HSE [5]	10	502	2.0%
TNO	154	16,200	1%
SRD	105	5500	2%

Table 5
Natural events (complete data set)

Phenomena	Event	Number of events	Percent
Atmospheric	Total	186	80
	Outside temperature	38	16
	Wind	35	15
	Rain	35	15
	Lightning	76	33
	Other (snow, ice)	2	1
Geological	Total	42	18
	Earthquake	19	8
	Volcano eruption	1	0
	Landslide, ground subsidence, soil erosion	22	9
Acquatic	Total	1	0
	Shoal	1	0
Biological	Total	3	1
	Beaver dam	2	1
	Wasp nest	1	0
Total	Total	232	99

that atmospheric phenomena account for 80% of the events, whereas geological phenomena accounts for 18%. Rather surprisingly biological phenomena account only for 1% with not even one accident initiated for instance by rats or ants. The conclusion seems obvious: our chemical industry and transport are very robust in relation to biological phenomena, and more vulnerable in relation to atmospheric phenomena.

In Table 6 the accidents are presented as a function of five year intervals. As seen from the table, the number of accidents increases rapidly with time. The number of accidents from 1971–1975 is only a third of the number of accidents in the period 1976–1980. This probably reflects changes in the reporting system and the organisation of the data bases rather than a real trend.

In Table 7 the mode of operation versus number of accidents is shown. The operation mode 'processing' refer to that the accident took place in a process unit, whereas 'storage' indicates that a storage tank was the main equipment affected by the accident. The data are, however, insufficient to distinguish between isolated storage and storage for processing installations. Transport include all transport modes, i.e. navigation, pipeline, road and rail transport. It is interesting to note that the sample consists of 102 transport accidents or 44%. This number is somewhat higher than a more general accident analysis [8].

Accidents concerning processing and storage are relevant with regard to the European Community Directive 501/82/EEC and amendments, and as seen from table they number 100 accidents, or 43%, on world basis. The geographical location of the accidents has been identified where possible, see Table 8. The distribution found here is similar to other analyses [9] where North America, and Western Europe accounted for 52% and 34%, respectively.

Table 6
Number of accidents as a function of time period (complete data set)

Period	Number of events	Percent
1941–1945	1	0
1946–1950	4	2
1951–1955	1	0
1956–1960	1	0
1961–1965	5	2
1966–1970	18	8
1971–1975	17	7
1976–1980	53	23
1981–1985	63	27
1986–1990	64	28
1991	5	2
Total	232	99

Table 7
Operation mode (complete data set)

Operation mode	Number of events	Percent
Processing	27	12
Storage	72	31
Processing or storage	1	0.5
Transport	102	44
Loading/unloading	8	3
Waste dumps	7	3
Off shore	10	4
Unknown	5	2
Total	232	99.5

Table 8
Geographical location of accidents (complete data set)

Country	Number of events	Percent
North America	92	40
EC	62	27
EC and Western Europe	71	31
Remaining countries	50	22
Sea	13	6
Unknown	6	3
Total number of accidents	232	–

The results of an analysis of the accidents in the EC countries are shown in Table 9. It is seen that Netherlands account for 31 of the accidents, or 46%, whereas six EC countries are not represented at all. It seems highly probable that this reflects the reporting system (the FACTS data base is made by TNO in Netherlands) rather than special phenomena in this country.

3.1. Results concerning processing and storage

Of special interest are the accidents relevant for the Major Accident Hazards Directive, in total 100 accidents. Here the results can be compared with the results obtained from analysis of MARS.

Table 10 shows geographical area versus number of accidents. North America (USA and Canada) and EC have nearly the same total number of accidents, and the remaining countries slightly less. (In four cases the place of the accident was not given and in one case the mode of operation was storage or processing.)

Storage accidents occur more than twice as often as accidents related to processing. However, for North America there are 11 times more storage accidents than processing, but for EC the number of accidents for the two modes is the same. This could once again be reflecting the reporting system, but differences in design cannot be excluded based on this investigation.

Quite surprisingly many of the North American accidents concerning storage were a lightning striking storage tanks containing petroleum products, namely 16 accidents out of 20 accidents, mostly in refineries.

The specific natural causes for processing/storage are listed in Table 11. It is interesting to note the high number of accidents caused by lightning. The MARS data

Table 9
Accidents in the EC, per country

Country	Number of events	Percent
France	6	10
Germany	15	24
Italy	6	10
Netherlands	29	47
Portugal	1	1
United Kingdom	5	8
Belgium, Denmark, Greece, Ireland, Luxemburg, Spain	0	0
Total	62	100

Table 10
Geographical area versus storage/processing accidents

Country (World basis)	Number of events				Ratio storage/processing
	Total	Percent	Storage	Processing	
North America	35	37	32	3	10.7
EC	32	34	18	14	1.3
Remaining countries	28	29	21	7	3.0
Total	95	100	71	24	3.0

Table 11
List of natural events, storage and processing

Phenomena	Event	Number of events in Mhidas and FACTS	Percent	Number of events in MARS
Atmospheric	Total	88	89	5
	Outside temperature	15	15	2
	Wind	4	4	2
	Rain	8	8	0
	Lightning	61	61	1
Geological	Total	10	10	0
	Earthquake	9	9	
	Volcano eruption	0	0	
	Soil erosion, ground subsidence, landslide	1	1	
Acquatic	Total	0	0	0
	Shoal	0	0	
Biological	Total	1	1	0
	Beaver dam	0	0	
	Wasp nest	1	0	
Total	Total	99	100	5

base contains five accidents, in which a natural event (lightning, wind and temperature) was a contributing factor. None of these accidents are included in the data from TNO or SRD.

4. Discussion

The initial analysis includes 232 accidents from the data bases Facts and Mhidas, of which 27 were common for the two data bases. Most of the accidents identified have happened in Western Europe and North America. The same trend has been observed by others [9] and is assumed to reflect the reporting system.

The information about the accidents is incomplete in many cases and the missing information regards e.g. quantity of substance and details in accident description and description of consequences. Even where information is available, it is important to note that the quality of some of the information of the accident case histories is 'medium to poor'. In general the information on the date of an accident is of high quality whereas 'causes' tend to have low quality information [4]. This problem means that there is a certain possibility that relevant accidents are not included as the causes are not identified fully, thus not revealing when a 'natural cause' is a contributing cause to an accident. If this is indeed the case, natural causes will tend to be under-reported in the accident data bases. It is less likely that the lack of information and quality of data will lead to an over-reporting of natural phenomena.

As illustrated by the findings in [5] the reduction of data due to lack of information can be significant; in the study only about 60% of the case histories found contained information about immediate and underlying causes. If the lack of information is random it will not affect the relative distribution of the accident parameters; if it is systematic there will be an over- or under-reporting of the accident parameters. On the basis of current information it seems improper to evaluate if natural causes are excluded more often than other causes.

The present investigation indicates that between 1% and 5% of accidents in fixed installations have natural events as a causative factor, possibly near the upper limit, or above. This range reflects also that the term 'natural event' is not well defined, and some variation in the percentage of accidents due to natural events should therefore be expected. Further an under-reporting of 'natural events' as cause of accidents in the general accident data bases would give the lower number of the range, as observed. The general data bases contain information on a wide range of accidents of different types of industrial activities, whereas MARS and the EPA study concern larger scale accidents for fixed installations (with loading/unloading as fuzzy border line) which have been thoroughly investigated. This difference in accidents included in the data material could influence the percentage of accidents caused by natural events.

No significant discrepancies between the designation of the causes in the accidents common to the data bases were found. Normally only minor variations among the designated causes were found which seems to indicate that once an accident has been described as having a natural cause, this information is captured in the data bases.

A classification scheme based on the type of phenomena has been developed and the most often reported natural cause of accidents is 'Atmospheric Phenomena' which account for 80% of the natural events found whereas 'Biological Phenomena' account for 1%. This indicates that the chemical industry and transport are very robust in relation to biological phenomena, and more vulnerable in relation to atmospheric phenomena.

Quite surprisingly accidents initiated by lightning accounts for 76 accidents in total or 33% of the accidents used as basis for this study. Looking at processing and storage accidents only, the percentage is as high as 61% (or 61 accidents) indicating that even though the dangers of lightning are well known the prevention techniques and/or their implementation may still be improved.

Finally, it is interesting to note that although the total number of accidents reported may not be high, certain types of accidents occur almost only in certain types of activities: e.g. rain is an important factor for accidents where supports are washed away with the consequence that railway tracks and pipelines fail. In other words 'natural events' are not a general safety problem but rather an important cause of accidents to consider for specific types of activities and industrial installations.

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