GLOBAL BLUEPRINTS FOR CHANGE

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The Global Blueprints for Change contain guidance for working together to improve the capability to identify indicators of physical, social, enterprise, and environmental vulnerabilities throughout the world and to select and implement realistic solutions to reduce them towards acceptable levels.

Theme A: LIVING WITH NATURAL AND TECHNOLOGICAL HAZARDS
Topic A.9: Mitigating the Interaction of Natural, Environmental, and Ecological Disasters

"A Perspective on the Interaction of Environmental and Ecological Disasters: Outline of a Blueprint for Change"

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A PERSPECTIVE ON THE INTERACTION OF ENVIRONMENTAL AND ECOLOGICAL DISASTERS
--Outline of a Blueprint for Change--

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Abstract: Disasters having the most serious and devastating consequences are those that occur in combination with other disasters. In some cases, the two (or more) disasters have an obvious causal relationship but in others it is not easy to identify the interdependence. Building codes often recognize this element and include a certain factor to incorporate the concept into the design process, e.g. using a higher importance factor for certain buildings or facilities whose failure may lead to secondary disasters. However, as the potential for human-made disasters increases at a high rate, a better recognition and quantification of such compound risk is necessary in order to provide means for its effective mitigation.

Causes of environmental disasters

The causes of environmental disasters can be grouped into two categories:

- leaks from reservoirs or pipelines containing pollutants,
- catastrophic failure of reservoirs and pipelines containing pollutants.

The term ‘reservoir’ is used here to designate any container of pollutant; land-based, mobile or maritime.

The releases (either leakage or large failure related) may be to water bodies, the ground, eventually reaching the ground and surface waters or it can be to the atmosphere. By far, the biggest cause of maritime pollution has been due to shipwrecks, i.e. the now familiar sight of an oil tanker sinking in the sea. The outlook for this type of event is very discouraging. The statistics given by the German Environmental Ministry indicate that, while for the decade 1978-1987 major oil tanker accidents worldwide numbered 4, this figure increased dramatically to 16 for the following decade (1988-1997). It is also important to note that aside from the very significant increase in the number of ship accidents (involving pollutant substance) the average size of the ship involved in the accident also got bigger making the consequence of each accident more disastrous.

Shipwrecks are of course in the second category of the causes mentioned above, but the reason for the failure may or may not be related to a natural disaster. In fact, most ship accidents occur as a result of the combination of bad weather and operational errors.

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What is intended to look at in this article are scenarios which involve major natural disasters as triggers to environmental catastrophes. Nuclear, chemical and petroleum industry accidents are investigated.

Consequences of environmental disasters

The consequences of environmental disasters depend on several factors:

- the amount of pollutants available to be released (i.e. source term)
- the type (toxicity, half life, etc.) of pollutants
- the energy involved in the release (i.e. leak, large failure, explosive failure, etc.)
- transmission characteristics of the soil (for liquid releases)
- Dispersion characteristics of the medium (atmosphere or hydrosphere)
- Proximity to population,
- Proximity to sensitive environment.
- On-site accident management,
- Off-site emergency preparedness.

The so called *source term* of the pollutant material depends on the type of installation and can vary significantly from stationary storage facilities and electricity generating plants to transport vehicles (although as indicated above, super tankers may have a very large source term). In general this is not a parameter that can easily be varied because it is a design, operation and utilisation dependent item.

The same is true for the *type of pollutant* involved. The type of industry and process will dictate this parameter.

The *energy involved in the release* is related to whether or not the release is associated with a leak (generally over a long period of time) or a sudden release due to a catastrophic failure of a retaining (or confining) structure. The latter case may be due to a natural disaster such as an earthquake, flood or high wind. This point will be investigated further.

The *transmission, dispersion and proximity to population and sensitive environment* are all an essential part of the 'environmental impact statement' which is required for every industrial facility. These are very important characteristics and may increase (or decrease) the impact of a release very significantly. It should be noted here that for releases caused by a catastrophic failure of retaining or confining structures as a result of a natural disaster, the dispersion characteristics could be altered. For example, a flood, after having destroyed the retaining or confining structure, would also constitute the medium of dispersion for the pollutant in an uncontrolled way.

On-site accident management is generally under the responsibility of the plant, whereas *off-site emergency preparedness* has to be done in co-operation with the local or national government. Again, it is important to note that if the release of the pollutant was caused by a natural disaster, then both the accident management and the emergency preparedness measures need to be revised accordingly. In other words, two disasters need to be considered simultaneously.

Considerations of risk

The classical definition of risk from natural disasters involves the joint probability of exposure to the hazard, the vulnerability (or fragility) of the structure(s) and the consequences of failure in terms of lost value.

In general, the risk is determined for each natural hazard individually. In engineering practice simultaneous occurrence of two so called 'rare' events is considered implausible and excluded from the design basis. The level of the hazard parameter's probability of exceedance per annum depends on the 'acceptable risk' for the facility which may be determined by a variety of factors such as the regulatory practice, insurance requirements, operator's cost/benefit analysis, etc. After this is done the design practice either uses the annual probability (actually frequency) of occurrence (such as 10^{-4}/per annum) or the average return period (10000 year event) to designate the *level of the hazard* for which the facility must be designed.

Depending on the type of facility and the country, this hazard level used for design may change significantly. As an example, in Sweden nuclear power plants are designed for seismic loads which correspond to 10^{-6} per year frequency. However, still the level of the SL-2 (or SSE) is not more than 0.1g. For the Chashma NPP in Pakistan, it was seen that the flood level produced by the upstream dam break (Tarbela Dam) would not change for frequencies less than 10^{-3}, i.e. the same level was computed for 10^{-3}, 10^{-4}, etc. because in fact there is a gorge between the dam and the site which physically restricts the flow of water to a certain volume per second. Barring the very unlikely event of the collapse of the gorge itself it is obvious that there is a physical threshold for the water level at the site. The same arguments were used for some seismic sources. The Vrancea source in Romania generated several events with M ~ 7.5 in this century. However, historically (i.e. past 1000 years or so), the interpreted effects of the earthquakes from the same source were not bigger than these. In fact, some seismologists have argued (contested by others) on the basis of geophysical data that earthquakes of M ~ 7.5 constitute a physical threshold for this seismic source.

In fact, physical (i.e. deterministic) conditioning of probabilistic analyses is more of a rule than exception in hazard evaluation.

The picture gets more complicated when the risk is evaluated, i.e. compounding the hazard probability values with vulnerabilities (or fragilities) and the value lost. This is not only because two other analyses are needed to compute the risk, but also as the probabilities start getting smaller and smaller (because of the need to multiply small numbers with each other), their interpretation becomes more difficult.

Suppose, the seismic risk analysis of a facility resulted in the following numbers;

$P(a>a_d) = 10^{-4}$

$\Sigma_i P(f \mid a = a_i) = 10^{-2}$

$P(D \mid f) = 10^{-1}$

where,

a : seismic acceleration

a_d : design acceleration

f : structural failure (defined using prescribed criteria)

D : disaster (defined using prescribed criteria)

The calculation of these probabilities involve a lot of work but there is an internationally accepted procedure which one can use. Now there are two other questions which are more difficult to answer;

- Is $P(D) = 10^{-7}$?
- If so, do the three equations above represent the unique path for the event 'D' to happen ?

To complicate the question further, combinations of several events could be considered. For example if the joint probability of two independent events is 10^{-4}, would they always result in a scenario similar to the above in terms of failure and disaster probabilities. A 10^{-2} earthquake concurrent with a 10^{-2} tornado may not necessarily result in the same scenario as the 10^{-4} earthquake (the above example). Neither would the combination of a 10^{-1} earthquake concurrent with a 10^{-3} tornado and so on. Even if the events affected the facility in the same manner (i.e. same parametric representation was possible for the two events), the phenomonological conditioning of the hazard curves would produce differences in the results.

For an event such as flood, the parameter of interest (i.e. the maximum water level) itself is a composite indicator. The maximum water level may be due to a combination of storm surge, high tide, wave action and precipitation which act simultaneously on the site. Therefore, instead of looking at the low frequency of one event only, the combination of several events with higher frequencies may provide a more reliable and credible hazard assessment. The December 1999 flooding of the Blayais NPP in France was caused by a combination mentioned above.

Natural disaster causing an environmental one

The probability of a combined disaster (natural disaster leading to an environmental one) can be based either on historical data or phenomonological considerations or a combination of the two. Clearly, the amount of data on this type of event is extremely limited, only a handful of events can be counted on a small scale - which may perhaps be considered as precursors. Several examples are cited below.

In June 1989, a gas pipeline started leaking near the city of Ufa, the capital of Bashkiria in the former USSR. The leak occurred in a very wide valley in the shape of a large bowl. Seeing the pressure drop, the operator decided to increase it as much as possible. This continued for at least two days (possibly more) and the bowl was filled with gas. Along the pipeline, there were two sets of rail tracks. Two trains travelling in opposite directions met in the valley and a spark from one of them caused a tremendous blast killing 1400 people in one of the trains (mainly school children going off to the Black Sea coast for holidays) and releasing chlorine from the other one.

On August 17, 1999, the earthquake which devastated the Sea of Marmara region in Turkey, also caused the collapse of a stack in the Tupras refinery initiating a fire in the in the tank farm which continued burning for several days. A radius of 5 kilometers was evacuated for fear of an explosion. This area included parts of the city of Izmit which had already experienced the worst earthquake of its recent history.

On January 30, 2000, a mining dam in Northern Romania failed because of heavy rains and floods releasing 100000 cubic meters of contaminated water into the Tisza (a tributary to the Danube). The main contaminant was cyanide (the mine was a gold mine) and the effects of this disaster has been devastating for both Romania and Hungary.

The number of such accidents is limited, but the trend shows an increase probably not unlike the statistics for ship accidents involving oil spills. For the moment, however, it is not possible to treat the numbers to calculate reliable statistics. Phenomonologically, the situation is different. Here, it is possible to use results from external event PRA studies which have been performed for many nuclear power plants worldwide. These studies have three levels and the first level that they investigate is the annual frequency of core damage (CDF). A typical CDF (external events only) for a nuclear power plant would be between 10E-4 to 10E-5 with some notable exceptions to the higher side of the frequencies. When this number is compared with the total CDF (i.e. due to both internal and external initiators) it is observed that the ratio generally varies from 0.1 to 0.5 depending on the site and the type of plant. This means that if a nuclear accident were to happen at a plant 10 % to 50 % of the time the cause of the accident would have been an external event (a natural or human-made disaster).

The second and third levels of PRAs deal with the calculation LERF (large early release frequency) and frequency of prescribed radiological consequences on humans and environment respectively.

For other (i.e. non-nuclear facilities), the CDF would correspond to the frequency of having an accident (Level 1). Levels 2 and 3 would be similar to the case for nuclear facilities with only a change in the pollutant substance.

Although similar percentages for (e.g. external event induced accidents/releases as a ratio of the total number of accidents/releases) non-nuclear critical facilities are not readily available from phenomonological studies, it is possible to make qualitative comparisons with the results obtained for nuclear power plants. These comparison will depend on the standards used for the site selection and design of nuclear and non-nuclear facilities. The site selection will influence both the potential impact of natural and human-induced events on the facility as well as the characteristics of the release and eventual exposure of the population and the environment to the released pollutant. The design, on the other hand will influence the vulnerability (fragility) and the release characteristics. From the point of view of siting and design standards, there is no question that the nuclear industry puts a much greater emphasis on safety and quality assurance than for example the petroleum and petrochemical industries. The percentages mentioned above depend not only on the site/design safety of the facility with respect to external events but also its safety with respect to process loads, operational occurrences, general safety culture, etc.

Supposing for the moment that similar percentages are valid for some non-nuclear facilities as nuclear power plants. This would entail the following:

$$P(Acc/EQ) = a_1$$

$$P(Rel/EQ) = a_2$$

$$P(Exp/EQ) = a_3$$

$$a_1 > a_2 > a_3 \qquad a_1 \sim 10^{-3} - 10^{-4}$$

$$P(EQ/Acc) = b_1$$

$$P(EQ/Rel) = b_2$$

$$P(EQ/Exp) = b_3$$

$$b_1 < b_2 < b_3 \qquad b_i \sim 0.1 - 0.5$$

Here,

EQ : earthquake
Acc : accident
Rel : release
Exp : exposure

The latter set of probabilities are Bayesian and can be calculated using:

$$P(EQ/Acc) = P(Acc/EQ) / \{\Sigma P_n (Acc/I_n)\}$$

where, I_n denotes the n-th accident initiator.

The type of question posed by the Bayesian approach is "If an accident occurred at the facility what is the probability that this was due to an earthquake ?".

Conclusions

The following conclusions can be drawn from the discussion above:

- The triggering of an environmental catastrophe by a natural disaster is an unlikely but a credible scenario.
- The likelihood of this scenario is increasing with time because of urbanization and industrialization.
- Disasters involving meteorological and climatic conditions may occur in unexpected places.
- The simultaneous occurrence of two 'disasters' will place additional and serious burden on on-site accident management and off-site emergency efforts unless planned beforehand.
- The nature and size of the composite disaster will depend on the facility, site and design characteristics.
- Dispersion characteristics may be negatively or positively influenced by the natural disaster (mainly flood or high winds).

Potential Case

One potential case for this scenario is the Caspian Sea which (with its basin) has very large oil and gas reserves. Petroleum and petrochemical facilities as well as pipelines of oil and gas constitute the facilities which may be damaged by natural disasters and which in turn may pose a serious risk to the environment. Fortunately, a NNP located on the

Eastern Coast of the Caspian Sea (Aktau NPP in Kazakstan, a fast breeder designated as BN-350) is being decommissioned at the moment.

Several serious natural hazards are present in the Caspian Sea basin;

- seismic hazard is high especially in the southern half of the basin,
- there is a major active fault crossing the sea; faults are also present in the southern part of the Caspian Coast
- there are 'mud volcanoes' in the Caspian Sea (these are mounds up to 30 meters high formed within a very short time),
- the water level in the Caspian is unstable, unpredictable changes occur without a valid explanation.
- because of the tectonic and geological instabilities in the sea and on the coast, there is a potential both for seiches and tsunamis in the Caspian Sea.
- the soil in at least some of the coastal areas is poor and easily liquefiable having the potential also to cause landslides into the sea.

Consequences of a big natural disaster in this area would be damage to the petroleum and petrochemical facilities and pipelines causing failure and polluting the Caspian Sea. Being a landlocked sea (or rather a large lake) the ecosystem of the Caspian is very sensitive and vulnerable. It is possible to incur irreparable damage to parts of this ecosystem.

Obviously the Caspian Sea is not the only candidate for a major disaster.

What to do?

For *new facilities* both the siting and design aspects should be carefully studied.

Site related aspects are divided into two parts; characteristics of the site which affect the size and frequency of a natural or human-induced hazard and the characteristics which affect the impact of the facility on man and the environment. The former is used to ensure that there are no features of the site which should preclude the operation of the type of facility proposed and also to determine the hazard curves which will form the design basis requirements of the facility for external events. The latter constitutes part of the environmental impact assessment and includes studies in dispersion in the atmosphere and the hydrosphere, sensitive aspects of the environment, food chains, etc.

Such detailed comprehensive studies are routinely performed for nuclear power plant sites. Depending on the amount and quality of the already available data, a site study can cost anywhere from 5 to 25 million US dollars.

Once the site is selected and characterized, the design of the facility should be made so that it is adequately protected from external events. A graded approach can be used to protect parts of the facility using higher standards. Components whose failure may lead to and accident and containers of significant amount of pollutants may be in this higher category.

The approach described above is appropriate for new facilities. For *existing* facilities, on the other hand, a different approach is needed. This comprises two stages; the re-evaluation phase and the upgrading phase (if needed).

The re-evaluation may involve the hazard assessment if this was not performed properly in the original design stage. Then the items which are important to safety need to be identified. Finally, the re-evaluation (i.e. their capacity to withstand external events) is performed on the basis of simple calculations, inspections (walkdowns) and experience data.

The well established methods of re-evaluation for nuclear power plants (either deterministic or probabilistic) can easily be adopted for other critical facilities.