Assessment of External Hazards at Radioactive Waste and Used Fuel Management Facilities – 13505

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ABSTRACT

One of the key lessons from the Fukushima accident is the importance of having a comprehensive identification and evaluation of risks posed by external events to nuclear facilities. While the primary focus has been on nuclear power plants, the Canadian nuclear industry has also been updating hazard assessments for radioactive waste and used fuel management facilities to ensure that lessons learnt from Fukushima are addressed.

External events are events that originate either physically outside the nuclear site or outside its control. They include natural events, such as high winds, lightning, earthquakes or flood due to extreme rainfall.

The approaches that have been applied to the identification and assessment of external hazards in Canada are presented and analyzed. Specific aspects and considerations concerning hazards posed to radioactive waste and used fuel management operations are identified. Relevant hazard identification techniques are described, which draw upon available regulatory guidance and standard assessment techniques such as Hazard and Operability Studies (HAZOPs) and "What-if" analysis. Consideration is given to ensuring that hazard combinations (for example: high winds and flooding due to rainfall) are properly taken into account. Approaches that can be used to screen out external hazards, through a combination of frequency and impact assessments, are summarized. For those hazards that cannot be screened out, a brief overview of methods that can be used to conduct more detailed hazard assessments is also provided.

The lessons learnt from the Fukushima accident have had a significant impact on specific aspects of the approaches used to hazard assessment for waste management. Practical examples of the effect of these impacts are provided.

INTRODUCTION

Natural external events are events that originate either physically outside the radioactive waste management facility or outside its control. Examples include, but are not limited to:

- High wind/Tornado
- Earthquakes
- Floods
- Soil failures
- High/low temperature events
- Lightning
- Geomagnetic storms
- Avalanches
- Frazil ice
- Sandstorms

The focus of this paper is on identification, screening and assessment of natural external events and their impact on radioactive waste management facilities. In particular, it provides an overview of relevant hazard identification techniques, such as Hazard and Operability Studies (HAZOPs) and "What-if" assessments. It also provides a methodology for screening external hazards using Review Level Conditions (RLCs) approach and screening combinations of hazards, which can be applied in safety assessments of waste management facilities.

HAZARD IDENTIFICATION TECHNIQUES

A systematic approach to hazard identification, which breaks down hazards by categories and considers several steps to identify relevant hazard exposure scenarios, can help to ensure that a comprehensive list of hazards is taken into account. While some initial screening may be necessary to rule out truly implausible events, such as volcanic hazard in an area not affected by volcanic activity, the initial list of hazards should not be unreasonably restricted.

Documentation Review

The initial step for the identification of external hazards for a waste management facility involves a literature review to locate all the relevant documents and guidance that would be useful in developing a full list of the hazards to be considered.

Some of the regulatory and guideline documents that can be consulted as part of this literature review are highlighted below.

- NUREG/CR-2300; Table 10.1;
- NUREG/CR-4839;
- NUREG 1407;
- ASME RA-SA-2009; Appendix 6-A;
- IAEA Safety Series No. 50-P-7; Table 1;
- IAEA Specific Safety Guide SSG-3;
- IAEA Safety Series No. 50-SG-S9

Other documents which may be consulted include facility-specific safety reports, environmental assessments and event records.

Finalization of a comprehensive list of initiating event development of hazard exposure scenarios, and rationalization of the resulting hazard listing can be carried out using one of the standard hazard identification techniques, such as HAZOP or "What-if" studies.

Hazard and Operability Studies

A HAZOP (HAZard and OPerability) study is a systematic and highly structured approach to hazard identification which considers not only hazards, but also the operability of the facility. Consideration of the operability of the facility can be helpful in developing hazard exposure scenarios or faults in systems designed to mitigate a given category of external event. This may include problems with procedures, facility layout or design that may result in possible design or operational solutions to such potential problems for future or existing facilities.

Other formal methodologies for fault identification exist, including "What if", Failure Modes and Effects Analysis (FMEA) and Process Hazard Analysis (PHA). "What if" (see below) and HAZOP have a number of features in common. Only HAZOP and "What if" are considered in the current paper, as the two most appropriate techniques for developing hazard exposure scenarios for external hazards. They both provide systematic reviews. They both look for divergence of a system or process from its intended function, and they both generate statements of the undesirable effects that such divergences can produce.

The key difference is in the structured approach used for HAZOP. This increases the amount of preparation required, and the level of detail in the output, however it gives more depth of consideration and more confidence that a wider consideration of hazards has been given. Principal HAZOP steps for the parameter-first approach are presented in Figure 1.

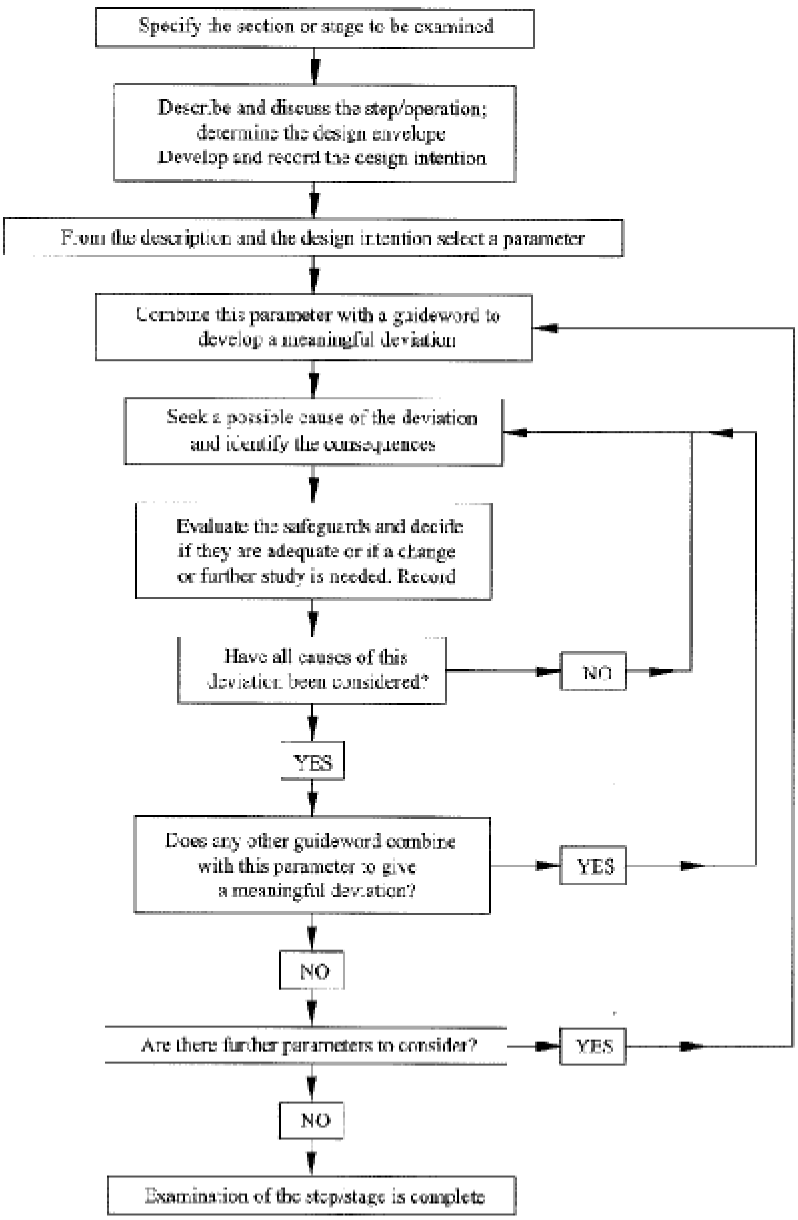

Figure 1 – HAZOP process flow [1]

What If

The purpose of a “What if” study is to provide a picture of the risks posed by a situation or system, and an understanding of the problems and consequences that could arise from these risks. “What if” is a brainstorming technique that makes use of people who are knowledgeable or expert in aspects of the problem or situation to be assessed.

As its name implies, “What if” involves fairly broad probing of undesired conditions that a system or design might experience, and based on these “What If” postulates, it uses the available expertise to identify hazards and the consequences of events that could arise from these hazards. “What if” studies can also be used to identify operability problems and process or design improvements. The preparation is often carried out in advance by the “What if” leader, but the method is very flexible and “What if” questions can be developed as part of the team review.

“What If” is best applied to situations where one or more of the following apply:

- An active process is not involved, or there is an active process but information on it is scarce
- A detailed study of a process is not the primary concern
- A concept or a conceptual design is to be assessed
- In situations where the scope of the problem is only broadly defined, or is in development
- At a stage in a project where options going forward are desired and can be used to advantage
- There is a desire to search for new problems
- More flexibility is sought than would be the case for a full HAZOP review.

CONSEQUENCE-BASED SCREENING OF EXTERNAL HAZARDS

A key lesson learned from Fukushima is the consideration of beyond-design-basis intensities/levels of hazards as inputs to a hazards analysis. The US NRC notes that consideration should be given to risks from beyond-design-basis external hazards (for instance, in reference [2]). Screening of external hazards can be implemented, consistent with this recommendation by using the concept of Review Level Condition (RLC) [3]. Note that this concept does not apply to external hazards with frequency of occurrence well below predefined safety goals/screening frequency levels (e.g. meteorite strikes).

The approach of using RLCs represents a consequence-based screening approach and is employed to assess the potential impact on nuclear safety of any hazard that cannot be screened out by distance or frequency. In general, the RLC concept implies a particular level of hazard that can challenge the operation of a nuclear facility and has a frequency of occurrence commensurate with predefined safety goals/screening frequency levels. The selection of the RLC should be based on:

- current national and International regulations and standards, and
- current information on credible hazards at the waste management facility site.

It is important to note that using a RLC-based approach does not imply that a radioactive waste facility is only designed for the hazard at a lower intensity. Indeed, it may already be designed to a review level condition of a certain hazard (i.e. the design basis may already match or exceed the RLC); for instance, a review level earthquake will most likely have been factored into the design of a facility in a seismically active region, simply by virtue of being a well-known hazard in that region.

Examples of review level conditions are provided below:

1. Earthquake – event corresponding to a 1E-04 occ./yr. earthquake for the region under study.
2. Flooding due to run-off: flooding resulting from a 12-hour Probable Maximum Precipitation (PMP) event combined with a 1 in a 100 year lake level.

SCREENING OF COMBINATION HAZARDS

Another lesson from the Fukushima accident is the need to consider combinations of natural hazards, or combinations involving natural hazards with other external hazards. It is possible for combinations of hazards to pose a different or greater challenge to a facility's safety than the individual hazards would pose by themselves. For example the impact from a seismic event could damage flood defenses. If a correlated seismically-induced tsunami or seiche were to occur, hazard exposure scenario would be different than for an external flood not preceded by an earthquake.

The first step in performing this assessment is to create a matrix of hazards that lists the likely combinations and identifies whether they together pose a challenge exceeding that posed by the individual hazards. A sample list is provided below in Table I. For any given project such matrices may contain hundreds of possible combinations.

Table I. Hazard Combination Matrix

	Earthquake	**Lightning**	**Flooding due to extreme rainfall**	**High Winds (hurricanes / tornadoes)**	**Toxic gas release near site**	**Aircraft crash**
Earthquake		No causal relationship (coincidental only). Cannot screen by frequency.	Coincidental only. Cannot screen by frequency.	Coincidental only. Possible to screen by frequency.	Can be coincidental or earthquake can cause release. Cannot screen by frequency in latter case.	Coincidental only. Possible to screen by frequency.
Lightning	No causal relationship (coincidental only). Cannot screen by frequency.		Correlated event. Part of a larger combination event (severe summer storm)	Correlated event. Part of a larger combination event (severe summer storm)	Can be coincidental or lightning strike can cause release. Cannot screen by frequency.	Correlated. However aircraft crash statistics takes into account inclement weather.
Flooding due to extreme rainfall	Coincidental only. Cannot screen by frequency.	Correlated event. Part of a larger combination event (severe summer storm)		Correlated event. Part of a larger combination event (severe summer storm)	Not applicable. Significant release of gas will not be achieved during such weather.	Coincidental only. Possible to screen by frequency.
High Winds (hurricanes/ tornadoes)	Coincidental only. Possible to screen by frequency.	Correlated event. Part of a larger combination event (severe summer storm)	Correlated event. Part of a larger combination event (severe summer storm)		Not applicable. Significant release of gas will not be achieved during such weather.	Not applicable. Aircraft crash statistics take into account inclement weather.

Toxic gas release near site	Coincidental. Can screen by frequency. Cannot be causal (release cannot cause quake).	Coincidental. Can screen by frequency. Cannot be causal (release cannot cause lightning).	Not applicable. Significant release of gas will not be achieved during such weather.	Not applicable. Significant release of gas will not be achieved during such weather.		Coincidental only. Possible to screen by frequency.
Aircraft crash	Coincidental only. Possible to screen by frequency.	Not applicable. Aircraft crash statistics take into account inclement weather.	Coincidental only. Possible to screen by frequency.	Not applicable. Aircraft crash statistics take into account inclement weather.	Coincidental only. Possible to screen by frequency.	

Note that Table I also provides a qualitative judgment on whether a screening by frequency is possible for illustrative purposes. Such an assessment should be supported by a formal quantitative analysis of frequencies and impacts.

Frequency assessment

After the combinations have been postulated and filtered to remove those that are not applicable (such as toxic gas release during a tornado), the next step is to determine the frequency of the combined hazard. Most of the combinations provided in the matrix above will be screened out on this basis, except for some natural hazards. One such example is the correlated severe summer storm event that brings with it flooding due to extreme rainfall and high winds. As the individual hazards originate from the same parent event (essentially, the atmospheric conditions leading to inclement weather), it is not possible to screen these out on a frequency basis. As such, a consequence-based assessment is required.

Consequence assessment

In order to perform this assessment, it is necessary to postulate appropriate criteria that a hazard should be compared against. For example, for a flooding event, the criteria for comparing the facility design against should consider a combination of the probable maximum precipitation value for a given watershed and a 100 or 500-year return period lake/river level. These could be converted to a flooding depth that would be compared against the elevation of key structures and equipment at a nuclear facility.

For certain hazards, it may not be possible to screen the hazard out in this manner, and a more detailed study would be required. For example, the high wind hazard is a complex phenomenon for which two different failure modes must be recognized: wind-based and missile-based. For the former, it would be necessary to understand the relative importance of straight-line winds and tornados for a given site; for the latter, it would be necessary to walk down the vicinity of the site to perform a missile survey. This information would then be combined into a High Winds probabilistic risk assessment.

"Super Combinations"

It is possible for more than two external hazards to occur at the same time. In all likelihood this would only be a concern if the hazards are correlated due to low frequencies associated with combinations involving three or more independent events. Such hazards are called "super combinations".

For example the summer storm event discussed above, involving wind and missile-borne hazards resulting from a tornado event could be enhanced by damage to electrical equipment due to flooding and lightning strikes. Tornados are often accompanied by severe weather conditions involving large amounts of precipitation. Therefore it would be insufficient to evaluate the risk of tornado damage to safety essential systems and equipment resulting only from wind and missiles. Partial or complete loss of roof or cladding over a building could also expose electrical equipment to rain which may cause equipment failure. At the same time damage to lightning masts may enhance risk of fire and loss of critical equipment due to lightning strikes. Such correlated hazards should be considered in developing fragility functions for a high wind Probabilistic Risk Assessment.

DETAILED IMPACT ASSESSMENT

An impact assessment is performed for a given hazard exposure scenario that cannot be screened out using the RLC approach. The assessment may involve both deterministic and probabilistic risk assessment scenario. Practical examples are provided below.

Riverine Flood Assessment

In the case of a riverine flood at a radioactive waste disposal or processing facility a deterministic assessment using the RLC approach to determine the flood depth is appropriate. Such an assessment would typically consider the Probable Maximum Flood (PMF) within a given watershed, and within local drainage areas that will be directly impacted by the site, taking into account all factors that could affect the facility. It may also consider the timing associated with the flooding event. The design flood event is used to determine the flood hazard is the PMF event. The PMF is the flood that may be expected from the most severe combination of critical meteorological and hydrologic conditions that are reasonably possible in a particular drainage area. Probable Maximum Precipitation (PMP) is defined as the greatest depth of precipitation for a given duration meteorologically possible for a given size storm area at a particular location at a particular time of year, with no allowance made for long-term climatic trends [4]. If required for long-term operation or disposal, climate change factors may have to be taken into account.

Where necessary to support the assessment, suitable hydrologic and hydraulic models should be developed and applied. An example of such assessment recently implemented by AMEC NSS is provided in [4]. This study was carried out for a planned deep geologic repository for intermediate and low level waste in Ontario, Canada. The overall conclusion from that assessment was that the identified potential maximum flood hazards can be mitigated through conventional engineering means and methods.

In the event of flood hazard assessment for an existing facility, waste processing buildings may require installation of additional flood barriers if there is potential for water to disperse contaminated material or impact safety-related systems, such as fire suppression or waste handling mechanisms. Near-surface waste storage or disposal facilities located in areas subject to flooding under the PMF conditions should be evaluated in relation to permeability of the capping system. It may be required to assess potential leaching of radioactive material and the resulting doses to workers and the public.

High Wind

High wind hazards generally fall into three categories:

- Thunderstorm Winds
- Extra-Tropical Storms (Hurricanes)
- Tornadoes

High winds and, in particular, wind gusts can cause structural damage or cause loose items to become airborne missiles. In addition, thunderstorms may spawn tornadoes where both high wind and missile generation hazards may impact the structures. This may result in a release of contaminants from the facility. However; wind also carries air contaminants away from their source, causing them to disperse more rapidly. In general, the higher the wind speed, the more contaminants are dispersed and the lower their concentration. For this reason the risk to general public due to the impact of radioactive substances released from a waste storage facility as a result of the high wind hazard is likely to be small.

However, this may not be the case for a spent nuclear fuel management facility, especially if the facility is handling spent nuclear fuel prior to it being sealed within a cask. For this type of facility, a comprehensive Level 1 Probabilistic Risk Assessment (PRA) may be required.

The High Wind PRA ASME Standard lists the following three technical areas as necessary to complete a High Wind PRA study:

- High Wind Hazard Analysis
- High Wind Fragility Analysis
- High Wind Facility Response Model and Risk Quantification

The execution of a High Wind PRA study essentially follows from the above, with some need for flexibility and iteration. Such an assessment requires evaluation of both wind and missile fragilities for safety related structures and systems as well as implementation of methodologies for assessing uncertainties.

CONCLUSIONS

Approaches that have been applied to the identification and assessment of external hazards at waste and used nuclear fuel management facilities in Canada have been presented in this paper. Specific aspects concerning changes that resulted from analyzing experience from the Fukushima accident were also identified. The approaches described in this paper have been employed for over 40 external hazards and nearly 300 hazard combinations at several nuclear sites.

Hazard assessment presented in this paper is a useful tool for identifying practical risk mitigation measures, which may involve changes in procedures or design modifications. For instance, if analysis demonstrated potential for a waste disposal cell to be filled with water in the event of a flood, resulting from a Probable Maximum Precipitation event, it may be necessary to ensure that leaching of radioactive material and resulting exposure are minimized. This could be achieved by installing flood barriers, or, if it were not possible, by provision of vacuum trucks with sufficient capacity to remove the water from flooded cells. In the case of a High Wind PRA showing unacceptably high risk, it can often be substantially reduced by simple and relatively inexpensive measures, such as strengthening the cladding on a critical building.

References

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