# Development of Methodology to Assess Application of Practical Elimination for Nuclear Power Plants

**J. Jung[1], D. Sivekumar[2] and S. Thambirasa[3]**
[1] University of Ontario Institute of Technology, Ontario, Canada
Jung.jong@uoit.net
[2] University of Ontario Institute of Technology, Ontario, Canada
Dylan.sivekumar@uoit.net
[3]University of Ontario Institute of Technology, Ontario, Canada
Suba.thambirasa@uoit.net

**An Undergraduate Level Submission**

## Disclaimer

The opinions and conclusions expressed in this work are those of the authors and do not necessarily coincide with the views of the CNSC.

## Summary

The Fukushima Daiichi nuclear accident is presented as the primary case study for the topic of practical elimination. A decision matrix was created to assess whether practical elimination has been achieved or not. Public acceptance is included as a factor in practical elimination. An evaluation of an underground High-Temperature Gas Cooled Reactor was performed, where it was determined that a greater than 10 earthquake on the Richter scale is practically eliminated, but can easily be overturned based on public acceptance. A plane crash scenario was also practically eliminated. The gap analysis performed concluded that the developed decision matrix requires reworking.

## 1. Introduction

The Fukushima Daiichi nuclear accident occurred on March 11th, 2011, and was initiated by an earthquake and tsunami in northeastern Japan. The magnitude 9 (on the Richter scale) earthquake caused no significant damage to the safety systems; however, the tsunami caused substantial flooding. Several IEs such as loss of offsite power and loss of heat sink were observed. Fukushima Daiichi accident also resulted in large releases of radionuclides into the biosphere and the ocean. The Fukushima Daiichi nuclear accident had several contributing factors, ranging from design faults, socio-political issues in Japan, poor safety culture, and weak implementation of risk management. Noting the Fukushima Daiichi nuclear accident occurred in the year 2011, this nuclear accident is an ideal case study because it is a topical and severe accident. Using this accident as the case study, the need for public acceptance and “Practical Elimination” in nuclear design to ensure high level of confidence in the nuclear industry will be investigated. Analyzing what occurred in the Fukushima Daiichi accident, and applying the “Practical Elimination” principles into the regulatory framework would greatly lower the probability of similar reoccurrence.

## 2. Practical Elimination Principles

### 2.1 Lessons Learned from Fukushima Daiichi Accident

The Fukushima Daiichi nuclear accident had several contributing factors, ranging from design faults, socio-political issues in Japan, poor safety culture, and weak implementation of risk management. Using the Fukushima Daiichi nuclear accident as a case study, a practical elimination methodology that utilizes design and safety analysis tools to reduce or eliminate plant conditions which can result in unacceptable consequences, can be developed. Analyzing what occurred in the Fukushima Daiichi accident, and applying the practical elimination principles into the regulatory framework is seen by many countries as an approach to prevent and mitigate future occurrences.

### 2.2 Defining Practical Elimination and Demonstration in Canadian Regulatory Framework

In Canada, the term practically eliminated is introduced in REGDOC 2.5.2 (glossary) as follows: "*The possibility of certain conditions being physically impossible or with high level of confidence to be extremely unlikely to arise*" (Canadian Nuclear Safety Commission [CNSC], 2014). Hand in hand with this concept is the term Design Extension Conditions (DEC, section 7.3.4) which are plant conditions expected to be identified and used to further improve the safety of the Nuclear Power Plant (NPP) by enhancing the plant's capabilities to withstand, without significant radiological releases, accidents that are either more severe than Design Basis Accidents or that involve additional failures. As a result of the Fukushima Lessons Learned Report, the CNSC now requires, in REGDOC 2.5.2 that "*The design shall be such that plant states that could lead to significant radioactive releases are practically eliminated. For plant states that are not practically eliminated, only protective measures that are of limited scope in terms of area and time shall be necessary for protection of the public, and sufficient time shall be made available to implement these measures*"(CNSC, 2014).

## 3. Design Elements

This section describes an evaluation matrix developed to assess practical elimination of a Beyond Design Basis Accident (BDBA) in a reactor system. The High Temperature Gas Cooled Reactor (HTGR) conceptual design [i]developed by the Idaho National Laboratory was chosen and analysed by the team using the evaluation matrix.

### 3.1 Design Assumptions for Developing Evaluation Matrix

A few assumptions were made to keep the problem scenario within scope. The reactor used for the scenario to test the evaluation matrix is a power reactor with an output capacity of 100 MWe. The reactor is located underground at a depth of 10 m, and there are no landing strips near the reactor for at least 20 km. Additionally, all barriers, both passive and active, are independent of each other; failure of one barrier does not lead to failure of another. Plant ageing was not considered in this study. Finally, it was assumed that if the BDBA can be considered practically eliminated, it implies that any similar accidents of lesser magnitude are also practically eliminated.

### 3.2 Evaluation of BDBA Scenarios

Figure 1 shows a simple flow diagram of two beyond design basis accidents considered for comparison. One event involves earthquake with magnitude 10 on Richter scale, while another involves a plane crashing on-site which produces a vibration of similar intensity to a magnitude 10 earthquake. Both events lead to a core containment rupture due to shear stress in the containment. The spherical fuel pellets are now spilled from the core and are on the floor of the containment building. In both scenarios, the plant was operating at 100%FP (normal operation) at onset of the initiating event.

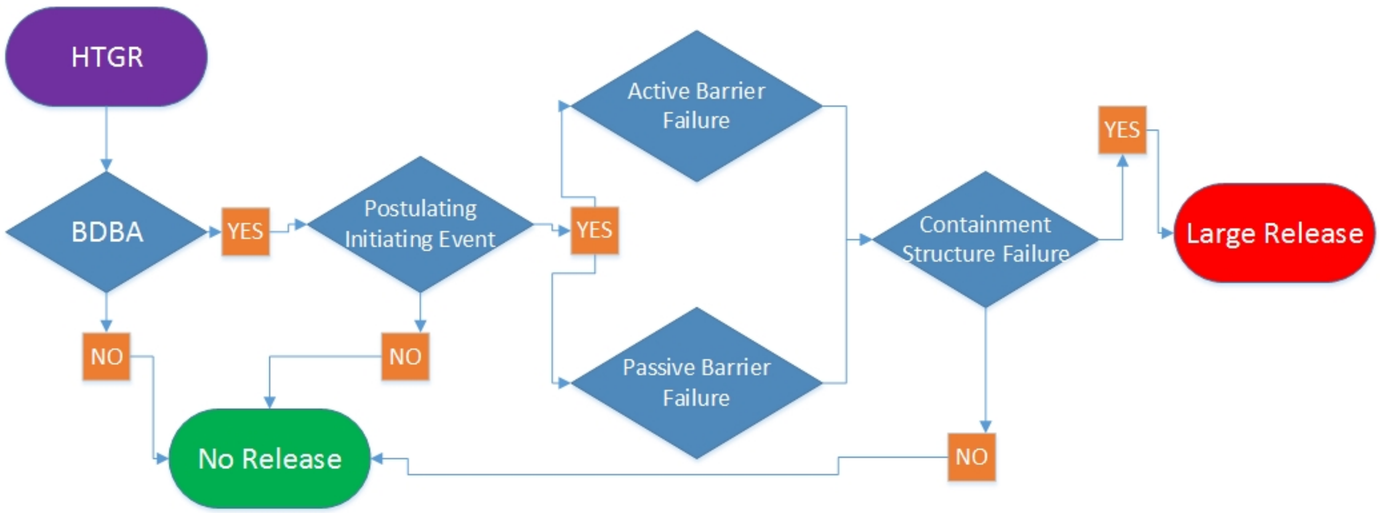


**Figure 1: Accident Scenario Flow Diagram**

### 3.3 Decision Making Matrix

A decision making process developed for the two BDBA scenarios (section 3.2) uses five criteria to evaluate the application of practical elimination: 1) Probability of Occurrence, 2) Severity of Scenario, 3) Defense in Depth of Barrier Design, 4) Human Factors, and 5) Public Acceptance. The importance of these criteria and how they can be measured are described below. Each criterion has a weighting factor and the sum of the weighting factors gives an overall assessment result. A total weighting factor greater than 10 will indicate that the reactor design has practically eliminated the BDBA scenario. A cap limit was not set for the overall assessment result to allow for improvements in safety as technology develops.

#### 3.3.1 Probability of Occurrence

The risks associated with a BDBA considers the consequences of the accident and the probability that the event would occur. Consequences of a BDBA can be prevented by implementing preventative measures at the NPP. However, only the evaluation of the probability of an event occurring can be changed. The probability of a BDBA occurring is stated to be less than $10^{-6}$ in Canada. This factor needs to be included in the decision making process for practical elimination because the frequency of a BDBA would affect the overall result. For example, if the occurrence of a tsunami with a height of 5 m in Darlington NPP is $10^{-20}$, then there is a high degree of confidence that the tsunami would not occur. However, there is always a chance it will occur. Due to the underlying risks of BDBA, the weighting factor for this criterion is -log(x) multiplied by a factor of 0.3. A basic analysis was performed where it was decided that the factor of 0.3 was an appropriate value in which there is neither too much nor too little importance to the risks associated with occurrence of BDBA.

3.3.2 Severity of Scenario

The severity of BDBA scenarios needs to be evaluated and included in the decision making matrix. For consistency with international practice, the IAEA INES Rating Scale[ii] will be used to assess the severity. The INES scale is structured such that a higher value represents a higher severity event. Therefore, the INES severity rating would be subtracted from the previous criterion's weighting value.

3.3.3 Defense in Depth of Barriers

The defense in depth principle provides additional safety margins for an accident. The type and number of additional barriers varies for each reactor. It is difficult to assess specific details of a barrier in the decision making matrix. However, it was assumed that the defence in depth principles are in place, and the effectiveness of the barriers can be measured. Redundancy in barrier design and diversity of barriers are considered in this criterion. The number of applicable barriers invoked for a BDBA will be multiplied by factor of 1.5. Weighing the total number of applicable barriers can be interpreted as the effectiveness of those barriers, i.e., must be at least 50% functional in a BDBA. This is a conservative evaluation. The number of different types of barriers would also be multiplied by 1.5 and added to determine a net weighting value; this would measure the diversity in the design of barriers.

3.3.4 Human Factors

When evaluating means of practical elimination for BDBA, human intervention plays a role. Human factors that are required to be considered during both normal operation and DBAs are: training of staff, operational response, procedures and emergency response. In the Fukushima Daiichi accident, there was shortage of staff because the tsunami killed several people. Everyone in the village was ordered to evacuate to mitigate consequences of radiation exposure. Transporting people to the site during an emergency is outside the scope for this analysis. However, a consequence of being short staffed and having fatigued workers can lead to intolerable consequences. Consequences of human errors can be mitigated by passive barriers so that bringing the plant to a safe state can be achieved with little human intervention. Staff can be onsite to restore functions to active barriers, to monitor the situation and to respond to changing accident conditions. To evaluate human factors for its role in practical elimination, the design will be assessed for the following precursors (which are designed to reduce human error): maintainability and operability, system operations and layout, work environment, system control and monitoring, and manufacturer. Any of the five precursors that are satisfied, a weighing factor of 1 would be added. If all five precursors are met, the maximum weighting factor for human factors criterion would yield a value of 5.

3.3.5 Public Acceptance

Involving the public during assessment of all the other four criteria is important to ensuring public trust and support of the utilities' project. Making decisions in a community without their knowledge or without their support can scuttle a nuclear project. By conducting public consultation at every stage of the decision making matrix, a willing community can be established, initiating a higher success rate for completion of the project. To evaluate whether public acceptance has been achieved at each stage, there will be a qualitative and quantitative assessment. Reviews sought on social media sites, and distribution of surveys in the community shall receive a weighting factor of at least 50%. If the public acceptance is below this limit, the criterion in which public acceptance failed to meet the acceptance criterion shall be re-evaluated. If public acceptance is greater than 50%, the next step in the decision making process can be evaluated. Public acceptance needs to be included in the overall evaluation matrix for practical elimination. A weighting factor of 0 will be assigned if only 50% of public acceptance is met. An increment of 5% gain in public acceptance will result in adding a weighting factor of 0.1. 100% public acceptance would result in a weighting factor of 1, but it is noted that this is a theoretical value since it is nearly impossible to receive 100% acceptance.

### 3.4 Conclusion

Based on the research conducted for the underground gas cooled reactor and using the decision making matrix developed, the plane crash BDBA was practically eliminated using the criteria chart created. In contrast, the Earthquake of magnitude greater than 10 on the Richter scale was not practically eliminated. It was also observed that the public acceptance of the BDBA could overturn the result of whether the design practically eliminated the scenario or not. The appropriateness of the weighting factor assigned to each criterion is open to debate. The predominant issue with the decision matrix is the lack of quality assurance, which needs to be implemented into the matrix. This attempt to consider the practical elimination principle for the decision making matrix has been successfully applied to an HTGR, and is framed for improvements and adaptations by others in the industry.

**Acknowledgments**

The authors would like to extend their appreciation to Marcel de Vos (Canadian Nuclear Safety Commission) who provided regulatory references when the team kick started the research during this academic year.

**References**

Canadian Nuclear Safety Commission. (2014). *Regulatory Document 2.5.2: Design of Reactor Facilities – Nuclear Power Plants*. Canada: Author.

Akbar, A. H. (n.d.). *Dimensions of Human Factors in Nuclear Power Safety*. Pakistan: Pakistan Atomic Energy Commission

Idaho National Laboratory. *The High Temperature Gas Cooled Reactor next Generation Nuclear Energy*. Retrieved February 3rd, 2015 from http://www.inl.gov/research/next-generation-nuclear-plant/

International Atomic Energy Agency (2015). *The International Nuclear and Radiological Event Scale*. Retrieved November 15th, 2014 from http://www-ns.iaea.org/tech-areas/emergency/ines.asp

IAEA. (2002). *Safety Reports Series No.23 - Accident Analysis for Nuclear Power Plants.* Vienna: IAEA.

Sebastian, M. P. et al. (2012). Learning from Fukushima. *Issues in Science and Technology*, 28(3), 79-84.

---

[i] For more detail into the Idaho National Laboratory's High Temperature Gas Cooled Reactor, please visit their website at http://www.inl.gov/research/next-generation-nuclear-plant/

[ii] For more details regarding how severity of a nuclear accident is evaluated, please visit the International Atomic Energy Agency at http://www-ns.iaea.org/tech-areas/emergency/ines.asp