WORKING DRAFT A

SELECTION OF LICENSING BASIS EVENTS

FOR THE

PEBBLE BED MODULAR REACTOR

IN THE UNITED STATES

JULY 2001

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1 INTRODUCTION

The purpose of this document is to describe the risk-informed process for selection of Licensing Basis Events (LBE) in support of planned efforts directed toward the licensing of the Pebble Bed Modular Reactor (PBMR). The process is based on the method (Reference 1) developed in the mid-80s for the Modular High Temperature Gas Cooled Reactors (MHTGR) and modified to reflect the advances that have been made since then in risk informed regulation.

Licensing Basis Events are used to demonstrate compliance with the Top Level Regulatory Criteria (Reference 2) for a spectrum of normal and off-normal plant conditions. Additionally, selection and evaluation of the LBE provide the insights that specify/confirm the functions required for compliance. These required functions lead to the development of the regulatory design criteria and to the selection of equipment and associated performance criteria relied on for compliance.

This report on the selection of LBE is the second in the series of documents describing the PBMR risk-informed licensing process. It builds on and utilizes the subject of the first report, Top Level Regulatory Criteria, which states ***what*** must be satisfied (Reference 2). The LBE describe ***when*** the criteria must be met. Subsequent reports in the series will describe the process for specifying the regulatory design criteriariteria, the ***how***, and for selecting and specifying the special treatment for Equipment Classification, the ***how well***.

Section 2 recaps the Top Level Regulatory Criteria in the risk chart format to be used in the LBE selection process. The characteristics of the PRA that are needed for the selection of the LBE are discussed in Section 3. Section 4 presents the step-by-step selection process for each type of LBE. Examples of the process are provided utilizing the DOE MHTGR preapplication submittals.

2 USE OF TOP LEVEL REGULATORY CRITERIA

Reference 2 provides the identification of the TLRC for the PBMR. Bases for the selection of the TLRC are identified to:

1) be a necessary and sufficient set of direct statements of acceptable health and safety as measured by the risks of radiological consequences to individuals and the environment.
2) be independent of reactor type and site.
3) utilize well defined and quantifiable risk metrics.

As presented in Reference 1 the spectrum of potential accidental radioactive releases from a plant are divided in the following three regions in a scenario frequency vs. consequence chart:

- Anticipated Operational Occurrences (AOO)
- Design Basis Events (DBE)
- Emergency Planning Basis Events (EPBE)

An examination of the entire frequency range and the identification of one or more of the TLRC as being applicable for each Region provide assurance that the selected criteria are adequately established. A summary of the TLRC and their applicable frequency ranges are provided in Table 3-1.

Anticipated Operational Occurrences are those conditions of normal operation which are expected to occur at least once during the life of the plant. Assuming a licensing basis design lifetime of 40 years yields a lower boundary for the AOO region of 2.5×10^{-2} per plant year. For this Region, 10CFR50, Appendix I has been chosen as the applicable criteria as it specifies the numerical guidance to assure that releases of radioactive material to unrestricted areas during normal reactor operations, including AOOs, are maintained As Low As Reasonably Achievable (ALARA).

The dose criteria are expressed in terms of the expected annual dose at the site boundary along the plume centerline for each event to be plotted against the criteria. Hence, for an event expected to occur twice per year the total dose from two events is compared to the Appendix I annual limit. This is used to derive an equivalent allowable dose for each event. For frequent events occurring more than once a year, this results in the sloped risk line shown in Figure 4-1. For less frequent events within the plant lifetime, no single event may exceed the allowable dose as indicated by the vertical dose line in the figure. Appendix I is the most limiting requirement of those identified for normal operation and anticipated operational occurrences.

The **Design Basis Event** region encompasses scenarios that are not expected to occur during the lifetime of one nuclear power plant. The frequency range covers events that are expected to occur during the lifetime of a population (several hundred) of nuclear

power plants; and therefore a lower limit of 10^{-4} per plant year is chosen. This frequency is consistent with the existing LWR design basis region even though LWR design basis accidents were not determined from a quantitative assessment of frequency. Estimates of LWR core damage accidents, which exceed the design basis, have been in the range of $1x10^{-5}$ to greater than $1x10^{-4}$. For this region, 10CFR100 and 10CFR50.34 (a)(1) provide the quantitative dose guidance for accidental releases for siting a nuclear power plant to ensure that the surrounding population is adequately protected.

In the design basis region, acknowledgement that relatively more frequently occurring events should meet more stringent criteria leads to the sloping dose criteria line. At the lower end (i.e. 10^{-4} per plant year), the criteria are 100% of the limit dose. The criteria linearly decrease to the upper end where 10% of the limit is used. This is consistent with the NRC's qualitative criterion, as reflected in the Standard Review Plan guidance, that the dose limitations from more frequent accidents be a fraction of the dose guidelines. The dose criteria are expressed in TEDE at the site exclusion area boundary (EAB). The 10CFR100 / 50.34.(a) (1) criteria are more limiting than the Reactor Safety Goals.

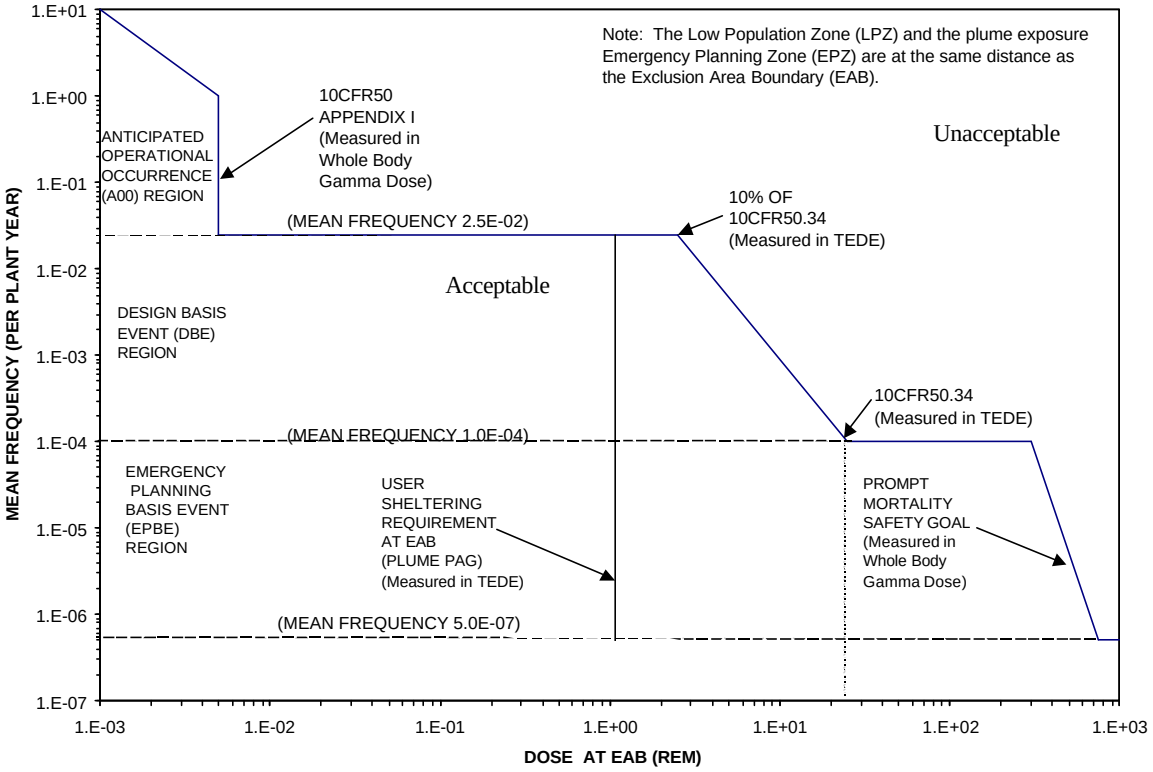
The **Emergency Planning Basis Event** region considers improbable events that are not expected to occur during the lifetime of several hundred nuclear power plants. This is to assure that adequate emergency planning is developed to protect the public from undesirable exposure to radiation for improbable events. The frequency cutoff implicit in the acute fatality risk goal in NUREG-0880 is taken as the lower frequency boundary of the EPBE Region. NUREG-0880 notes that the individual mortality risk of prompt fatality in the U. S. is about 5×10^{-4} per year for all accidental causes of death. The prompt mortality risk design objective limits the increase in an individual's annual risk of accidental death to 0.1% of 5×10^{-4}, or an incremental increase of no more than 5×10^{-7} per year. If the frequency of a scenario or set of scenarios is at or below this value, it can be assured that the individual risk contributions from these scenarios would still be within the safety goal independent of the magnitude of consequences. Therefore this value is used as the lower frequency bound for the EPBE Region.

The incremental mortality cancer risk allowed by the safety goal is 5×10^{-7} fatalities per year. The illustration of the prompt mortality risk curve displayed in Figure 2-1 is approximated and presented in terms of whole body dose in rem. The prompt mortality risk is more limiting than the latent fatality risk. The use of the safety goals to draw the criteria line in this region is very conservative when applied to the dose at the site boundary along the plume centerline as a person at this point would be located at the point of maximum risk over the area within 1-mile of the site boundary in which the average individual risk must meet the safety goal. When the individual risk at this point meets the safety goal, the average individual risk within 1-mile of the site boundary would be much less than $5x10^{-7}$ per year value.

The Protective Action Guidelines (PAG) from EPA-400-R-92-001 are shown as a dose limit as expressed in TEDE at the emergency planning zone (EPZ). The PAG apply to the design and emergency planning basis regions. Depending on the size of the EPZ, the

PAG can be the most limiting criteria. The PBMR will be designed with the option to preclude the need for offsite sheltering, that is, the EPZ would be at the EAB.

FIGURE 2-1
PBMR RISK CRITERIA CHART



3 USE OF PROBABILISTIC RISK ASSESSMENT (PRA)

The purpose of this section is to define the objectives, scope, level of detail, treatment of uncertainties, and conformance with relevant industry standards for the PBMR PRA that will be needed to support the proposed risk informed licensing approach for U.S. sited PBMR plants.

3.1 Rationale for Use of PRA

Probabilistic Risk Assessment provides a logical and structured method to evaluate the overall safety characteristics of the PBMR plant. This is accomplished by systematically enumerating a reasonably complete set of accident scenarios and by assessing the frequencies and consequences of the scenarios individually and in the aggregation of results to predict the overall risk profile. It is the only available safety analysis method that captures the dependencies and interactions among systems, structures, components, human operators and the internal and external plant hazards that may perturb the operation of the plant that could produce an accident. The quantification of both frequencies and consequences must address uncertainties because it is understood that the risk is determined by the potential occurrence of rare events. These quantifications provide an objective means of comparing the likelihoods and consequences of different scenarios and of comparing the assessed level of safety against the TLRC.
PRA is selected because for the following objectives

- Provide a systematic examination of dependencies and interactions and the role that each SSC and operator action plays in the development of each accident scenario; this is referred to in the PRA community as the capability to display the cause and effect relationships between the plant characteristics and the resulting risk levels.
- Provide quantitative estimates of accident frequencies and consequences under the most realistic set of assumptions that can be supported by available evidence.
- Address uncertainties through full quantification of the impact of identifiable sources of uncertainty on the results and by appropriate structured sensitivity studies to understand the risk significance of key issues.
- Apply conservatism only through the examination of explicit percentiles of uncertainty distributions and not by inappropriate combinations of non-physical conservative assumptions.
- Provide a reasonable degree of completeness in treatment of appropriate combinations of failure modes; including multiple failures necessary to determine risk levels

I t is important that all key assumptions that are used to develop success criteria, to develop and apply probability and consequence models, and to select elements for incorporation into the models are clearly documented and are scrutible. Uncertainties in the collective state of knowledge are not introduced by PRA but rather are systematically exposed by the rigorous set of questions that are addressed in the development of the PRA models and results. PRA provides a means of decomposing the general problem of uncertainty and the limitations of our state of knowledge that challenge any attempt to

assess the adequacy of safety into a structured set of questions about the scope, completeness, and dependencies within and among each element of the PRA.

3.2 Objectives of PBMR PRA

In order to determine the scope and necessary characteristics of the PRA that will be required for the development of licensing bases for the PBMR it is important to list the objectives of the evaluation. The objectives include:

- To confirm that the Top Level Regulatory Criteria, including that the safety goal Quantitative Health Objectives for individual and societal risks are met at a U.S. site or sites
- To support the identification of licensing basis events
- To provide a primary technical basis for the development of regulatory design criteria for the plant
- To support the determination of safety classification and special treatment requirements of systems, structures, and components (SSCs).
- To support the identification of emergency planning specifications including the location of the site boundary.
- To support the development of technical specifications

3.3 Elements of the PBMR PRA

In the case of LWR PRAs, the scope of a PRA is defined in two dimensions, with one dimension used to define the scope of the accident sequence end state and the other for the scope of initiating events and plant initial states to consider. The different treatment of end states is expressed in terms of three PRA Levels. The Level 1 PRA is used to describe the part of the PRA needed to characterize the core damage frequency (CDF); Level 2 is used to describe the aspects of the scenarios involving releases of radioactive material from the containment including the frequencies of different release states and estimates of the source terms for the releases; and Level 3 is used to characterize the aspects of the scenarios involving transport of radioactive material from the site to the ultimate determination of consequences to public safety, health, and the environment so that the frequency of different consequence magnitudes is quantified.

LWR accident initiating events are normally placed into two major categories, one for internal events and the other to capture external events such as seismic events and transportation accidents. (Internal plant flooding events are normally included as part of the internal events scope, but internal plant fires are normally included within the external events scope.) Due to the combination of inherent LWR characteristics and the fact that major changes to thermal hydraulic configuration occur during shutdown, the expansion of scope to include shutdown and low power conditions usually requires a completely different set of initiating events and event sequence models compared with the PRA models for full power initial conditions.

The scope of the PBMR PRA needed to support this risk-informed approach to PBMR licensing will be as comprehensive and reasonably complete as would be covered in a full scope, all modes, Level 3 PRA covering a full set of internal and external events. However, the inherent features of the PBMR tend to simplify the number of different elements that need to be assembled to accomplish a comparably scoped PRA in relation to an LWR.

The first observation in defining the PBMR PRA elements is that the traditional Level 1-2- 3 model of an LWR PRA that was originally defined in NUREG/CR-2300 and still used today does not fit the unique characteristics of the PBMR. Since there is no counterpart for the LWR core damage end-state, the splitting up of event sequences involving releases into Level 1 and Level 2 segments does not apply to the PBMR. The elements of the PBMR PRA are integrated around a single, event sequence model framework that starts with initiating events and ends in PBMR specific end states for which radionuclide source terms and offsite consequences are calculated. The integral PBMR PRA encompasses the functions of a full scope Level 1-2- 3 PRA.

Another distinction in the definition of PBMR PRA elements is in the treatment of initial operating states such as full power, low power and shutdown modes. In the LWR case, the early PRA work was focused on the full power-state as intuitively representing the most limiting potential for producing risk significant sequences. In the late 1980's to early 1990's it was realized that accidents initiated during shutdown were even more risk significant until controls were applied to better manage safety functions during plant activities at shutdown. Importantly, PRAs for shutdown conditions in LWRs were much more complex than for full power as there were many plant configurations to deal with and many different time frames during an outage that created a need to develop separate PRA models for each unique configuration. By contrast, the different configurations of the PBMR do not have so many different applications of the safety functions and therefore lend themselves to a single integrated PRA that accounts for all operating and shutdown states. Furthermore, the on-line refueling aspect and specifications for maintenance on the large rotating machinery (i.e., the turbo units and power turbine generator) mean that the fraction of time the plant is shutdown is expected to be an order of magnitude less than current LWRs. Hence for each PBMR PRA element, it is necessary to address applicable sequences in all modes of operation and this can be accomplished without the need for separate models for each mode of operation.

The modular aspect of the PBMR creates the potential for anywhere from one to as many as 10 reactors located at the same site. The PRA needs to account for the risk of multiple modules, which is comparable to the LWR PRA case of a multiunit site. The existence of multiple modules increases the likelihood of scenarios that impact a single module independently, and creates the potential for scenarios that may dependently involve two or more modules.

The elements of the PBMR PRA, which comprise a full scope treatment of initiating events and end states, include:

1. Initiating Events Analysis
2. Event Sequence Development
3. Success Criteria Development
4. Thermal Hydraulics Analysis
5. Systems Analysis
6. Data Analysis
7. Human Reliability Analysis
8. Internal Flooding Analysis
9. Internal Fire Analysis
10. Seismic Risk Analysis
11. Other External Events Analysis
12. Event Sequence Quantification (includes full uncertainty quantification)
13. Source Term Analysis
14. Consequence Analysis (includes full uncertainty quantification)
15. Risk Integration and Interpretation of Results
16. Peer Review

As emphasized in the current LWR PRA standards, the PBMR PRA must be capable of a thorough treatment of dependent failures including the comprehensive treatment of common cause initiating events, functional dependencies, human dependencies, physical dependencies, and common cause failures impacting redundant and diverse components and systems.

The ASME PRA standard includes both High Level and Supporting Criteria for dependency treatment that arises in essentially all of the above elements. In general, the PBMR PRA will conform tothe ASME PRA standard for PRA Capability Category III, a full quantification of uncertainties is required that must reflect the iterative nature of the PRA as the PBMR evolves from conceptual design, completion of construction, and eventual commissioning. Quantification of uncertainties provides the capability to determine the mean frequencies and consequences of each accident family to be compared against the TLRC, to compare specific percentiles of the uncertainty distributions against the criteria, and to compute the probability that specific criteria are met.

In order to support the evaluation of regulatory design criteria, the PRA will be capable of evaluating the cause and effect relationships between design characteristics and risk as well as be able to support a structured evaluation of sensitivities to examine the risk impact of adding and removing selected design characteristics.

3.4 Applicability of LWR PRA Practices and Standards

The increased use of PRA in the risk-informed regulatory process has led to a number of initiatives to address and improve PRA quality. These initiatives include an industry PRA peer review program (Reference 3) and efforts to develop PRA standards by the ASME (Reference 4), ANS (References 5 and 6) and NFPA (Reference 7). The concepts and principles that are being developed in these initiatives address both fundamental

aspects of PRA technology and certain aspects that are rooted in characteristics of LWRs that are not shared by the PBMR. While the fundamental aspects are applicable, the following aspects of these quality initiatives will be modified to apply to a PBMR PRA.

- The current quality initiatives are focused on PRAs that are used to calculate CDF and LERF. If one replaces CDF and LERF with the PBMR task of providing estimates of each characteristic PBMR accident family, which is defined by appropriate combinations of PBMR specific initiating events and end-states, then the associated high level and supporting requirements can be viewed as directly applicable to the PBMR.
- As noted in the previous section it is not appropriate to fit a PBMR PRA into the mold of the Level 1 -2 -3 framework.Instead an integrated PRA that develops sequences from initiating events all the way to source terms and consequences is developed.
- As noted in the previous section, it is not necessary to perform a completely different set of PRA models for full power vs. low power and shutdown, such that the PBMR lends itself to an integrated treatment of accident sequences that cover all operating and shutdown modes.
- Unlike the current LWR applications in which it is rarely necessary to extend the PRA to Level 3, the initial PBMR applications will need to include off-site dose consequences to demonstrate the safety case and to meet licensing framework objectives.
- In view of the applications envisioned for the PBMR PRA, a full scope treatment of internal and external events is anticipated.

With these adjustments it is reasonable to apply the applicable LWR PRA standards and peer review process to assessing PBMR PRA quality until such time as PBMR specific standards and peer review processes are developed. A proposal for application of these standards to each PBMR PRA element is provided in Table 3-1. Note that the ASME standard proposes three Capability Categories to address PRA requirements for different applications. The applications envisioned for the PBMR are assumed in this PRA plan to use ASME PRA Capability Category III. This is a reasonable assumption because of the expectation that the PRA will be integral to the licensing basis of the reactor. These are the standards assumed for defining the scope, level of detail, and capability levels needed to support the risk informed approach to licensing the PBMR.

Table 3-1 Comparison of PBMR PRA Technical Elements and Applicable PRA Standards

PBMR PRA Technical Elements	Applicable PRA Standards	Comments
1. Initiating Events Analysis	• ASME PRA Standard Initiating Events Analysis • ANS shutdown PRA standard for low power and shutdown states	• PBMR and LWR PRAs essentially equivalent for this element; separate shutdown PRAs not needed for PBMR
2. Accident Sequence Definition	• ASME PRA Standard Accident Sequence Analysis • ANS shutdown PRA standard for accident sequence analysis in low power and shutdown states	• Replace LWR focus on CDF and LERF with focus on major PBMR accident classes; separate shutdown PRAs not needed for PBMR
3. Success Criteria Development	• ASME PRA Standard Success Criteria and Supporting Engineering Analysis	• Use of PRA to support licensing basis will make it easier to delineate realistic vs. conservative success criteria relative to LWRs
4. Thermal Hydraulics Analysis	• ASME PRA Standard Success Criteria and Supporting Engineering Analysis	• Computer codes to support this developed in Germany and being installed at PBMR; Existing LWR codes are not applicable to PBMR conditions
5. Systems Analysis	• ASME PRA Standard Systems Analysis	• PBMR and LWR PRAs essentially equivalent for this element except that PBMR has fewer systems to analyze
6. Human Reliability Analysis	• ASME PRA Standard Human Reliability Analysis	• PBMR and LWR PRAs essentially equivalent for this element
7. Data Analysis	• ASME PRA Standard Data Analysis	• PBMR and LWR PRAs essentially equivalent for this element
8. Internal Flooding Analysis	• ASME PRA Standard Internal Flooding Analysis	• PBMR and LWR PRAs essentially equivalent for this element
9. Internal Fires Analysis	• NFPLA Standard for Internal Fires Analysis	• PBMR and LWR PRAs essentially equivalent for this element
10. Seismic Analysis	• ANS PRA Standard External Events Analysis	• PBMR and LWR PRAs essentially equivalent for this element
11. Other External Events Analysis	• ANS PRA Standard External Events Analysis	• PBMR and LWR PRAs essentially equivalent for this element
12. Accident Sequence Quantification	• ASME PRA Standard Quantification	• LWR separation of accident sequences into Level 1-2-3 not appropriate for PBMR; scope of accident sequences includes doses at the site boundary; risk importance measures to be developed and analyzed for each major PBMR accident class
13. Source Term Analysis	• No corresponding standard	• This task is similar to the T/H and source terms analysis in an LWR Level 2 PRA which is not currently covered in LWR PRA standards
14. Accident Consequence Analysis	• No corresponding standard	• This task is similar to the consequence analysis in an LWR PRA which is not currently covered in LWR PRA standards
15. Risk Integration and Interpretation	• No corresponding standard	• This task is needed to integrate the frequency and consequence information into a frequency-consequence format and to interpret the results compared to TLRC
Not applicable	• ASME PRA Standard Level 2/LERF	• The treatment of physical and chemical

Table 3-1 Comparison of PBMR PRA Technical Elements and Applicable PRA Standards

PBMR PRA Technical Elements	Applicable PRA Standards	Comments
	Analysis	processes that impact source terms are reflected as an integral process into the PBMR accident event trees and fault trees; there is no segregation into Level 1-2-3 as in LWR PRA
16. Peer Review	• ASME PRA Standard for full power internal events, ANS external events and low power and shutdown sections on peer review; NEI guide for industry PRA Certification Peer Review process	• A peer review can be performed for each site specific PBMR PRA that reflects the PRA scope and uses applicable aspects of the NEI PRA Certification Peer Process.

4 SELECTION OF LICENSING BASIS EVENTS

With a PBMR PRA as outlined above, the selection of LBE proceeds by comparing the risk results with the three frequency-consequence regions defined on the PBMR risk criteria chart of Figure 2-1. This section describes the selection process for each of the three subsets of LBE, namely for the Anticipated Operational Occurrences, the Design Basis Events, and the Emergency Planning Basis Events. The process is utilized as the design detail and technology development proceed so that the PRA certainty advances and a final set of LBE are selected.

4.1 Anticipated Operational Occurrences

Anticipated Operational Occurrences (AOO) are selected from those families of events whose mean frequency falls within the AOO region, as shown on the risk criteria chart, and that would exceed the 10CFR50 Appendix I criteria on a mean value basis were it not for design selections that control radionuclide release. Those that meet this condition, or a bounding set of these, are designated AOO.

Families of events may have significant uncertainties in the estimate of their frequencies. The consideration of these uncertainties is necessary to ensure that all events will be assessed against the appropriate criteria. The mean value of frequency, which involves an integral over the complete uncertainty spectrum, is the selected parameter for accounting for frequency uncertainties. An additional factor (2 at the early stage of the design) is placed on the mean frequency to assure that event families falling just above or below a region are evaluated in the most stringent manner.

AOO typically have associated with them relatively small consequences. Furthermore, the uncertainties in the consequences of AOO are relatively small, and are monitored and reduced during the life of the plant. Therefore, although the PRA assessment provides the entire consequence distribution, including the mean, and upper and lower bound doses, it is appropriate that the consequences of AOO meet 10CFR50 Appendix I criteria on a mean-value basis. The mean-value represents a first order consideration of uncertainty. This consideration of uncertainty is consistent with LWR precedent for AOO.

An example of the AOO selection process utilizing comparison of a PRA with TLRC is taken from the MHTGR preapplication licensing as shown in Figure 4-1. Table 4-1 from Reference 8 provides the list of the five families of events designated as AOO in the figure. AOO-5, a small primary coolant leak in one of the MHTGR modules, is the only event with an offsite consequence. Both frequency and consequence uncertainty bands are explicitly shown in the figure.

While the other four AOO do not involve an offsite release, each involves a source sufficiently large that could exceed 10CFR50 Appendix I limits if it were not for a design feature, e.g., protection of the primary coolant boundary or isolation of the steam generator.

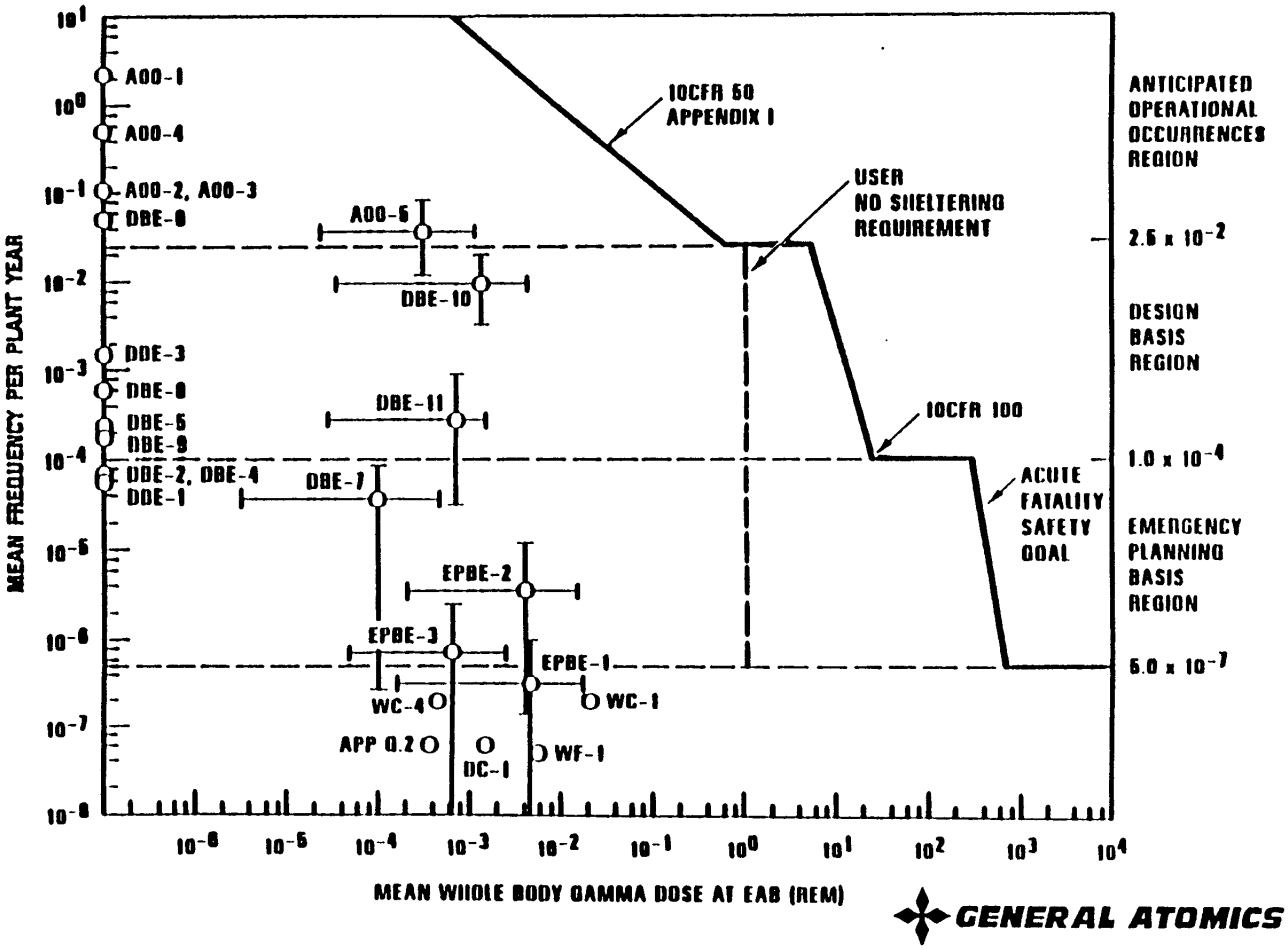


Figure 4-1 Comparison of MHTGR PRA Event Families with the MHTGR Top Level Regulatory Criteria

Table 4-1 Identification of MHTGR Anticipated Operational Occurrences (Reference 8)

AOO Designation	Anticipated Operational Occurrence
AOO-1	Main loop transient with forced core cooling
AOO-2	Loss of main and shutdown cooling loops
AOO-3	Control rod group withdrawal with control rod trip
AOO-4	Small steam generator leak
AOO-5	Small primary coolant leak

4.2 Design Basis Events

Design Basis Events are selected from those families of events whose mean frequency falls within (or within a factor of) the DBE region as shown on the risk criteria chart and that would exceed the 10CFR50.34 criteria on a mean value basis were it not for design selections that control radionuclide release. Those that meet this condition are designated DBE.

Figure 4-1 again provides an example from the MHTGR. Table 4-2 from Reference 8 provides the list of the eleven families of events designated as DBE in the figure for the MHTGR. These are lower frequency events that oftentimes involve multiple failures, both dependent and independent. An external event is included as DBE-5, which is the 0.3g SSE. Five of the eleven events have mean frequencies outside the DBE region, but were included because of their large uncertainties.

Three of the DBE have offsite doses and the mean and upper and lower bound doses are shown. Within the DBE region the both the mean values and upper bound (95% confidence) doses are compared to the criteria. The mean values provide a more consistent comparison of the doses in this region to those in the other two regions, and the upper bounds are used to be consistent with the traditional use of conservative assumptions in performance of design basis accident safety analyses for LWRs.

The PBMR would be expected to have many of these same events, albeit with different frequencies and consequence values. However, since the PBMR does not have a high pressure source of water in steam generators, water inleakage is expected to have less risk significance.

4.3 Emergency Planning Basis Events

Emergency Planning Basis Events are selected from those families of events whose mean frequency falls within (or within a factor of) the EPBE region as shown on the risk criteria chart. Those that meet this condition are designated EPBE.

Figure 4-1 again provides an example from the MHTGR. Table 4-3 from Reference 8 provides the list of the three families of events designated as EPBE in the figure for the MHTGR. These are lower frequency events that involve multiple failures, both dependent and independent. An event is included as EPBE-5, which involves all of the plant's four modules. One of the events has a mean frequency outside the EPBE region, but was included because of its large uncertainty.

All EPBE have offsite doses and the mean and upper and lower bound doses are shown. The EPBE and DBE mean doses are compared to the PAG and the EPBE mean doses together with those of the DBE and the AOO are summed over their entire frequency distribution and compared to the safety goal QHO.

Events below the EPBE region are examined to assure that the residual risk is negligible with respect to the latent mortality safety goal and to provide general assurance that there is no “cliff” in which a high consequence event goes unnoticed. The five low frequency events in Figure 4-1 below the EPBE region without an LBE number (e.g., WC-1) are examples for the MHTGR.

The PBMR would be expected to have similar events to EPBE-3 involving more than one module and still lower frequency events beyond the licensing basis would be examined to assure low residual risk.

Table 4-2 Identification of MHTGR Design Basis Events
(Reference 8)

DBE Designation	Design Basis Event
DBE-1	Loss of HTS and SCS cooling
DBE-2	HTS transient without control rod trip
DBE-3	Control rod withdrawal without HTS cooling
DBE-4	Control rod withdrawal without HTS and SCS cooling
DBE-5	Earthquake
DBE-6	Moisture inleakage
DBE-7	Moisture inleakage without SCS cooling
DBE-8	Moisture inleakage with moisture monitor failure
DBE-9	Moisture inleakage with steam generator dump failure
DBE-10	Primary coolant leak
DBE-11	Primary coolant leak without HTS and SCS cooling

Table 4-3 Identification of MHTGR Emergency Planning Basis Events
(Reference 8)

EPBE Designation	Emergency Planning Basis Events
EPBE-1	Moisture inleakage with delayed steam generator isolation and without forced cooling
EPBE -2	Moisture inleakage with delayed steam generator isolation
EPBE -3	Primary coolant leak in all four modules with neither forced cooling nor HPS pumpdown

5 REFERENCES

1. "Licensing Basis Events for the Standard MHTGR," Department of Energy Report, DOE-HTGR-86-034, Revision 1, February 1987.

2. "Top-Level Regulatory Criteria for the Standard MHTGR," Department of Energy Report, DOE-HTGR-85002, Revision 3, September 1989.

3. NEI-0002, Industry PRA Certification Peer Review Process

4. ASME PRA Standard, Draft 14, May 2001.

5. ANS PRA Standard for Low Power and Shutdown PRA

6. ANS PRA Standard for External Events

7. NFPLA Standard for Fire PRA

8. "Preliminary Safety Information Document for the Standard MHTGR," Department of Energy, DOE-HTGR-86-024, Volume 1, September 1988