P B M R

Pebble Bed Modular Reactor (Pty) Ltd.
Reg. No: 1999/17946/07

3rd Floor, Lake Buena Vista Building 1267 Gordon Hood Avenue Centurion Republic of South Africa
PO Box 9396 Centurion 0046 Tel (+27 12) 677-9400 Fax (+27 12) 663-3052/8797/ 677-9446

Date:	Your Ref.:	Our Ref.:	Enquiries:
August 28, 2006		USDC20060828-1	E.G. Wallace
			TEL:US 423-344-6774

ATTN: Document Control Desk
U.S. Nuclear Regulatory Commission
Washington, D.C. 20555-0001

NRC Project No. 732

Attention: Mr. N. Prasad Kadambi

Subject: PBMR White Paper: SSC Classification

Ref: PBMR (Pty) Ltd. Letter, Subject: Submittal of PBMR Preapplication White Papers, May 1, 2006

Enclosed is the PBMR white paper entitled "Safety Classification of Structures, Systems, and Components for the Pebble Bed Modular Reactor", Revision 1. As described in the reference, this white paper describes our approach to the classification of structures, systems, and components (SSCs) for the PBMR design and sets forth certain facts for review and discussion in order to facilitate an effective submittal leading to a PBMR design certification.

If you have any questions about this submittal, please feel free to contact me.

Yours sincerely,

Edward G. Wallace
Senior General Manager- US Programs
PBMR (Pty) Ltd.

Enclosure
cc: Ms. Christiana Lui, RES
Ms. Margaret T Bennett, RES
Mr. Stuart J. Rubin, RES
Mr. Lawrence J. Burkhart, NRR

US DESIGN CERTIFICATION

SAFETY CLASSIFICATION OF STRUCTURES, SYSTEMS, AND COMPONENTS FOR THE PEBBLE BED MODULAR REACTOR

Document Number	**:**	**043553**
Revision	**:**	**1**
Status	**:**	**Approved**

Signatures for approved documents are held on file in the Document Control Centre of PBMR (Pty) Ltd

This document is the property of PBMR (Pty) Ltd.
The content thereof may not be reproduced, disclosed or used without the Company's prior written approval.

ABSTRACT

This pre-application paper outlines the relevant regulatory policy and guidance for a risk-informed approach for establishing the safety classification of Structures, Systems, and Components (SSCs) for the Pebble Bed Modular Reactor (PBMR), and sets forth certain facts for review and discussion in order to facilitate an effective submittal leading to a PBMR design certification under 10 CFR Part 52.

CONFIGURATION CONTROL

Document History

Rev.	Date	Preparer	ECPs	Changes
A	2006/08/13	F Silady	None	New document.
B	2006/07/01	F Silady	None	Updated after Comments Review.
1	2006/08/24	F Silady	None	Document edited and sent for approval.

Document Approval

Action	Function	Designate	Signature
Prepared	Preparer Function	F Silady	See signatures on file
Reviewed	Independent Reviewer	E Burns	See signatures on file
Approved	Project Manager	E Wallace	See signatures on file

Document Retention Time

This document is a Quality Record and shall be retained in accordance with PRC0012.

© Copyright 2006 by PBMR

CONTENTS

FIGURES

TABLES

ABBREVIATIONS

This list contains the abbreviations used in this document.

Abbreviation or Acronym	Definition
ACS	Active Cooling System
AOO	Anticipated Operational Occurrence
ATWS	Anticipated Transient Without Scram
BDBE	Beyond Design Basis Event
CCS	Core Conditioning System
CDF	Core Damage Frequency
CFR	Code of Federal Regulations
DBA	Design Basis Accident
DBE	Design Basis Event
DCA	Design Certification Application
DOE	Department of Energy
DPP	Demonstration Power Plant
EAB	Exclusion Area Boundary
EPS	Equipment Protection System
GDC	General Design Criteria
HPB	Helium Pressure Boundary
HVAC	Heating, Ventilation and Air-conditioning
HX	Heat Exchanger
ISI	In-service Inspection
IST	In-service Testing
LBE	Licensing Basis Event
LERF	Large Early Release Frequency
LWR	Light Water Reactor
MHTGR	Modular High-Temperature Gas-cooled Reactor
MPS	Main Power System
NRC	Nuclear Regulatory Commission (USA)
NSRST	Non-Safety-Related with Special Treatment
NUREG	NUclear REGulatory Commission report
PBMR	Pebble Bed Modular Reactor
PCU	Power Conversion Unit
PRA	Probabilistic Risk Assessment
QA	Quality Assurance
QC	Quality Control
QHO	Quantitative Health Objective

Abbreviation or Acronym	Definition
RAI	Request for Additional Information
RCCS	Reactor Cavity Cooling System
RCS	Reactivity Control System
RDC	Regulatory Design Criteria
RPS	Reactor Protection System
RSS	Reserve Shutdown System
RTNSS	Regulatory Treatment of Non-Safety-Systems
SAR	Safety Analysis Report
SAS	Small Absorber Spheres
SBO	Station Black Out
SBS	Start-up Blower System
SR	Safety-Related
SRM	Staff Requirements Memorandum
SSC	Structures, Systems, and Components
SSE	Safe Shutdown Earthquake
TLRC	Top Level Regulatory Criteria

1. INTRODUCTION

1.1 SCOPE AND PURPOSE

The risk-informed licensing approach proposed for the Pebble Bed Modular Reactor (PBMR) includes the definition of Top Level Regulatory Criteria (TLRC) that provide frequency and dose limits for Licensing Basis Events (LBEs). In this respect, the TLRC determine ***what*** must be met for licensing approval. The selection of the LBEs answers the question of ***when*** the TLRC are to be met. Additional elements of the PBMR licensing approach answer the questions of ***how*** and ***how well*** the TLRC are to be met. This paper describes one of these latter elements: a risk-informed approach for the safety classification of PBMR Structures, Systems, and Components (SSCs). A companion paper on Defense-in-Depth [1] also addresses how the TLRC are to be met during LBEs.

1.2 STATEMENT OF THE ISSUES

The issues addressed in this white paper are framed in terms of answering the following questions regarding the safety classification of SSCs to support the PBMR Design Certification Application (DCA):

1. What is the role of safety classification of SSCs in the risk-informed performance-based licensing approach for the PBMR?
2. What is an appropriate, systematic, and reproducible approach for safety classification of SSCs in a risk-informed, performance-based licensing approach?
3. What are appropriate safety class categories for SSCs?
4. How are deterministic approaches used and integrated into the safety classification process?
5. How are probabilistic approaches used and integrated into the safety classification and special treatment processes?
6. What is the approach for assigning special treatment to assure the required degree of reliability and capability for SSCs classified as safety-related?
7. What is the approach for assigning special treatment to assure the required degree of reliability and capability for SSCs classified as non-safety-related with special treatment?

The regulation and policy foundation for deriving this list of issues is developed in Section 2 of this white paper. The PBMR approach to classification of SSCs is outlined in Section 3 and will be discussed and reviewed at future Nuclear Regulatory Commission (NRC) workshops. Section 4 defines the issues identified in the review of the regulatory foundation and in the technical development of the SSC approach, and provides PBMR's proposed resolution of these issues.

1.3 SUMMARY OF PRE-APPLICATION OUTCOME OBJECTIVES

The objective of this paper (and the follow-up workshops) is to obtain NRC agreement on the list of issues for the safety classification of SSCs to support PBMR certification as well as agreement on the approach to resolving these issues. Specifically, PBMR would like the NRC to agree with the following statements, or provide an alternative set of statements with which they agree:

1. The PBMR risk-informed, performance-based approach to safety classification and special treatment that blends the strengths of probabilistic and deterministic methods is acceptable.
2. The use of three safety classification categories and the bases for SSC classification in each category are acceptable:

   Safety-Related

   - For SSCs relied on to perform required safety functions to mitigate the consequences of Design Basis Events (DBEs) to comply with the dose limits of 10 CFR §50.34.
   - For SSCs relied on to perform required safety functions to prevent the frequency of Beyond Design Basis Events (BDBEs) with consequences greater than the 10 CFR §50.34 dose limits from increasing into the DBE region.

   Non-Safety-Related with Special Treatment

   - For SSCs relied on to perform safety functions to mitigate the consequences of Anticipated Operational Occurrences (AOOs) to comply with the offsite dose limits of 10 CFR Part 20.
   - For SSCs relied on to perform safety functions to prevent the frequency of DBEs with consequences greater than the 10 CFR Part 20 offsite dose limits from increasing into the AOO region.

   Non-Safety-Related

   For all other SSCs, no special treatment.

3. The special treatment for the Safety-Related (SR) category of classification is commensurate with that needed for the SSCs to perform their capability and reliability requirements during DBEs and high consequence BDBEs to meet the 10 CFR §50.34 dose limits.
4. The special treatment for the Non-Safety-Related with Special Treatment (NSRST) category is commensurate with that needed for the SSCs to perform their capability and reliability requirements during AOOs and high consequence DBEs to meet the 10 CFR Part 20 offsite dose limits.

1.4 RELATIONSHIP TO OTHER PRE-APPLICATION FOCUS TOPICS/WHITE PAPERS

This paper on the safety classification of SSCs is linked to the companion defense-in-depth paper as noted above. In addition, it relies on input from PBMR pre-application papers on Probabilistic Risk Assessment (PRA) Approach [2] and LBE Selection [3].

© Copyright 2006 by PBMR

Inherent in the PBMR safety design and licensing approach, is the development and quantification of mechanistic source terms for the spectrum of LBEs. Papers on the fuel, the reactor unit materials, and verification and validation of the analytical models and computer codes are key inputs to the mechanistic source terms.

In addition, the papers on the fuel and reactor unit materials demonstrate for key PBMR SSCs the use of the LBE selection, the safety classification and the defense-in-depth elements of the PBMR licensing approach.

2. REGULATORY FOUNDATION

2.1 NRC REGULATIONS

Under NRC regulations, SSCs for reactors are primarily classified into one of two categories: 1) safety-related or 2) non-safety-related. 10 CFR §50.2 defines safety-related SSCs as:

'those structures, systems and components that are relied upon to remain functional during and following design basis events to assure:

(1) The integrity of the reactor coolant pressure boundary;

(2) The capability to shut down the reactor and maintain it in a safe shutdown condition; or

(3) The capability to prevent or mitigate the consequences of accidents which could result in potential offsite exposures comparable to the applicable guideline exposures set forth in §50.34(a)(1) or §100.11 of this chapter, as applicable.'

The PBMR approach adheres to this definition of safety-related SSCs with the caveat that the safety functions and DBEs should be specific to the PBMR technology.

The NRC has other classifications; however, those classification schemes generally parallel the criteria provided above. For example:

- 10 CFR Part 50, Appendix B requires that safety-related SSCs be subject to a quality assurance program.
- 10 CFR. §50.49 requires environmental qualification of electric equipment that is safety-related and relied upon to remain functional during and following DBEs, and of certain non-safety-related equipment.
- 10 CFR §50.55a requires that certain pressure boundary components (which are also safety-related components) be designed and classified in accordance with the ASME Code.
- Appendix S to 10 CFR Part 50 states that SSCs that meet criteria similar to those discussed above shall be designed to withstand a Safe Shutdown Earthquake (SSE) and remain functional.

In addition, there are other requirements and guidance that pertain to selected non-safety-related SSCs. For example, fire protection SSCs are subject to requirements in 10 CFR §50.48; certain equipment needed to mitigate Anticipated Transients Without Scram (ATWS) and Station Black Out (SBO) events are subject to the requirements in 10 CFR §§50.62 and 50.63, respectively; and radwaste systems are subject to requirements in the General Design Criteria (GDC) in Appendix A to 10 CFR Part 50.

10 CFR §50.69 'Risk-informed categorization and treatment of structures, systems and components for nuclear power reactors' defines safety significance categories for SSCs based on combinations of safety classification and risk significance as determined in a PRA. The following four safety significance categories are defined in this part of the regulations:

> *'Risk-Informed Safety Class (RISC)-1 structures, systems, and components (SSCs) means safety-related SSCs that perform safety significant functions.*
>
> *Risk-Informed Safety Class (RISC)-2 structures, systems and components (SSCs) means nonsafety-related SSCs that perform safety significant functions.*
>
> *Risk-Informed Safety Class (RISC)-3 structures, systems and components (SSCs) means safety-related SSCs that perform low safety significant functions.*
>
> *Risk-Informed Safety Class (RISC)-4 structures, systems and components (SSCs) means nonsafety-related SSCs that perform low safety significant functions.*
>
> *Safety significant function means a function whose degradation or loss could result in a significant adverse effect on defense-in-depth, safety margin, or risk.'*

This regulation provides for relaxation of specific special treatment requirements defined in the GDC of 10 CFR Part 50 for plants licensed under 10 CFR Part 50 and for design certifications under 10 CFR Part 52. In effect, this regulation provides a way to 'back-fit' risk insights into the traditional approach for safety classification by first performing a traditional safety classification according to 10 CFR §50.2, then performing a PRA, and expanding the two categories of safety class and non-safety class in terms of the above four safety significance categories.

PBMR recognizes this regulation as a reasonable way to back-fit risk-informed decision making for existing and evolutionary Light Water Reactor (LWR) plants that use the traditional deterministic approach to SSC safety classification. This regulation also provides an important precedent that acknowledges the ability to link special treatment requirements to the risk significance of an SSC. In deriving useful guidance from this regulation, the following issues need to be addressed: Since the traditional safety classification of SSCs has been defined in terms of LWR-specific DBEs and safety functions, this scheme would have to be revised to be applicable to the PBMR. In addition, the risk significance of SSCs that is factored into these categories is defined in terms of LWR specific risk metrics such as Core Damage Frequency (CDF) and Large Early Release Frequency (LERF). As discussed more fully in the companion paper on the PBMR PRA, the risk significance of SSCs for the PBMR must be defined in terms of PBMR-specific risk metrics. Finally, the idea that safety class and risk significance are orthogonal axes upon which to define these four safety significance categories will not be applicable to the PBMR. The fact that the LBEs are derived from the PRA and the process for their selection as described in the LBE paper will incorporate the risk-significant events into the design basis. Thus the need for having these four categories can be removed.

2.2 NRC POLICY STATEMENTS

2.2.1 Probabilistic Risk Assessment Policy Statement

On August 16, 1995, the Commission adopted the following Policy Statement regarding the expanded use of Probabilistic Risk Assessment (PRA) [4]:

> '(1) *The use of PRA technology should be increased in all regulatory matters to the extent supported by the state-of-the-art in PRA methods and data and in a manner that complements the NRC's deterministic approach and supports the NRC's traditional defense-in-depth philosophy.*
>
> *(2) PRA and associated analyses (e.g., sensitivity studies, uncertainty analyses, and importance measures) should be used in regulatory matters, where practical within the bounds of the state-of-the-art, to reduce unnecessary conservatism associated with current regulatory requirements, regulatory guides, license commitments, and staff practices.'*

The approach to performing the PBMR PRA in support of the DCA and the expected uses of the information provided by the PRA to support the licensing basis are consistent with the expectations in this policy statement. The PBMR DCA will address both the stated NRC intent to rely more on PRA methods, and the need to acknowledge and meet existing regulations.

2.2.2 Policy Issues Related to Certification of Non-Light Water Reactors

SECY-03-0047, 'Policy Issues Related to Licensing Non-Light Water Reactor Designs' [2] offers staff recommendations on seven relevant policy issues that had been originally defined in SECY-02-0139 [5]. Of the seven issues, Issue 4: 'To what extent can a probabilistic approach be used to establish the licensing basis?' specifically relates to the safety classification of SSCs:

'The staff recommends that the Commission take the following actions:

> *'Modify the Commission's guidance, as described in the Staff Requirements Memorandum (SRM) of July 30, 1993, to put greater emphasis on the use of risk information by allowing the use of a probabilistic approach in the identification of events to be considered in the design, provided there is sufficient understanding of plant and fuel performance and deterministic engineering judgment is used to bound uncertainties.*
>
> - *Allow a probabilistic approach for the safety classification of structures, systems, and components.'*
> - *Replace the single failure criterion with a probabilistic (reliability) criterion.*
>
> *This recommendation is consistent with a risk-informed approach. It should be noted that this recommendation expands the use of probabilistic risk assessment (PRA) into forming part of the basis for licensing and thus puts greater emphasis on PRA quality, completeness, and documentation.'*

The Commission approved this recommendation in its Staff Requirements Memorandum on SECY-03-0047 [6].

© Copyright 2006 by PBMR

The PBMR application will include a design-specific PRA and will demonstrate compliance with this staff recommendation. Risk information is being used and will be presented to support the 'probabilistic approach in the identification of events to be considered in the design'. The need for a quality PRA and 'sufficient understanding of plant and fuel performance' are acknowledged and will be addressed by other papers on the PBMR PRA approach, the verification and validation of evaluation models and code suites, fuel design and qualification, the development of the mechanistic source terms that will be used in the PRA, and in the deterministic safety analysis of DBEs. The integration of the PRA with and reliance upon deterministic analyses and engineering judgment will be demonstrated as discussed in the companion paper on the PBMR PRA approach. This includes a use of the PRA to evaluate the application of prevention and mitigation strategies as discussed in the paper on defense-in-depth [1]. The classification of SSC will follow a deterministic approach based on the LBEs derived from the PRA results as described in this paper. This approach is viewed by PBMR to be consistent with the NRC policy reflected in SECY-03-0047. Special treatment requirements will be defined to establish the necessary and sufficient reliability and capability to perform PBMR-specific safety functions defined in the LBEs, as described more fully in Section 3. Consistent with this policy statement, the PBMR approach to SSC classification and special treatment will not include application of the single failure criterion per se, but rather will apply redundancy as needed to provide an adequate level of reliability in the performance of safety functions and in the prevention and mitigation of accidents.

2.3 NRC GUIDANCE

NRC's guidance related to classification of SSCs generally parallels the NRC regulations discussed above. For example, Regulatory Guide 1.29 indicates that safety-related SSCs should be classified as Seismic Category I.

Additionally, for passive reactors, the NRC has established guidance governing the Regulatory Treatment of Non-Safety-Systems (RTNSS). This guidance is contained in documents such as SECY-93-087 [7], SECY-94-084 [8], and SECY-95-132 [9]. In summary, this guidance provides special treatment and other requirements for non-safety-related systems that perform important defense-in-depth functions to mitigate transients and accidents, commensurate with their importance to safety.

As explained more fully in Section 3, the PBMR approach to safety classification and special treatment of SSCs includes a category similar to RTNSS.

2.4 RECENT NRC PRECEDENTS INVOLVING GAS-COOLED REACTORS

In the late 1980s and early 1990s, the NRC conducted a pre-application review of the Modular High-Temperature Gas-Cooled Reactor (MHTGR) at the request of the Department of Energy (DOE). The DOE proposed to classify the TRISO fuel for the MHTGR as safety-related, but not the reactor coolant pressure boundary or the containment. In addition, the DOE proposed to use only the third of the three criteria in 10 CFR §50.2 (i.e. SSCs needed to mitigate accident doses comparable to those in 10 CFR §50.34) for the classification of safety-related MHTGR SSCs and not the other two criteria (i.e. reactor coolant pressure boundary and SSCs needed for safe shutdown).

The NRC addressed this position in SECY-93-092, *Issues Pertaining to the Advanced Reactor (PRISM, MHTGR, and PIUS) and CANDU 3 Designs and their Relationship to Current Regulatory Requirements* (April 8, 1993), Enclosure 1, page 28 [10] The NRC stated:

> *'The NRC LWR safety classification criteria are based on the fundamental regulatory standard to require defense in depth for a reactor design and to require safety-related SSCs to separately protect the three barriers to potential releases of fission product radioactivity to the public: the fuel, the reactor coolant pressure boundary, and the containment. This approach by definition requires that safety-related SSCs be identified to protect more than just one of the traditional barriers, e.g., more than just the fuel barrier to radionuclide transport.'*

The NRC repeated this conclusion when it published the results of its MHTGR review in NUREG-1338, *Pre-application Safety Evaluation Report for the Modular High-Temperature Gas-Cooled Reactor* [11]. In Sections 4.2.5 and 5.2.7 of NUREG-1338, the NRC stated that it would apply the LWR criteria for safety-related SSCs to the MHTGR, and it concluded that the DOE's classification approach did not satisfy the NRC's regulations governing the classification of safety-related SSCs. However, the NRC also stated that it would consider reduction of design, installation, and maintenance requirements for safety-related SSCs for the MHTGR during the design approval (which was never issued). The NRC also stated that it would apply the RTNSS to non-safety-related SSCs in the MHTGR.

In 2001 to 2002, the NRC staff conducted a pre-application review of the PBMR at the request of Exelon. In a letter to Exelon dated March 26, 2002 [12], the NRC staff provided its assessment of the licensing approach proposed by Exelon, including the TLRC. With respect to classification of SSCs, the NRC staff stated:

> *'In its licensing approach, Exelon proposes that an appropriate set of regulatory design requirements for treatment of safety-related SSCs be developed for each DBE [design basis event] on a case-by-case basis, and that risk-informed special treatment then be applied to the corresponding SSCs. . . . The approach proposed by Exelon is a novel approach that has not been previously considered by the staff in its risk-informed activities. Because Exelon's approach proposes to use frequencies and dose-consequences rather than CDF [core damage frequency] and LERF [large early release frequency] as risk metrics, it is not directly comparable with the risk-informed options currently being developed by the staff for risk-informing Part 50 regulations. The special treatment requirements for classified SSCs will be developed based on the required function for each DBE. The approach proposed by Exelon has the potential to impose special treatment requirements on equipment at the component level. Establishing requirements at the component level would present difficulties in documenting the design criteria for each component and establishing a consistent application of special treatment requirements on a system level. Also, while Exelon has stated that it does not anticipate the need for special treatment of SSCs solely for the purpose of preventing or mitigating EPBEs [emergency planning basis events], the staff emphasizes that SSCs relied on to avoid exceeding TLRC [top level regulatory criteria], or to keep the frequencies of similar event sequences within*

the acceptable range (e.g., within the AOO [anticipated operational occurrence], DBE, or EPBE range) should be classified as safety-related. The staff also expects that the treatment applied to safety-related SSCs should consider the limiting environment under which the SSCs must be available to perform their safety-related design function. In addition, Exelon's discussion of monitoring the performance of SSCs does not specifically address the monitoring of safety-related SSCs to identify unexpected equipment performance or to ensure that the regulatory design requirements are being met. Because Exelon proposes to use PRA [probabilistic risk assessment] to classify components as safety-related, there must be sufficient monitoring to ensure the validity of the SSC reliability and availability assumptions that are used in the engineering evaluation (i.e., PRA) underlying Exelon's safety-related classifications. The staff notes that the term safety-related may not be directly applicable to the PBMR concept, and that a more appropriate term may have to be developed. The staff will continue to pursue these issues with Exelon during the staff's pre-application review. (Enclosure, pp. 15-16)'

Following the Exelon review, the NRC staff provided the Commission a status report on the policy implications from licensing non-LWR designs and the staff's plans for seeking Commission guidance on resolving the issues. Three overarching policy issues and four policy issues of a more specific nature were discussed in SECY-02-0139 [13]. Of the seven issues, Issue 4: 'To what extent should a probabilistic approach be used to establish the plant licensing basis?' specifically relates to the safety classification of SSCs. In the Staff Requirements Memorandum on SECY-03-0047 [6], the Commission approved the staff's recommendation to allow a probabilistic approach for the safety classification of SSCs.

The NRC findings in these reviews for the DOE MHTGR and the Exelon PBMR licensing approaches have been taken into account in the formulation of the PBMR approach that is described in Section 3.

3. PBMR APPROACH TO STRUCTURES, SYSTEMS, AND COMPONENTS SAFETY CLASSIFICATION

This section describes the PBMR approach to SSC safety classification. Section 3.1 states the purpose for classifying SSCs. Section 3.2 describes the relation of safety classification to the other elements of the licensing approach. Section 3.3 enumerates the classification process with examples. Finally, Section 3.4 addresses the approach to special treatment requirements.

3.1 PURPOSE OF SAFETY CLASSIFICATIONS

Structures, Systems, and Components (SCCs) are classified relative to their safety significance to focus attention and resources on their design, construction, and operation commensurate with their safety significance.

3.2 RELATION OF SAFETY CLASSIFICATION TO OTHER ELEMENTS OF LICENSING APPROACH

The key elements of the PBMR licensing approach are provided in Table 1. Safety classification is one of the elements of the PBMR licensing approach that answers the question of ***how*** the TLRC are to be met during LBEs and deterministic Design Basis Accidents (DBAs). The relation of safety classification to the LBEs is discussed in Section 3.2.1 and the deterministic DBAs in Section 3.3.2. Safety Functions and Regulatory Design Criteria are complementary elements of the approach that also address the question of ***how*** the TLRC are met; they are addressed in Sections 3.2.2 and 3.3.3, respectively. The element of the licensing approach that provides assurance as to ***how well*** the TLRC are met is the Special Treatment Requirements, which is discussed in Section 3.4 following the discussion of the process for SSC safety classification in Section 3.3. Defense-in-depth is addressed in the companion paper [1].

Table 1: Elements of the PBMR Licensing Approach

Top Level Regulatory Criteria (TLRC)	Establish ***what*** must be achieved
LBEs Deterministic DBAs	Define ***when*** the TLRC must be met
Safety Functions Defense-in-Depth Regulatory Design Criteria Safety Classification of SSCs	Establish ***how*** it will be assured that the TLRC are met
Special Treatment Requirements	Provide assurance as to ***how well*** the TLRC are met

© Copyright 2006 by PBMR

3.2.1 Licensing Basis Events

Previous PBMR pre-application papers have discussed the selection of the LBEs [2] and [3] with the use of PRA. The process begins with identification of TLRC that are generic, quantitative measures of acceptable consequences or risks derived from NRC regulations. A full scope PRA of the PBMR identifies event sequences that are compared to the TLRC expressed in terms of frequencies and consequences. Event sequences expected to occur within a PBMR plant lifetime, where a plant is defined as up to eight reactor modules, are classified as AOOs. AOOs are evaluated against the dose limits of 10 CFR Part 20. Event sequences not expected to occur within a PBMR plant lifetime, but which might occur within a fleet of several hundred PBMR plants, are classified as DBEs. DBEs are conservatively evaluated against the dose limits of 10 CFR §50.34. The AOOs and DBEs are the event families from the PRA that would exceed the respective dose criteria were it not for some SSC or feature of the plant that mitigates the consequences. Rare events sequences with frequencies lower than DBEs are classified as BDBEs. BDBEs, together with the AOOs and DBEs, are collectively compared to the individual risk limits of the NRC Safety Goal Quantitative Health Objectives (QHOs). Figure 1 compares the LBEs selected from the preliminary PRA results of the 268 MWt PBMR Demonstration Power Plant (DPP) with the TLRC. The NRC acute fatality Safety Goal is shown on the plot as a bounding limit in that it is plotted at the Exclusion Area Boundary (EAB). If each BDBE meets this limit, the cumulative risk of all LBEs will meet the NRC Safety Goals with large safety margins as discussed in the next section. Table 2 provides the corresponding legend for the DBEs in the figure.

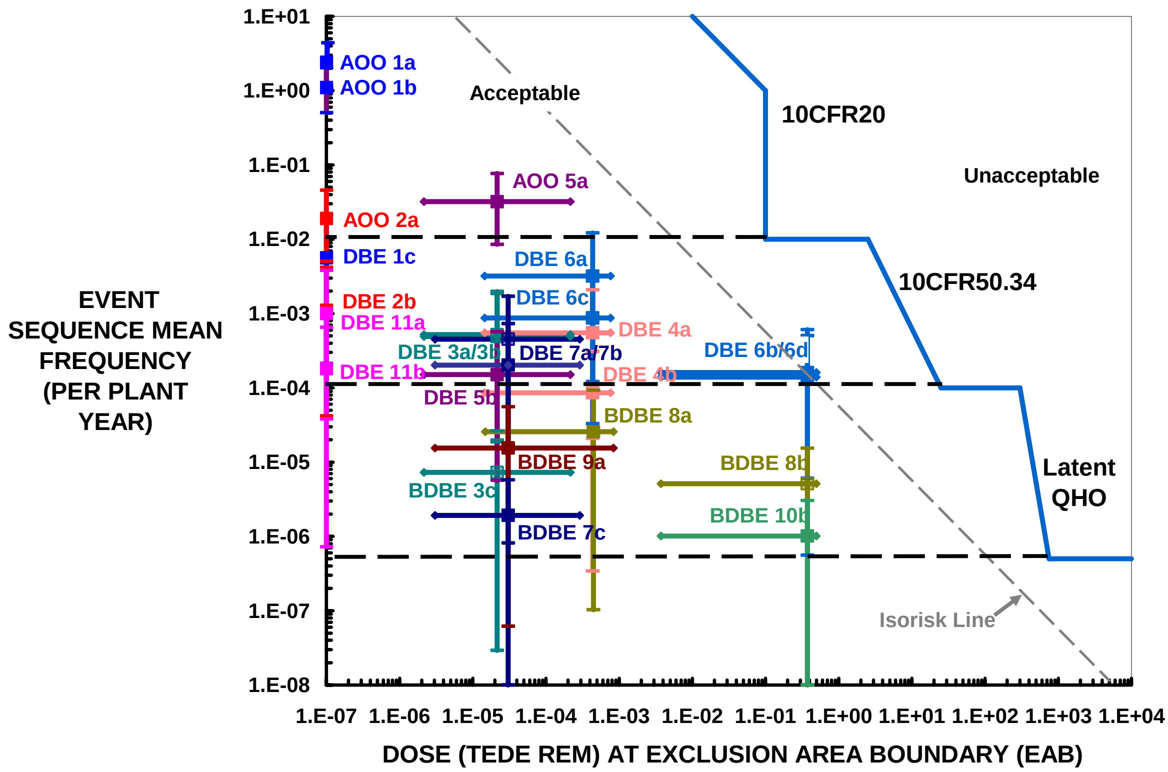


Figure 1: Frequency-Consequence Chart Comparing Licensing Basis Events for the 268 MWt PBMR Demonstration Power Plant to Top Level Regulatory Criteria

© Copyright 2006 by PBMR

Table 2: Identification of Design Basis Events in Preliminary Probabilistic Risk Assessment for the 268 MWt PBMR Demonstration Power Plant

DBE Designation	Design Basis Event Sequence
DBE-1c	Loss of Power Conversion Unit (PCU) with core conduction cooling to Reactor Cavity Cooling System (RCCS)
DBE-2b	Control rod withdrawal with Core Conditioning System (CCS) forced cooling
DBE-3a	Small, automatically isolated Helium Pressure Boundary (HPB) break with Start-up Blower System (SBS) forced cooling
DBE-3b	Small, manually isolated HPB break with CCS forced cooling
DBE-4a	Small, unisolated HPB break with depressurization with RCCS cooling
DBE-4b	Small, unisolated HPB break without depressurization with RCCS cooling
DBE-5b	Heat Exchanger (HX) tube break, manually isolated with RCCS cooling
DBE-6a	HX tube break unisolated with depressurization with RCCS cooling with filtered release
DBE-6b	HX tube break unisolated with depressurization with RCCS cooling with unfiltered release
DBE-6c	HX tube break unisolated without depressurization with RCCS cooling with filtered release
DBE-6d	HX tube break unisolated without depressurization with RCCS cooling with unfiltered release
DBE-7a	Medium, auto-isolated HPB break with SBS forced cooling
DBE-7b	Medium, isolated HPB break with CCS forced cooling
DBE-11a	Safe shutdown earthquake with SBS forced cooling
DBE-11b	Safe shutdown earthquake with CCS forced cooling

3.2.2 Safety Functions

Based on a review of the LBEs, safety functions needed to meet the TLRC are identified for the PBMR. Figure 2, which illustrates the top-level functions with emphasis on the reactor sources, includes functions needed for protection of both the public and on-site personnel.

As shown, the design includes functions for radionuclide retention within the fuel particles, fuel spheres, Helium Pressure Boundary (HPB), reactor building, and site. Not all of the functions in Figure 2 are required for each TLRC. Safety analyses have been performed to determine which are the required safety functions for the reactor sources, as identified as the minimum subset that is shaded, to keep the DBEs within the offsite dose limits of 10 CFR §50.34. The functions shown without shading are not required, but are included in the design to provide an element of defense-in-depth, and to meet user requirements for plant availability and investment protection. The required safety functions include those to:

- Maintain control of radionuclides
- Control heat generation (reactivity)
- Control heat removal
- Control chemical attack
- Maintain core and reactor vessel geometry
- Maintain reactor building structural integrity

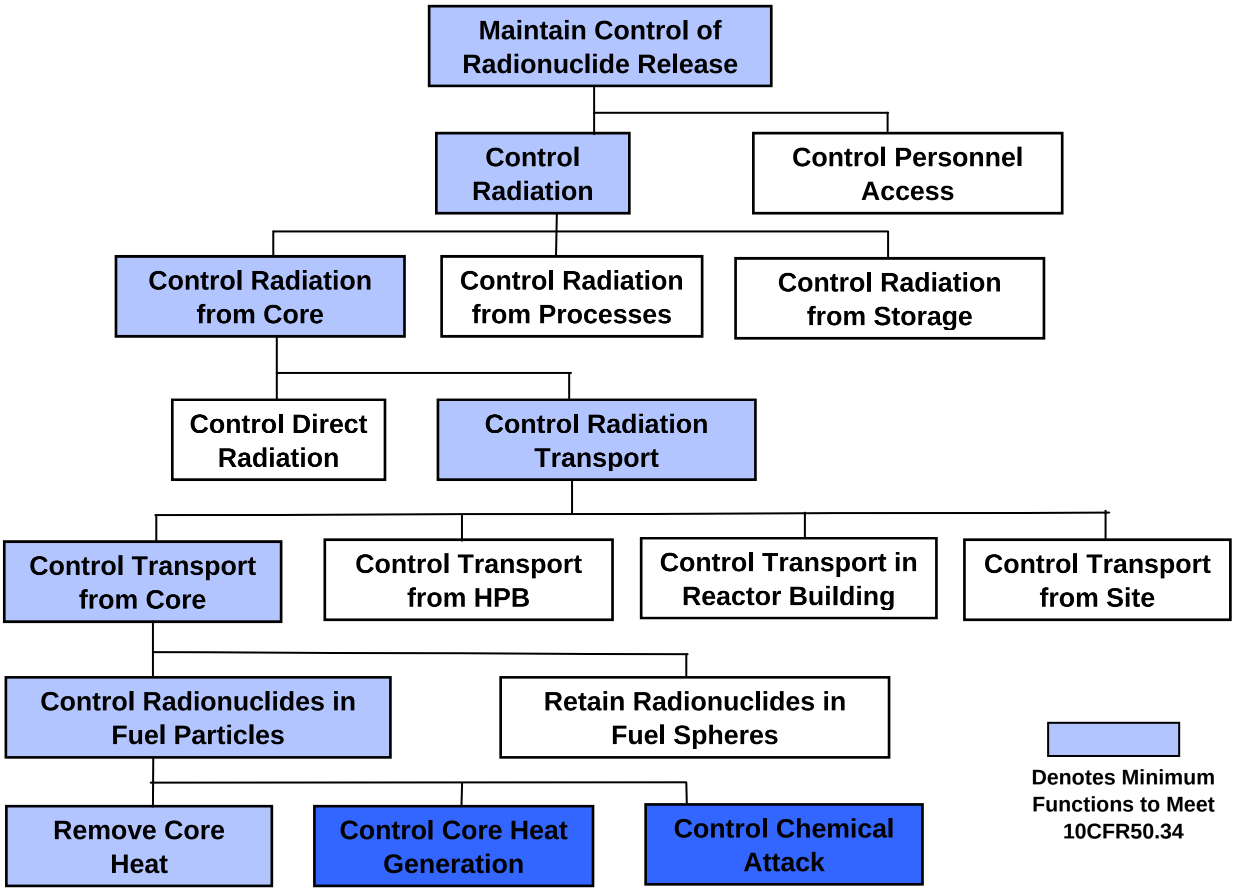


Figure 2: PBMR Safety Functions Needed during Licensing Basis Events to Meet Top Level Regulatory Criteria

3.3 PROPOSED SAFETY CLASSIFICATION PROCESS

Safety classification provides assurance that the frequency and consequences of the event sequences meet the TLRC. Section 3.3.1 discusses a generic example of two related LBEs that forms the basis for the criteria by which SSCs are classified. Sections 3.3.2 and 3.3.3 discuss the two criteria for classifying a set of SSCs as safety-related: SSCs that are relied on to perform the safety functions necessary to mitigate the consequences of DBEs are classified as safety-related; SSCs that are relied on to perform the safety functions which prevent high consequence BDBEs from increasing in frequency into the DBE region (where their consequences would be unacceptable) are also classified as safety-related. Examples are provided for the PBMR using the DBEs discussed in the prior papers [2] and [3].

The next sections discuss the approach to topics closely aligned with safety-related SSCs. Section 3.3.4 discusses the deterministic DBAs that will form the bases for the DCA safety analyses, and Section 3.3.5 discusses PBMR-specific Regulatory Design Criteria (RDC). Sections 3.3.6 and 3.3.7 discuss the two criteria for classifying a set of SSCs as non-safety-related with special treatment. Remaining SSCs are classified as non-safety-related with no special treatment.

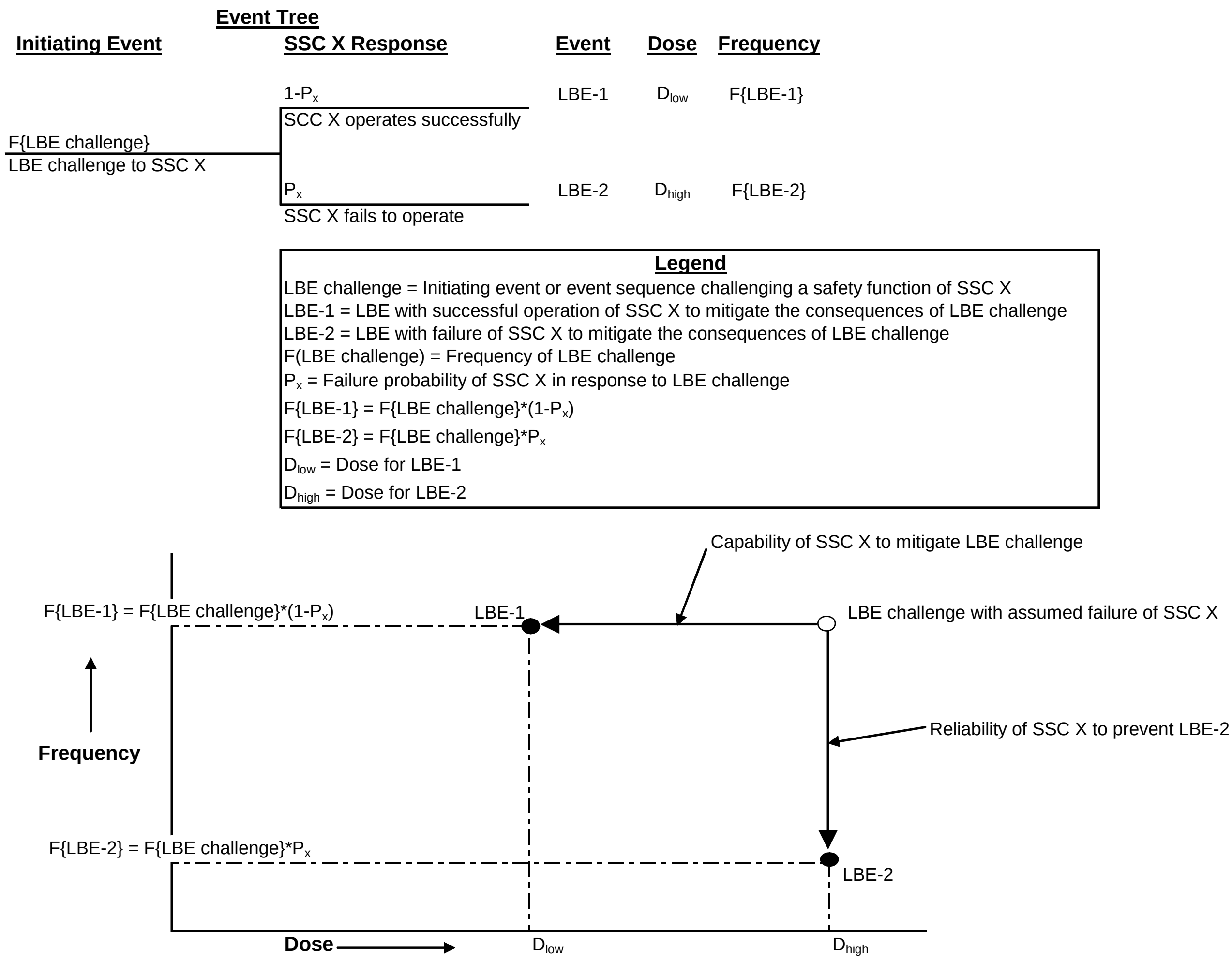
3.3.1 Basis for Criteria for Safety Classification

Safety classification of SSCs is made in the context of the performance of SSCs with respect to specific safety functions during the spectrum of LBEs. The safety classification process and the corresponding special treatment control the frequencies and consequences of the

LBEs within the TLRC. The LBE frequencies are a function of the frequencies of initiating events from internal events, internal and external hazards, and the reliabilities and capabilities of the SSCs (including the operator) to prevent an initiating event from progressing to an accident, to mitigate the consequences of an accident, or both to prevent the former and mitigate the latter. In some cases, the initiating events are failures of SSCs themselves, in which case the reliability of the SSC in the prevention of the initiating event needs to be considered. In other cases, the initiating events represent challenges to the SSC in question, in which case the reliability of the SSC to perform a safety function in response to the initiating event needs to be considered. Finally, there are other cases in which the challenge to the SSC in question is defined by the combination of an initiating event and combinations of successes and failures of other SSCs in response to the initiating event. All of these cases are included in the PRA and represent the set of challenges presented to a specific SSC.

A simple model of an SSC, referred to as SSC X, involved in two related LBEs, is illustrated in Figure 3. The simplified event tree at the top of this figure shows the relationship between these two LBEs. LBE-1 is the LBE in which SSC X successfully performs its safety function in response to an ‘LBE challenge’ event. The LBE challenge event could be an initiating event, or some combination of an initiating event and a combination of successes and/or failures of other SSCs in response to an initiating event. In LBE-2 the event tree sequence is that in which SSC X fails, according to some failure probability. The **capability** of SSC X to mitigate the consequences of the LBE challenge is measured by the differences in doses between LBE-1 and LBE-2. The **reliability** of the SSC in the performance of its safety function along LBE-1 is measured by the SSC failure probability, which is the difference in frequency between LBE-1 and LBE-2. Given a safety classification as discussed in the next sections, special treatment is specified to ensure that SSC X has the capability for mitigation and reliability for prevention that are sufficient so that LBE-1 and LBE-2 are within their respective TLRC.

© Copyright 2006 by PBMR



Frequency-Consequence Chart

Figure 3: Simple Model of a Structure, System or Component in Accident Prevention and Mitigation

3.3.2 Structures, Systems and Components Classified as Safety-Related for Mitigation during Design Basis Events

The first step in the process of classifying SSCs as safety-related is to determine the required safety functions. A delineation of the SSCs available to support the PBMR safety functions is provided in the companion paper on defense-in-depth. The required safety functions are the functions that need to be performed during DBEs for the dose limits of 10 CFR §50.34 to be met. The next step is for each required safety function to examine the DBEs to determine which SSCs are available and have sufficient capability. From the matrix of SSCs available for each safety function and all DBEs, a set of SSCs is classified as safety-related for a given required safety function to assure that it is accomplished. Considerations in this classification include the alternative set of SSCs that will be most readily shown with appropriate special treatment to have the capability and reliability needed.

Table 3 illustrates the process for the required safety function to remove core heat. For each DBE, the question is asked which possible SSCs or sets of SSCs are available and sufficient to remove core heat under the conditions of that DBE's initiating event and sequence of events. The availability of SSCs to mitigate an event is dependent on the specific DBE being evaluated. DBE-1c is initiated by a loss of the Power Conversion Unit (PCU) so that the first set of SSCs that removes core heat by forced cooling of the primary helium through the core to the PCU and transferring the heat to the Active Cooling System (Active Cooling System) water heat sink is not available for this event. The next two alternative sets of SSCs involving forced cooling with the Start-up Blower System (SBS) and the Core Conditioning System (CCS) are also not available, as indicated in the table. However, the next alternative set of SSCs is available. This alternative set does not provide forced core cooling, but removes heat from the core by passive conduction, convection, and radiation heat transfer mechanisms. Core heat is removed radially through the reactor vessel and then by radiation and convection to the active mode of the surrounding standpipes of the Reactor Cavity Cooling System (RCCS), which transfers the heat by pumping water to heat exchangers shared with a separate loop of the ACS. As indicated by the bold italics, this is the definition of DBE-1c. However, there are also other similar alternatives that rely on heat removal by passive means from the reactor vessel, which are available and sufficient to remove the core heat. The next alternative shown is the successful operation of the passive mode of the RCCS that is designed to transfer the heat by boiling off the water inventory in its stored tanks. The final alternative is heat dissipation to the reactor building walls and surrounding ground heat sinks.

In a similar fashion, the alternative sets of SSCs for heat removal are reviewed for the other DBEs, as indicated in the columns of the table. The event described above, DBE-1c, involves heat removal with the reactor immediately shut down. DBE-1c includes contributors from internal events that cause the loss of the PCU as well as external events such as the loss of the offsite power. DBE-2b involves heat removal with the initiating event of a group of control rods withdrawn. DBE-6c involves conduction heat transfer with the helium coolant depressurized. DBE-11b is for an external event of the SSE. Thus, by examining the spectrum of internal and external events, the full set of conditions and requirements applicable to the alternative sets of SSC is explicitly considered.

After filling in the table column-by-column, the results are reviewed. If there is no alternative set of SSCs that is sufficient and available for each DBE (i.e. there is not at least one row with all ‘Yes’), then the design is changed or alternatives are grouped together as required and the resultant alternative set of SSC is classified as safety-related. If there is one alternative set that is available and sufficient for all DBEs, it is classified as safety-related. If there is more than one alternative set of SSC that is determined to be available and sufficient, the set that is selected as the safety-related set is the one that reflects the highest level of confidence that it will perform its required safety function. In this example, the PBMR has three sets of SSCs that are available and sufficient to remove core heat in all the DBEs: one with the active mode of the RCCS, one with the passive mode of the RCCS, and one without the RCCS. The passive mode RCCS set of SSCs is selected, as indicated in the diagram, as the one to be relied on for core heat removal, since it is the simplest and expected to be the most reliable. The heat removal to the building and ground is also passive, but results in a plant investment loss and involves more assumptions and greater uncertainties in the analyses. Hence, a factor in the selection is the ability to reduce the uncertainties and to apply the principles of defense-in-depth.

© Copyright 2006 by PBMR

Table 3: Example of Safety Classification Process for Required Safety Function to Remove Core Heat[1]

Are SSCs Available and Sufficient to Remove Core Heat in the DBE?							SSCs Classified as Safety Related?
Alternative Sets of SSCs	**DBE 1c**	**DBE 2b**	**DBE 6c**	**DBE 7a**	**DBE 7b**	**DBE 11b**	
Reactor PCU ACS	***No***	***No***	***No***	***No***	***No***	***No***	
Reactor SBS ACS	***No***	***No***	***No***	***Yes***	***No***	***No***	
Reactor CCS ACS	***No***	***Yes***	***No***	Yes	***Yes***	***Yes***	
Reactor Reactor vessel Active RCCS ACS	***Yes***	Yes	***Yes***	Yes	Yes	Yes	
Reactor Reactor vessel Passive RCCS	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Reactor Reactor vessel Building & ground	Yes	Yes	Yes	Yes	Yes	Yes	

Note: ***Italics*** indicates response during DBE

[1]Example based on preliminary PRA for the 268 MWt PBMR Demonstration Power Plant

A second required safety function to *control heat generation* is shown in Table 4. As indicated, the reactor's negative temperature coefficient is available in all DBEs. In addition, other control and protection systems are available, depending on the event, to insert the Reactivity Control System (RCS) control rods or Small Absorber Spheres (SAS) of the Reserve Shutdown System (RSS). In most DBEs, the Equipment Protection System (EPS) successfully inserts the control rods. For DBE-2b, the inadvertent withdrawal of a group of control rods, the Reactor Protection System (RPS) will respond by releasing the control rods to insert by gravity. In all DBEs the operator has time (i.e. on the order of tens of hours) to manually actuate either the control rods or the SAS. And finally, no action could be taken with complete reliance on the negative temperature coefficient to initially shut the reactor down and, in the longer term, after tens of hours of xenon decay, to maintain the reactor at an acceptable fuel temperature, albeit with the generation of a small amount of power. (Note that these options again reflect defense-in-depth.) Of these alternatives, the negative temperature coefficient and the manual insertion of the control rods is selected as safety-related, since this is the most fundamental and reliable choice for immediate and long-term control of heat generation, and is therefore the alternative that is judged to perform its required safety function with the highest level of confidence.

© Copyright 2006 by PBMR

Table 4: Example of Safety Classification Process for Required Safety Function to Control Heat Generation[1]

Are SSCs Available and Sufficient to Control Heat Generation in the DBE?								SSCs Classified as Safety Related?
Alternative Sets of SSCs	**DBE 1c**	**DBE 2b**	**DBE 3a**	**DBE 4a**	**DBE 5a**	**DBE 6a**	**DBE 11a**	
Reactor neg temp coeff EPS RCS control rods	***Yes***	***No***	***Yes***	***Yes***	***Yes***	***Yes***	***Yes***	
Reactor neg temp coeff RPS RCS control rods	***No***	***Yes***	***No***	***No***	***No***	***No***	***No***	
Reactor neg temp coeff Operator action RCS control rods	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Reactor neg temp coeff Operator action RCS SAS	Yes	Yes	Yes	Yes	Yes	Yes	Yes	
Reactor neg temp coeff	Yes	Yes	Yes	Yes	Yes	Yes	Yes	

Note: ***Italics*** indicates response during DBE

[1]Example based on preliminary PRA for the 268 MWt PBMR Demonstration Power Plant

3.3.3 Structures, Systems and Components Classified as Safety-Related for Prevention during High Consequence Beyond Design Basis Events

BDBEs are events that are analyzed with all the plant SSCs considered realistically, i.e. presumed available in the PRA according to their reliability and availability following each initiating event. Since some BDBEs may have consequences above those for DBEs and still comply with the NRC Safety Goal QHOs, assurance should be provided that the frequency of high consequence BDBEs remains below the lower frequency of the DBE region. Any BDBEs with consequences above the DBE region's dose limits of 10 CFR §50.34 are reviewed to determine which safety functions are preventing them from increasing in frequency into the DBE region where their consequences would be unacceptable. The alternative sets of SSCs available and sufficient to perform the functions that keep a high consequence BDBE frequency very low are identified and, if needed, one set is classified as safety-related.

As shown in Figure 1, there are no BDBEs expected for the PBMR DPP with consequences greater than the DBE region's dose limits of 10 CFR §50.34. Nevertheless, this process will be followed for the multi-module PBMR DCA design to confirm that multiple modules do not introduce a plant level BDBE event that exceeds 10 CFR §50.34 dose limits.

The safety classification process for mitigating DBEs and preventing high consequence BDBEs has been carried out for the required safety functions of the PBMR. The preliminary list of PBMR safety-related SSC and their corresponding safety functions is shown in Table 5.

Table 5: Preliminary Listing of PBMR Safety-Related Structures, Systems and Components

Specific SSC Selected as Safety-Related	Required Safety Function Performed by SSC
Fuel	Retain radionuclides Control heat generation (Reactor negative temperature coefficient in Table 4)
Fuel and Graphite Spheres	Remove core heat (Reactor in Table 3) Control heat generation (Reactor negative temperature coefficient in Table 4)
Reactivity Control System	Control heat generation
Reactor Core Structure	Remove core heat (Reactor in Table 3) Control heat generation (Reactor negative temperature coefficient in Table 4) Maintain core geometry
Core Barrel	Remove core heat (Reactor in Table 3) Maintain core geometry
Reactor Vessel	Remove core heat Maintain core geometry Control chemical attack
Reactor Cavity Cooling System	Remove core heat
Reactor Building and Citadel	Maintain core geometry

3.3.4 Deterministic Design Basis Accidents

As addressed more fully in the paper on the selection of LBEs [3], deterministic DBAs are identified from the DBEs by assuming that only SSCs classified as safety-related are available to perform the safety functions required to meet 10 CFR §50.34 dose limits. After the safety-related SSCs are selected, all of the DBEs are reanalyzed deterministically with only the safety-related SSCs responding in a mechanistically conservative manner.

The deterministic DBAs generally do not have the same sequence of events as the corresponding DBEs, since the latter consider the expected plant response with all SSCs responding, whether safety-related or not. Note that the deterministic DBAs are the analog of the traditional LWR DBAs analyzed in Safety Analysis Report (SAR) Chapter 15. A key advantage in the PBMR approach is that the safety-related SSCs with their basis rooted in PRA are designed for the expected response of the entire plant (for the DBE sequence families) as well as the safety-related response (the deterministic DBAs). Furthermore, the approach allows the transition to be made to the traditional deterministic response with only safety-related SSCs responding to deterministic DBAs and all SSCs responding to DBEs, so that both the conservative and expected plant behaviour are properly modeled.

Table 6 provides the list of deterministic DBAs and their relation to the DBEs. For example, DBE-5b is the event sequence family in which the Heat Exchanger (HX) break is manually isolated. In the corresponding deterministic DBA-6, the safety-related response of the plant does not have this operator action.

Table 6: Relation of PBMR Deterministic Design Basis Accidents to Design Basis Events

DBE Designation	Design Basis Event	Deterministic DBA Designation	Deterministic Design Basis Accident
DBE-1c	Loss of PCU with core conduction cooling to RCCS	Deterministic DBA-1	Loss of PCU with core conduction cooling to passive mode of RCCS
DBE-2b	Control rod withdrawal with CCS forced cooling	Deterministic DBA-2	Control rod withdrawal with core conduction cooling to passive mode of RCCS with unfiltered release
DBE-3a	Small, automatically isolated HPB break with SBS forced cooling	Deterministic DBA-3	Small, unisolated HPB break with core conduction cooling to passive mode of RCCS with unfiltered release
DBE-3b	Small, manually isolated HPB break with CCS forced cooling		
DBE-4a	Small, unisolated HPB break with pumpdown with RCCS cooling	Deterministic DBA-4	Small, unisolated HPB break with core conduction cooling to passive mode of RCCS with unfiltered release
DBE-4b	Small, unisolated HPB break without pumpdown with RCCS cooling		
DBE-5b	HX tube break, manually isolated with RCCS cooling	Deterministic DBA-6	HX tube break, unisolated with core conduction cooling to passive mode of RCCS with unfiltered release
DBE-6a	HX tube break unisolated with pumpdown with RCCS cooling with filtered release		
DBE-6b	HX tube break unisolated with pumpdown with RCCS cooling with unfiltered release		
DBE-6c	HX tube break unisolated without pumpdown with RCCS cooling with filtered release		
DBE-6d	HX tube break unisolated without pumpdown with RCCS cooling with unfiltered release		
DBE-7a	Medium, automatically isolated HPB break with SBS forced cooling	Deterministic DBA-7	Medium, unisolated HPB break with core conduction cooling to passive mode of RCCS
DBE-7b	Medium, isolated HPB break with CCS forced cooling		
DBE-11a	Safe shutdown earthquake with SBS forced cooling	Deterministic DBA-11	Safe shutdown earthquake with core conduction cooling to passive mode of RCCS
DBE-11b	Safe shutdown earthquake with CCS forced cooling		

Even with the consolidation of the DBEs into a smaller number of deterministic DBAs, there is still a spectrum of challenges that must be addressed based on the initiating event and on the progression of the event sequence. Furthermore, as with the DBEs, a deterministic DBA with no consequences, such as DBA-1, is just as important as the one with the highest predicted consequences in terms of identification of SSCs that should be classified as safety-related.

3.3.5 Regulatory Design Criteria

Regulatory Design Criteria (RDC) are statements written at a functional level to describe the requirements for SSCs performing the required safety functions needed during DBEs to assure compliance with 10 CFR §50.34. The RDC are similar in nature and purpose to the LWR GDC in 10 CFR Part 50, Appendix A, and address PBMR-specific safety functions not addressed in the GDC. The RDC have a one-to-one correspondence to the required safety functions (for example, those shaded in Figure 2).

Examples of RDC from the MHTGR licensing process are provided in [11] (designated there as 10 CFR Part 100 design criteria). The two that correspond to the two examples in the previous section are:

- **Remove Core Heat:** The intrinsic dimensions and power densities of the reactor core, internals, and vessel, and the passive cooling pathways from the core to the environment shall be designed, fabricated, and operated such that the fuel temperatures will not exceed acceptable values.
- **Control Heat Generation:** The reactor shall be designed, fabricated, and operated such that the inherent nuclear feedback characteristics ensure that the reactor thermal power will not exceed acceptable values. Additionally, the reactivity control system(s) shall be designed, fabricated, and operated such that during insertion of reactivity the reactor thermal power will not exceed acceptable values.

Regulatory design criteria are also written for lower-level functions that provide additional specificity. For example, design criteria are developed for sub-functions to the function remove core heat: conduct heat from core to vessel wall, radiate heat from vessel wall, maintain geometry for conduction and radiation, and transfer heat to ultimate heat sink.

3.3.6 Structures, Systems and Components Classified as Non-Safety-Related with Special Treatment for Mitigation of Anticipated Operational Occurrences

Since by definition AOOs are expected to occur in the plant lifetime, operational measures will be implemented to assure that the 10 CFR Part 20 dose limits are not exceeded for these events. In an analogous fashion to the mitigation of DBEs, the functions that are needed to meet 10 CFR Part 20 dose limits for AOO events are determined from a review of the PRA. The SSCs available to perform each of these safety functions are reviewed to select a set to receive greater attention from a risk, safety margin, and defense-in-depth perspective and are classified as NSRST. These SSCs are subject to the special treatment options discussed in Section 3.4.

3.3.7 Structures, Systems and Components Classified as Non-Safety-Related with Special Treatment for Prevention of High Consequence Design Basis Events

Since DBEs can have consequences above those acceptable for AOOs, assurance must be provided that the frequency of those with consequences greater than the 10 CFR Part 20 dose limits for the AOO region is as low as predicted. SSCs performing the prevention safety functions (i.e. SSCs whose successful operation would prevent the occurrence of a DBE) are candidates for classification as NSRST. The first step in the process is to identify DBEs with consequences higher than the 10 CFR Part 20 dose limits. The next step is to determine the prevention safety functions for these higher consequence DBEs. The final step is to select a set(s) of SSCs that will receive special treatment that perform each of those functions.

DBE 6b and 6d in Figure 1 are shown to have consequences that are acceptable relative to the 10 CFR §50.34 dose limits. However, if their frequencies were higher and they were in the AOO region, they would exceed the 10 CFR Part 20 dose limits. Figure 4 provides the abbreviated event tree for these DBEs that are initiated with a small leak in the pre-cooler or intercooler heat exchangers of the Main Power System (MPS) of the PBMR. As shown, the leak is not isolated in DBE-6a-d and heat removal is by conduction cooldown to the RCCS. In two of the sequences, DBE-6a and 6b, the operator successfully depressurizes the primary helium to helium storage to mitigate the release of the circulating activity out through the leak in the HPB into the reactor building. The more important response in terms of consequence mitigation is whether the reactor building Heating Ventilating and Air Conditioning (HVAC) filters function successfully. In DBE-6b and 6d, the system fails and the delayed release from the heat-up of the fuel is not filtered, which leads to their relatively higher consequences.

Therefore, from an inspection of the DBE sequences and the corresponding consequences, to keep the frequency of DBE-6b and 6d below the AOO region, one or more of the following safety functions are required:

- Prevent the delayed radionuclide release from the fuel.
- Retain radionuclides from the delayed release within the reactor building.

The option available for the first function is to provide forced cooling so that the fuel does not heat up in its passive conduction cool-down mode. However, in the DPP design for this example, the CCS is not designed to operate with an unisolated leak in the MPS HXs. (An alternative strategy would be to specify a capability for the CCS to operate with an unisolated MPS HX leak. However, in this example, such a capability is not assumed.) The option available for the second function is the set of SSCs that provide filtering with the HVAC. Those SSCs are classified as non-safety-related with special treatment. Special treatment, as discussed in Section 3.4, would be applied to the filters and associated SSCs needed for successful operation during these high consequence events. This may have the added benefit of providing assurance of their capability and reliability for operation in other events too.

Another important step for this classification category is to review the basis for the frequencies and consequences of the PRA upon which the LBE selection has been made to determine if it includes any SSCs that have special treatment. If so, the influence of the special treatment on the reliability and capability of these SSCs needs to be evaluated in terms of whether the events would remain in the LBE category if the PBMR classification and corresponding special treatment were relaxed or increased.

© Copyright 2006 by PBMR

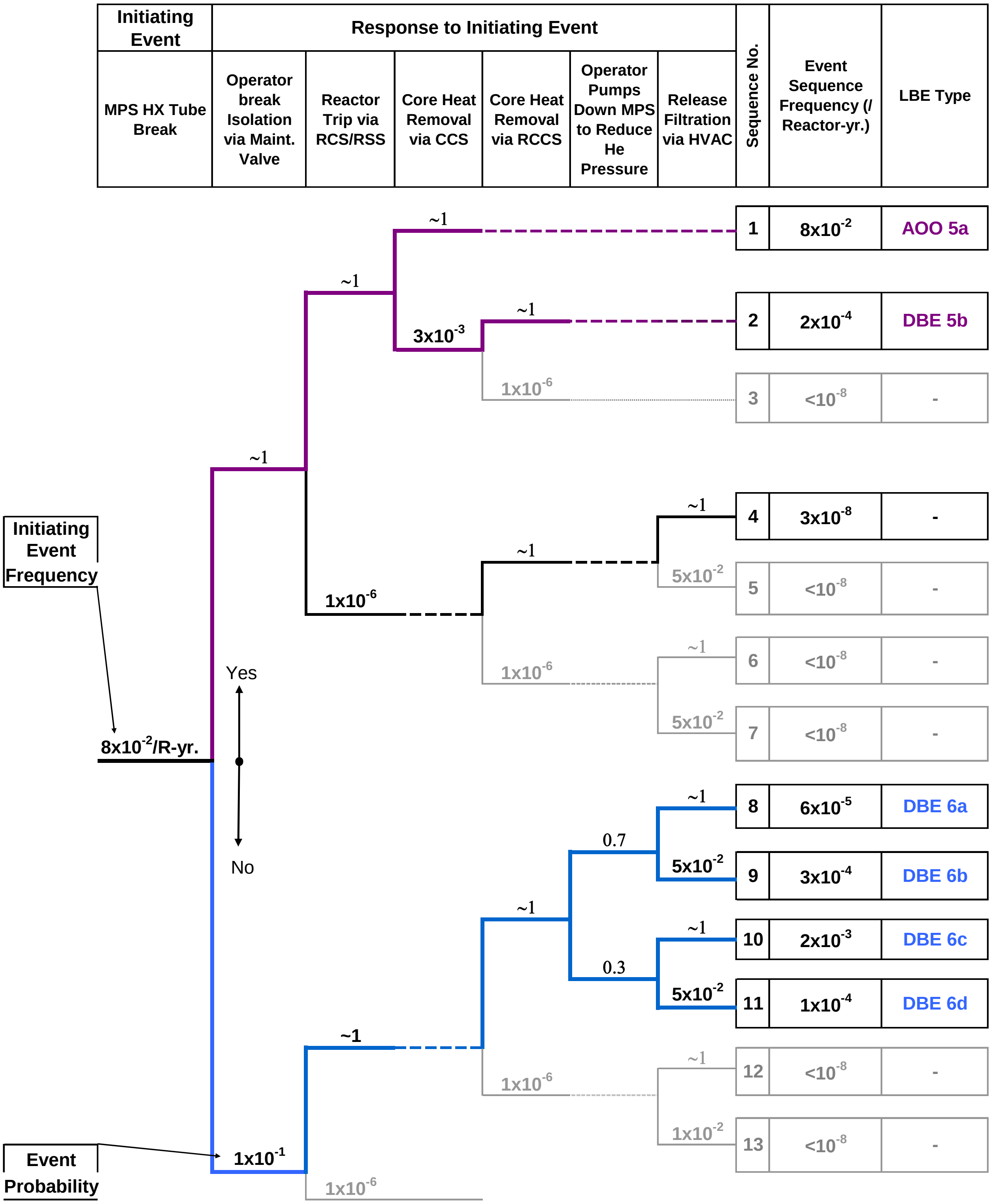


Figure 4: Abbreviated Event Tree for PBMR Main Power System Heat Exchanger Initiating Event

3.4 APPROACH TO SPECIAL TREATMENT

The purpose of special treatment requirements is twofold: Firstly, special treatment helps ensure that the reliability and capability of each safety-related SSC are necessary and available in the prevention and mitigation of LBEs. The requirements for the reliability and capability of safety-related SSCs are derived from the frequencies and consequences of the

LBEs that correspond to the SSCs in relation to the TLRC. Secondly, special treatment requirements increase the confidence that the safety-related SSCs will perform their safety functions in light of uncertainties about the reliabilities and capabilities of these SSCs. Hence, special treatment requirements help ensure that the frequencies and consequences of the LBEs fall within the TLRC as well as reduce the uncertainties about SSC reliability and performance in the context of the safety functions they perform in preventing and mitigating LBEs. The purpose of the special treatment is to increase the level of assurance that the SSCs will perform as predicted in the PRA under expected LBE conditions with the assessed uncertainties and in the DCA for conservative deterministic DBA conditions. As such, the special treatment requirements are an important element of defense-in-depth.

Section 3.4.1 describes the relationships among the reliability and capability of SSCs in each safety classification, the frequencies and consequences of the LBEs, and the TLRC. Special treatment requirements vary for SSCs depending on their safety classification. Section 3.4.2 addresses the special treatment for the safety-related SSCs and Section 3.4.3 for the non-safety-related with special treatment category.

3.4.1 Reliability and Capability of Structures, Systems and Components in the Prevention and Mitigation of Licensing Basis Events

As discussed in Section 3.3, SSCs may participate in LBEs in one or more of the regions of the TLRC frequency-consequence chart. This participation includes those LBEs in which the SSC performance mitigates the consequences of the challenge, as well as those in which its reliability helps to reduce the LBE frequency and higher consequences LBEs. Generic LBE examples from all three SSC safety classification categories, safety-related, non-safety-related with special treatment, and non-safety-related, are shown in Figure 5. SSC A is an example of an SSC whose successful performance is necessary to mitigate the consequences of an AOO and to prevent a corresponding DBE whose consequences exceed the AOO dose criteria. Special treatment applied to this category of SSC helps to control the corresponding LBEs (AS and AF) within their respective LBE categories. An assumed degradation in performance of component A with respect to its mitigation capability would result in the frequency and dose of event AS approaching that of challenge A. An assumed degradation in the reliability of this SSC would also result in the frequency and dose of event AF approaching that of challenge A. In the extreme case of degradation, both events would track to challenge A.

By varying the LBE frequency along the path from point AF to challenge A, one may simulate degradation of the SSC in comparison to what was predicted in the PRA, or one may investigate the impact of uncertainties in the assumed reliabilities of the SSCs. Hence, special treatment measures may not only change the locations of the LBEs on the frequency-dose plot, but also may reduce the uncertainty on the associated frequencies and doses.

SSC B shows a similar behavior through the relationships among events BS, BF, and challenge B for the safety-related. SSC B is classified as safety-related because its mitigation capability is necessary to keep the doses of DBEs within the limits specified in 10 CFR §50.34, and its reliability is necessary to prevent the high consequence BDBE from moving into the DBE region where its consequences would be unacceptable.

SSC C is an example of an SSC that is classified as non-safety-related because its corresponding LBEs are within the TLRC even when severe degradation of its performance is assumed.

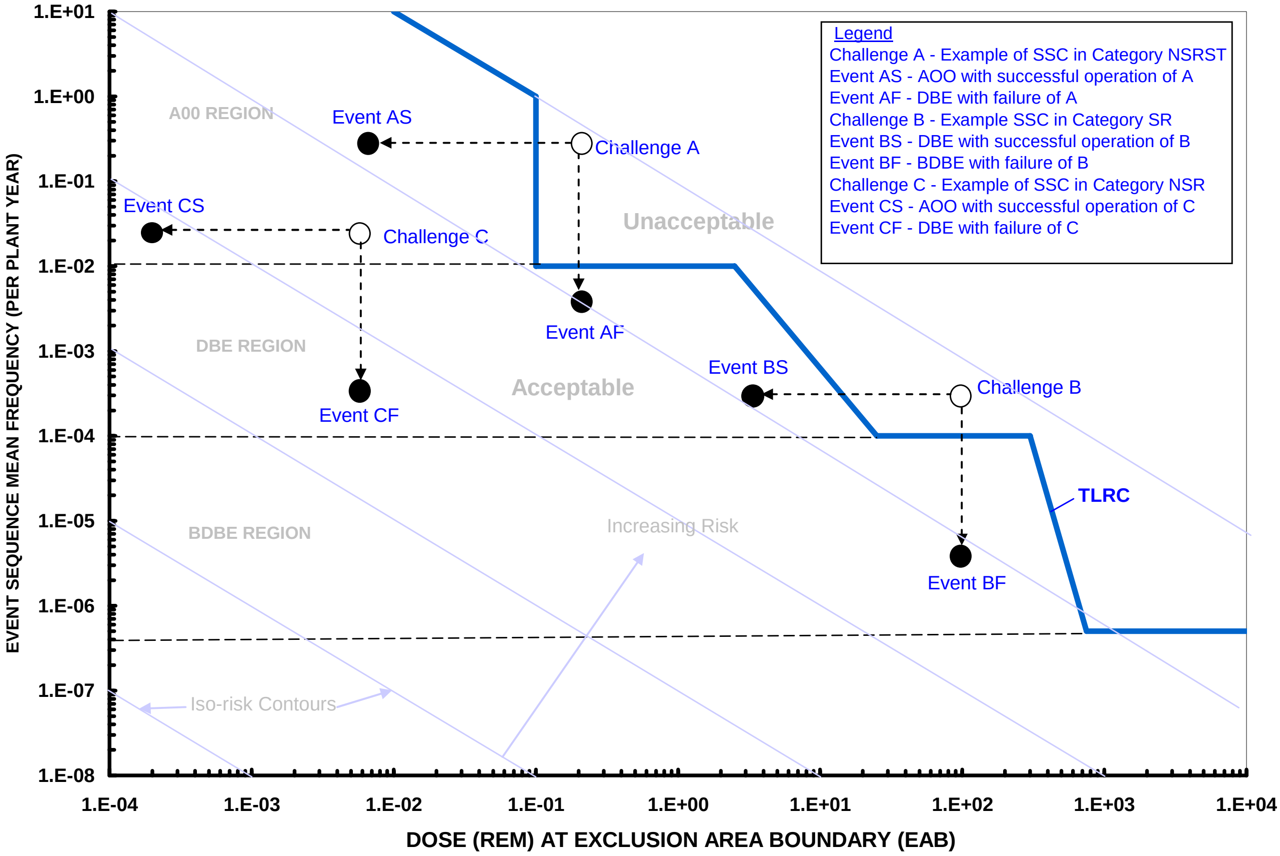


Figure 5: Impact of Safety Classified Structures, Systems and Components in Prevention and Mitigation of Licensing Basis Events

3.4.2 Special Treatment for Safety-Related Structures, Systems and Components

The special treatment for the safety-related category of classification is commensurate with that needed for the SSCs to achieve their capability and reliability requirements during DBEs to meet the 10 CFR §50.34 dose limits. Capability requirements are derived from accident mitigation considerations, whereas reliability requirements are derived from accident prevention considerations as illustrated with the examples of the previous section. Special treatment measures for this category focus on both the capability of SSCs to mitigate DBEs and the reliability of SSCs to prevent high consequence BDBEs. These measures begin by establishing the capabilities of the SSCs that are ascribed in the PRA to the successful performance of safety functions during DBEs and the reliability requirements that are needed to prevent high consequence BDBEs. The elements of the special treatment requirements for safety-related SSCs are listed in Table 7. These include the elements of special treatment that are included in 10 CFR Part 50 for safety-related SSCs in currently licensed reactors.

Since the PBMR safety design approach places emphasis on retention of radionuclides within the fuel during normal operation and all LBEs, it is anticipated that the full spectrum of special treatment will be employed in the design, manufacture, and operation of the fuel. Operational monitoring will be of particular importance.

Further, since the PBMR safety design relies on inherent characteristics of primarily passive components and structures to perform the required safety functions to retain the radionuclides in the fuel, the special treatment measures appropriate and effective for passive components will be employed.

© Copyright 2006 by PBMR

The special treatment for the safety-related SSCs is keyed to the required safety functions during the deterministic DBAs. For example, for the reactor vessel, there are three required safety functions as shown in Table 5:

- Remove core heat
- Maintain core geometry
- Control chemical attack

Thus, for the spectrum of deterministic DBAs in Table 6, the reactor vessel must be available and sufficient to remove core heat by conduction and radiation, which will require specific and focused special treatment measures such as the use of appropriate codes and standards for vessel design, manufacture, construction, and pre-service and in-service inspection. For maintaining core geometry or control of chemical attack, similar special treatment measures will apply, but their focus and the specifics will be different, as they will be keyed to their specific safety functions during specific DBEs.

3.4.3 Non-Safety-Related with Special Treatment Structures, Systems and Components

The special treatment for the non-safety-related with special treatment category of SSCs is also commensurate with that needed for the SSCs to perform their capability and reliability requirements during AOOs. As noted in the previous section, the LBEs for this category of SSCs are inherently more frequent and pose less severe challenges on the SSC than those for the safety-related category. Importantly, SSCs in this category do not have to perform required safety functions during DBEs in order to meet the 10 CFR §50.34 dose limits, whereas the safety-related SSCs are relied on to meet this requirement. Due to the high frequency of the events, the level of uncertainty in predicting the SSC performance and reliability is also less than for the safety-related SSCs. Hence, the special treatment requirements are more modest. In addition, the degree of reliability required of these SSCs is less than is the case with safety-related SSCs. Hence, the special treatment that is needed to provide the necessary reliability and capability is less than is the case with the safety-related category.

The elements of the special treatment measures for this category of SSCs are presented for comparison with the corresponding elements for the safety-related category in Table 7. As with the safety-related category of SSCs, this category begins by defining the capabilities and reliabilities of the SSCs that are needed to enforce the design and reliability assumptions in the PRA and to meet the TLRC as discussed in the previous section. Seismic design requirements for this category are limited to those associated with relatively high frequency seismic events which do not require seismic qualification testing. In contrast, safety-related SSCs must be capable of performing their safety function during design basis seismic events. Note that even when an element of special treatment is applied to NSRST classified SSCs, the specific requirements refer to a different set of LBEs to prevent and to mitigate in comparison with the safety-related category, and hence the specific requirements will be different.

Referring back to the example SSCs and their associated LBEs in Figure 5, it should be noted that special treatment measures in Table 7 include those that determine the location of the points on the frequency-dose plot, and also reduce the uncertainties associated with the LBE frequencies and doses. Hence, the process of assigning SSCs to safety classes and defining special treatment requirements is not only a function of the PRA expected results, but also a function of the uncertainties in the PRA results and the underlying models and assumptions. In some cases, special treatment may be applied to enforce assumptions made in the PRA about the characteristics of SSCs that are modelled as well as those that may be screened out due to a low frequency of occurrence.

Note that the SSCs in this category serve a role of preventing DBEs, and hence of preventing challenges to the safety-related SSCs. The special treatment requirements for the safety-related SSCs are defined in a manner so as to be both necessary and sufficient to ensure that the consequences of DBEs are adequately mitigated and that any BDBEs with potentially high consequences are adequately prevented. When special treatment is applied to the NSRST classified SSCs, such treatment applies an additional element of prevention for these same DBEs and BDBEs. The safety classification and the approach to defining special treatment measures provide an important element of defense-in-depth for the PBMR by strengthening the strategies of accident prevention and mitigation.

Table 7: Elements of Special Treatment for Safety-Related and Non-Safety-Related with Special Treatment Structures, Systems and Components

Special Treatment Requirements	Safety-Related SSCs	Non-Safety-Related with Special Treatment SSCs
Design requirements for SSC capabilities to mitigate specific LBE challenges	√√	√
Numerical targets for SSC reliability and availability to perform safety functions	√√	√
Design requirements for independence, redundancy, and diversity	√√	√
Design requirements for safety margins and design conservatism	√√	
Codes and Standards for design, material procurement, fabrication, construction, and operation	√√	√
Seismic design basis	√√	√
Seismic qualification testing	√√	
Equipment qualification testing	√√	
Quality Assurance and Quality Control	√√	√
Operational performance monitoring	√√	√
Operational controls	√√	√
Technical specifications	√√	√
Materials surveillance testing	√√	
Pre-service and In-service inspection	√√	√
Pre-service and In-service testing	√√	

Notes:

√√ Indicates a level of special treatment for safety-related SSCs.

√ Indicates a lower level of special treatment for NSRST classified SSCs due to more frequent and less severe challenges.

4. ISSUES FOR PRE-APPLICATION RESOLUTION

The issues addressed in this paper are framed in terms of the following questions about the safety classification of SSCs that will be performed to support the PBMR DCA. The PBMR position on the appropriate response to these questions has been discussed in detail in Section 3 and is summarized below following the listing of each question.

1. What is the role of safety classification of SSCs in the risk-informed performance-based licensing approach for the PBMR?

PBMR Response: Safety classification is used to assist in defining the special treatment to assure that SSCs are capable of preventing and mitigating LBEs. Special treatment is applied to safety-classified SSCs to provide assurance that the reliability and capability of the SSCs relied on to perform required safety-functions during LBEs meet the TLRC. The special treatment to be applied is graded commensurate with the risk-importance of the LBEs. This is consistent with how this issue has been treated for LWRs in 10 CFR §50.69.

2. What is an appropriate, systematic, and reproducible approach for safety classification of SSCs in a performance-based, risk-informed licensing approach?

PBMR Response: The structured process for the safety classification of SSCs is linked to the safety functions that SSCs perform during LBEs to meet the TLRC. The LBEs are examined to determine the safety functions required to meet the TLRC. The deterministic process for safety classification proposed for the PBMR has both mitigation and prevention elements. The following four steps are employed in this process:

a. Evaluation of Mitigation of DBE Consequences

SSCs relied on to perform the safety functions required for DBEs to meet 10 CFR §50.34 dose limits to the public are classified as *safety-related*. This step assures that SSCs are available for mitigation of the consequences of DBEs.

b. Evaluation of Prevention of High Consequence BDBEs

SSCs relied on to perform safety functions required to prevent the frequency of BDBEs with consequences greater than the 10 CFR §50.34 dose limits from increasing into the DBE region are classified as *safety-related*. This step assures that SSCs are available for prevention of events with unacceptable consequences for DBEs.

c. Evaluation of Mitigation of AOO Consequences

SSCs relied on to perform the safety functions required for AOOs to meet 10 CFR Part 20 dose limits to the public are classified as *non-safety-related with special treatment*. This step assures that SSCs are available for mitigation of the consequences of AOOs.

d. Evaluation of Prevention of High Consequence DBEs

SSCs relied on to perform safety functions required to prevent the frequency of DBEs with consequences greater than the 10 CFR Part 20 offsite dose limits from increasing into the AOO region are classified as *non-safety-related with special treatment*. This step assures that SSCs are available for prevention of events with unacceptable consequences for AOOs. It also assures limited challenges to safety-related SSCs.

The above approach incorporates both prevention and mitigation strategies in the risk management of accidents. Hence, it is consistent with and incorporates the PBMR approach to defense-in-depth as discussed more fully in the companion paper on that topic [1].

3. What are appropriate safety class categories?

PBMR Response: The three SSC safety classification categories are:

a. Safety-Related
   - For SSCs relied on to perform required safety functions to mitigate the public consequences of DBEs to comply with the dose limits of 10 CFR §50.34.
   - For SSCs relied on to perform required safety functions to prevent the frequency of BDBEs with consequences greater than the 10 CFR §50.34 dose limits from increasing into the DBE region.

b. Non-Safety-Related with Special Treatment
   - For SSCs relied on to perform safety functions to mitigate the consequences of AOOs to comply with the offsite dose limits of 10 CFR Part 20.
   - For SSCs relied on to perform safety functions to prevent the frequency of DBEs with consequences greater than the 10 CFR Part 20 offsite dose limits from increasing into the AOO region.

c. Non-Safety-Related with No Special Treatment

   For all other SSCs.

4. How are deterministic approaches used and integrated into the safety classification process?

PBMR Response: The approach for safety classification of SSCs is deterministic. Given the LBEs and their respective TLRC, the choice of SSCs available to perform safety functions during each of the events is established deterministically. For example, for the mitigation step that leads to SSCs classified as safety-related, the SSCs available for the core heat removal safety function for each DBE are identified. A deterministic selection is then made as to which SSCs will be relied on to mitigate the consequences across the spectrum of DBEs such that 10 CFR §50.34 dose limits are met as shown with the deterministic DBAs.

5. How are probabilistic approaches used and integrated into the safety classification and special treatment processes?

PBMR Response: The approach for safety classification of SSCs relies on the comprehensive and systematic selection of LBEs based on probabilistic and deterministic methods in a PRA. The categorization of LBEs into AOOs, DBEs, and BDBEs relies on the frequencies and consequences of the LBEs in comparison to the TLRC. SSCs are then classified for regulatory purposes as either safety-related or non-safety-related with special treatment; each SSC has capability and reliability requirements confirmed; the former are assured by primarily deterministic means and analyses and the latter by probabilistic methods and analyses. Special treatments are then deterministically selected in a graded fashion commensurate with the safety functions required during each LBE and the level of assurance needed over the plant lifetime or to reduce the uncertainty around the performance of specific SSCs that make a significant safety contribution. Finally, the PRA can be used to assess the improvements in safety or reduced uncertainty for special treatments selected.

6. What is the approach for assigning special treatment to assure the required degree of reliability and capability for SSCs classified as *safety-related*?

PBMR Response: The special treatment for the safety-related category of classification is commensurate with that needed for the SSCs to perform their capability and reliability requirements during DBEs to meet 10 CFR §50.34 dose limits. Capability requirements are derived from accident mitigation considerations, whereas reliability requirements are derived from accident prevention considerations. Special treatment measures may include: design margins and conservatism, elements of redundancy and diversity, material procurement, fabrication Quality Assurance (QA) and Quality Control (QC), operational monitoring, In-service Inspections (ISI), In-service Testing (IST), and surveillance samples. Although redundancy and diversity may be applied if needed to meet the necessary reliability requirement, there is no blanket requirement to meet the single failure criterion, consistent with SECY-03-0047 [2].

7. What is the approach for assigning special treatment to assure the required degree of reliability and capability for SSCs classified as *non-safety-related with special treatment*?

PBMR Response: The special treatment for the non-safety-related with special treatment category of classification is commensurate with that needed for the SSCs to perform their capability and reliability requirements during the LBEs and the corresponding TLRC. Capability requirements are derived from accident mitigation considerations, whereas reliability requirements are derived from accident prevention considerations. Special treatment measures may include Quality Assurance (QA) and Quality Control (QC), operational monitoring, inspections, testing and surveillance samples.

© Copyright 2006 by PBMR

5. PRE-APPLICATION OUTCOME OBJECTIVES

The objective of this paper and the follow-up workshops and paper revisions is to get NRC agreement on the list of issues for the selection of LBEs to support PBMR certification as well as agreement on the approach to solving these issues. Specifically, we would like the NRC to agree with the following statements, or provide an alternative set of statements that they agree with.

1. The PBMR risk-informed, performance-based approach to safety classification and special treatment that blends the strengths of probabilistic and deterministic methods is acceptable.
2. The use of three safety classification categories and the bases for SSC classification in each category are acceptable:

   Safety-Related (SR)

   - For SSCs relied on to perform required safety functions to mitigate the consequences of DBEs to comply with the dose limits of 10 CFR §50.34.
   - For SSCs relied on to perform required safety functions to prevent the frequency of BDBEs with consequences greater than the 10 CFR §50.34 dose limits from increasing into the DBE region.

   Non-Safety-Related with Special Treatment (NSRST)

   - For SSCs relied on to perform safety functions to mitigate the consequences of AOOs to comply with the offsite dose limits of 10 CFR Part 20.
   - For SSCs relied on to perform safety functions to prevent the frequency of DBEs with consequences greater than the 10 CFR Part 20 offsite dose limits from increasing into the AOO region.

   Non-Safety-Related (NSR)

   For all other SSCs, no special treatment.

3. The special treatment for the SR category of classification is commensurate with that needed for the SSCs to perform their capability and reliability requirements during DBEs and high consequence BDBEs to meet the 10 CFR §50.34 dose limits.
4. The special treatment for the NSRST category is commensurate with that needed for the SSCs to perform their capability and reliability requirements during AOOs and high consequence DBEs to meet the 10 CFR Part 20 offsite dose limits.

The process of gaining agreement on the issues is expected to involve the following steps:

Step 1 NRC review of this paper for agreement on the list of issues and the PBMR response.

Step 2 The holding of a workshop on the issues identified in the paper and a discussion of the approach that is proposed for resolution.

Step 3 NRC issuance of preliminary comments and requests for additional information to clarify points not understood or adequately developed in the paper.

Step 4 PBMR preparation of a revised paper which address any Requests for Additional Information (RAIs) that can be addressed in the near term and identification of requested information that will be included with the DCA submittal.

Step 5 NRC issuance of a safety evaluation report on its findings related to the safety classification of SSCs and their intended use.

6. REFERENCES

1. PBMR (Pty) Ltd, 'U.S. Design Certification – Defense-in-Depth Approach for the Pebble Bed Modular Reactor,' August, 2006.

2. PBMR (Pty) Ltd, 'U.S. Design Certification – Probabilistic Risk Assessment Approach for the Pebble Bed Modular Reactor,' June 13, 2006.

3. PBMR (Pty) Ltd, 'U.S. Design Certification – Licensing Basis Event Selection for the Pebble Bed Modular Reactor,' June 30, 2006.

4. U.S. Nuclear Regulatory Commission, 'Use of Probabilistic Risk Assessment Methods in Nuclear Regulatory Activities; Final Policy Statement,' Federal Register, Vol. 60, No. 158, pg. 42622-42629, August 16, 1995.

5. SECY-02-0139, 'Plan for Resolving Policy Issues Related to Licensing Non-Light Water Reactor Designs,' U.S. Nuclear Regulatory Commission, July 22, 2002.

6. SRM-03-0047, 'Staff Requirements Memorandum for SECY-03-0047 – Policy Issues Related to Licensing Non-Light Water Reactor Designs,' U.S. Nuclear Regulatory Commission, June 26, 2003.

7, SECY-93-087, 'Policy, Technical, and Licensing Issues Pertaining to Evolutionary and Advanced Light-Water Reactor (ALWR) Designs,' U.S. Nuclear Regulatory Commission, April 2, 1993.

8. SECY-94-084, 'Policy and Technical Issues Associated with the Regulatory Treatment of Non-Safety Systems in Passive Plant Designs,' U.S. Nuclear Regulatory Commission, March 28, 1994.

9. SECY-95-132, 'Policy and Technical Issues Associated with the Regulatory Treatment of Non-Safety Systems (RTNSS) in Passive Plant Designs (SECY-94-084),' U.S. Nuclear Regulatory Commission, May 22, 1995.

10. SECY-93-092, 'Issues Pertaining to the Advanced Reactor (PRISM, MHTGR, and PIUS) and Canadian Deuterium Uranium Reactor (CANDU) 3 Designs and Their Relationship to Current Regulatory Requirements,' U.S. Nuclear Regulatory Commission, April 6, 1993 (Correction issued April 28, 1993).

11. NUREG-1338, 'Preapplication Safety Evaluation Report for the Modular High-Temperature Gas-Cooled Reactor (MHTGR),' U.S. Nuclear Regulatory Commission, December 1995.

12. U.S. Nuclear Regulatory Commission Letter, Subject: NRC Staff's Preliminary Findings Regarding Exelon Generation's (Exelon's) Proposed Licensing Approach For The Pebble Bed Modular Reactor (PBMR), March 26, 2002.

13. SECY-02-0139, 'Plan for Resolving Policy Issues Related to Licensing Non-Light Water Reactor Designs,' U.S. Nuclear Regulatory Commission, July 22, 2002.

© Copyright 2006 by PBMR