NATIONAL NUCLEAR REGULATOR

For the protection of persons, property and the environment against nuclear damage

POSITION PAPER

CONSIDERATIONS OF EXTERNAL EVENTS FOR NEW NUCLEAR INSTALLATIONS

PP-0014

Rev 0

professionalism integrity valuing our people excellence teamwork

UNRESTRICTED

APPROVAL RECORD				
	Name	Designation	Signature	Date
Prepared	S Nhleko	Specialist: Design Safety		
	S Masike	Specialist: Environmental and Radiation Protection		
Reviewed	T Hill	Manager: NPP		
	P Bester	Coordinator: Special Nuclear Projects		
	T Pather	Manager: NTWP		
Recommended for Approval by	O Phillips	Senior Manager: SARA		
Approved	T Tselane	Interim Chief Executive Officer		

Please note:

The original, signed document is retained by Record Management.

TABLE OF CONTENTS

1 INTRODUCTION

The requirements for building a new nuclear installation are dictated by both design characteristics and site characteristics. In South Africa a detailed assessment of site characteristics will be completed for each selected site as part of a nuclear installation licence or nuclear installation site licence application.

The factors that should be considered in assessing sites cover the following three main aspects:

1) Identification and characterization of external events used as design basis events including events that might preclude the use of the site for its intended purpose;
2) Location and characteristics of the population around the site and the physical factors affecting the dispersion of released radioactivity that might have implications for the radiological risk to people;
3) Suitability of the site for the engineering and infrastructure requirements of the facility.

This paper deals with the first aspect and specifically present the NNR position on the characterization of external events and selection of design basis parameters required for ensuring robust design of new nuclear installations against external events and to meet defined safety goals.

Section 4 (5) of the NNR regulations on licensing of sites for new nuclear installations [**1**] requires that natural phenomena and potential man-made hazards must be appropriately accounted for in the design of new nuclear installations. RD-0024 contains the principal safety criteria used by the NNR for licensing of nuclear installations [**2**]. However, relevant guidelines (in terms of requirements for external events) for demonstrating compliance with the principal safety criteria are not outlined. Guidelines on the selection of design basis parameters required for structural design including safety goals and or performance goals are also not explicitly given. The NNR, through this position paper, recognizes the need to enhance these requirements, taking into account recent developments in the nuclear industry. This paper addresses external events and focuses on provisions that can be considered acceptable to the NNR for dealing with external events for new nuclear installations, as well as existing nuclear installations for which the design basis hazard levels for external events at a particular site need to be updated. It demonstrates the derivation of target safety goals from the principal safety criteria used by the NNR for licensing of nuclear installations and illustrates recommended procedures for establishing design basis hazard levels to be adopted for the design of new nuclear installations against external events. This document focuses on those external events that mainly govern the structural design.

2 PURPOSE

The purpose of this document is to:

1. Outline considerations for conducting site investigations for evaluation of hazards related to external events;
2. Demonstrate the derivation of target safety goals which are required when establishing the design basis parameters for the design of nuclear installations against external events using the performance-goal based approach;
3. Clarify the NNR position on the selection of design basis hazard levels applicable to new nuclear installations.

3 SCOPE

This document deals with the NNR position for conducting site investigations in order to derive design basis hazard levels for external events. It is applicable to applicants of new nuclear installation licenses as well as existing holders of a nuclear installation license engaged in updating design basis hazard levels for external events at a particular site.

4 TERMS, DEFINITIONS, ACRONYMS AND NOTATIONS

4.1 Terms & Definitions

"best estimate" means the point estimate of a parameter that is not biased by conservatism or optimism. A best estimate should include some statistical information to place the value in context with its associated uncertainty.

"beyond design basis external event" means a postulated external event more severe than the design basis external event used in the design to establish the acceptable performance requirements of the structures, systems, and components.

"conservatism" means the incorporation of favourable or unfavourable bias in the estimated value of a parameter in order to achieve a desired safety margin especially when there is uncertainty about the value of the parameter.

"core damage" means uncovery and heat up of the reactor core to the point at which prolonged oxidation and severe fuel damage are capable of causing release of fuel products from the fuel cladding and or release of fuel products into containment.

"design basis external event" means a postulated external event used in the design to establish the acceptable performance requirements of the structures, systems, and components.

“external events” means events originating outside the nuclear installation, including natural and manmade events with the potential to cause adverse conditions or even damage to safety important structures, systems or components.

“expert judgement” means information provided by a technical expert, in the expert’s area of expertise, based on opinion, or on an interpretation based on reasoning that includes evaluations of theories, models, or experiments.

“large early release” means the rapid, unmitigated release of airborne fission products from the containment occurring before the effective implementation of off-site emergency response and protective actions.

“new nuclear installation” means a nuclear installation constructed after the date on which the NNR regulations on licensing of sites for new nuclear installations [**1**] came into effect.

“off-site” means outside the boundary of a site

“on-site” means within the boundary of a site

“operating basis external event” means a postulated external event for which the structures, systems, and components are designed to remain operational.

“safety goal” means basic and limiting safety goal required to ensure safety.

“target safety goal” means a surrogate safety goal (more stringent than the safety goal) required for additional margin of safety or conservatism above the safety goal.

4.2 Acronyms and notations

CDF	Core damage frequency
CGS	(South African) Council for Geo-Science
DF	Design factor
DBEE	Design basis external event
FDBEE	Frequency of design basis external event
FOBEE	Frequency of operating basis external event
FOSID	Frequency of onset of significant inelastic deformation
IAEA	International Atomic Energy Agency
LERF	Large early release frequency
NNR	(South African) National Nuclear Regulator
OBEE	Operating basis external event
pa	per annum
PRA	Probabilistic risk assessment
PSA	Probabilistic safety analysis
PSHA	Probabilistic seismic hazard analysis
SABS	South African Bureau of Standards
SANS	South African National Standards
SID	Significant inelastic deformation

SG	Safety Goal
SG_{CDF}	Safety Goal for core damage frequency
SG_{LERF}	Safety Goal for large early frequency
SG_{OBEE}	Safety Goal for operating basis external event
SSCs	Systems, structures and components
SSHAC	Senior seismic hazard analysis committee
SSRS	Site-specific response spectrum
TSG	Target Safety Goal
TSG_{CDF}	Target Safety Goal for core damage frequency
TSG_{LERF}	Target Safety Goal for large early release frequency
UHS	Ultimate heat sink
UHRS	Uniform hazard response spectrum

5 NATURAL EXTERNAL EVENTS

External events of natural origin, as considered in this paper, are events that originate outside the machinery and operation of the plant, and arise from forces of nature and not from human activities. It is a fundamental nuclear safety requirement that credible events of natural origin that may have an impact on nuclear safety should be identified and selected as design basis events in the site evaluation process [**3**]. Examples of external natural events include the following:

— Natural seismicity
— Extreme meteorological conditions (of temperature, snow, hail, frost, subsurface freezing, hurricanes, tornadoes, cyclones, tropical typhoons and straight winds);
— Extreme wet and dry seasons (drought);
— Floods (due to tides, tsunamis, seiches, storm surges, precipitation, waterspouts, dam forming and dam failures, snow melt, landslides into water bodies, channel changes and work in the channel);
— Abrasive dust and sand storms;
— Lightning;
— Volcanism;
— Biological phenomena;
— Collision of floating debris (ice, logs, etc.) with accessible safety related structures such as water intake structures and ultimate heat sink (UHS) components;
— Meteorite impact;

This list is not exhaustive and other external events, not included in the list, may be identified and selected as design basis external events (DBEEs) at the site. However, all natural hazards that may affect the site shall be considered and shall be subjected to screening, bounding, or detailed analyses. External events PRA methods should be consulted for acceptable and up-to-date screening procedures.

6 HUMAN-INDUCED EXTERNAL EVENTS

External human-induced events considered in this paper are of accidental origin and result from sources that are not directly involved in the operational states of the nuclear installations. Examples of external human-induced events include but are not limited to the following:

- Mining-induced seismicity;
- Dam-induced seismicity;
- Aircraft crashes;
- Explosions (deflagrations and detonations) with or without fire, with or without secondary missiles, originating from off-site and on-site sources (but external to buildings), such as hazardous or pressurized materials in storage, transformers, pressure vessels or high energy rotating equipment;
- Release of hazardous gases (asphyxiant, toxic) from off-site and on-site storage including hazardous material undergoing transportation;
- Release of radioactive material from off-site sources with respect to the design being considered;
- Release of corrosive gases and liquids from off-site and on-site storage;
- Fire generated from off-site sources (mainly for its potential for generating smoke and toxic gases);
- Collision of ships or floating debris with accessible safety related structures, such as water intakes and ultimate heat sink (UHS) components;
- Collision of vehicles at the site with safety related SSCs;
- Any combination of the above as a result of a common initiating event (such as an explosion with fire and release of hazardous gases and smoke).

Considerations relating to the physical protection of the plant from sabotage, vandalism and wilful actions by third parties, which must also be treated in design, are not directly addressed in this document. However, the methods described herein may also have certain application for such scenarios. All human-induced hazards that may affect the site shall be considered and shall be subjected to screening, bounding, or detailed analyses.

7 GENERAL REQUIREMENTS FOR INVESTIGATIONS FOR DESIGN BASIS EXTERNAL EVENTS

The hazard associated with each external event should be identified and investigated to a sufficient level of detail by conducting site-specific and regional studies. The procedures for selecting the site, identification and evaluation of hazards should follow accepted industry practice regarding the use of the-state-of-the-art methodologies and should address IAEA requirements and guidelines [3, 5, 6, 7, 8]. The method and the level of each investigation should be commensurate with the consequences associated with the hazard. It should also take into account the hazard recurrence intervals or the anticipated hazard exceedance probabilities and the duration of exposure of the nuclear installation to the hazard (the relationship between these parameters is given by Equation A1 in Appendix A and typical values are listed in Table A1 of the same appendix). Hazard design basis faults should be assumed to occur under the most penalizing normal plant operating conditions. Analyses should take into account simultaneous effects, common cause failure mechanisms, defense in depth and consequential effects. The potential impact of the construction of the nuclear installation (and changes in the surrounding built environment) in modifying the hazard must also be assessed and be included in the hazard evaluation. Future characteristics of the hazard that are likely to have an impact on hazard estimates should be incorporated.

Investigations should be based on published and unpublished scientific information derived from various sources that present related pertinent data for the site region, site vicinity and site area in which the site is located. These sources should include provincial and state agencies, academic institutions, national building codes, industry, non-governmental, professional organizations and local communities.

The procedures, methods, standards, guidelines, investigation teams and peer review panels selected for conducting investigations should be justified and demonstrated to be acceptable to the NNR before the beginning of each investigation. Each investigation should fully address site-specific issues. When international procedures and guidelines are followed, these should be demonstrated to be flexible enough to address site-specific challenges. When international experts conduct site-specific investigations there should be adequate provisions for involving national and local resource experts possessing a sufficient level of knowledge about the site region and the site vicinity.

7.1 Graded approach

Nuclear installations cover a broad range of technologies and facilities that process, store, or handle radioactive materials. Thus a graded approach should be used in determining the scope, extent, level of detail and the effort to be devoted to each hazard evaluation study. The main factor taken into consideration in the application of a graded approach should be the magnitude of the risks associated with the activities performed at the nuclear installation. Account should be taken of occupational doses, radioactive discharges and the generation of radioactive waste during operation and the potential consequences of anticipated operational occurrences and accidents, including their probability of occurrence and the possibility of occurrence of very low probability.

7.1.1 Requirements for nuclear power plants

The NNR position has been formulated for nuclear power plants as they demand the most stringent standards to be applied. However, the document shall apply equally to research reactors and other nuclear installations in the nuclear fuel cycle with some modifications where necessary as discussed in Section 7.1.2.

7.1.2 Requirements for research reactors and other facilities in the nuclear fuel cycle

Currently, South Africa has one type of research reactor with multiple uses such as, physics and materials research, irradiation and isotope production. The current reactor (SAFARI-1) is of a pool type design and it is assumed that any future research reactor built in South Africa will be of this type. From the safety point of view, usually these reactors have a small internal energy (no pressure circuit) and the intrinsic characteristic of neutron stability. They generally do not need a pressure containment and are located in a leak proof building with a small design pressure difference from the outside. The requirements contained here shall also apply to research reactors and hazardous non-reactor facilities in the nuclear fuel cycle. Any modifications shall be justified by the use of the graded approach [**11**]. Examples of non-reactor facilities include the Vaalputs national radioactive waste disposal facility, the Thabana pipe storage facility, the Hot Cell Complex and Isotope production facility.

7.1.3 Hazard classification of buildings and SSCs according to safety functions and assignment to design classes

It is important that external event investigations take into account the design and operational characteristics of the planned installation. Hazard classification (for example seismic classification or categorization) should be performed for buildings and SSCs based on the fundamental safety functions by adopting international and national standards, accepted classification schemes and practices. Based on this classification, the following requirements shall be imposed on buildings and SSCs, such as, application of nuclear design codes, quality assurance, seismic qualification, in-service inspection (periodic tests), qualification and reliability data. The classification scheme must be matched by the design code that supports it. An example of a seismic classification is shown below.

— Seismic Category 1 (SC1): for SC1 structures, full functionality, is required for the design basis earthquake (DBE). No cumulative damage is allowed in order to withstand the next earthquake exactly as the first one. This implies a quasi-elastic behaviour of the whole structure in an event of a DBE. This behaviour is referred to the global structural response, ignoring the unavoidable cracking of concrete before and during the earthquake likely to occur in localized areas of the structure before the onset of significant inelastic deformation. This condition is considered sufficient but not necessary to comply with the safety requirements.
— Seismic Category 2 (SC2): for SC2 structures, capability of supporting safety related components, equipment and systems needs to be maintained. This allows limited inelastic deformation and is guaranteed by lower ductility coefficients than for SC3 structures (see below) in the event of the DBE.
— Seismic Category 3 (SC3): These structures require non-collapse and allows for inelastic behaviour. Behaviour is guaranteed by adequate ductility coefficients.
— Seismic Category 4 (SC4): for SC4 structures, conventional design standards for industrial buildings can be applied.

7.2 Screening of events

The applicant is expected to develop, document, and implement a systematic approach for identifying all natural external events that may have an impact on safety. The hazards described in the document are indicative of the types of external events to be considered.

The following criteria could be used to eliminate postulated hazards being included in the safety assessment:

(1) A phenomenon which occurs slowly or with adequate warning with respect to the time required to take appropriate protective action.
(2) A phenomenon which in itself has no significant impact on the operation of a nuclear power plant and its safety assessment.
(3) A phenomenon which by itself has a probability of occurrence less than the 10^{-8} per year (event sequence frequency).
(4) Locate the nuclear power plant sufficiently distant from the postulated phenomenon to mitigate its effects.
(5) A phenomenon which is included or enveloped by design for another phenomenon. For example, storm surge and seiche are included in lake flooding; toxic gas is included in pipeline accident or industrial or military facility accident.

Alternative screening methods prescribed in PRA standards can be used provided they are demonstrated to be compatible with the NNR licensing criteria as well as having a sound technical and defensible basis.

7.3 Quality management and project management systems

Project related activities shall be conducted in accordance with an accepted quality management system consistent with the NNR requirements as documented in NNR regulations and guidance documents [21].

A project work plan should be prepared prior to, and as a basis for, the execution of each external event investigation project or hazard evaluation study. The work plan should convey the complete set of general requirements for the project, including applicable regulatory requirements. It should also cover all activities for data collection and data processing, field and laboratory investigations, analyses and evaluations. The work plan should delineate the following specific elements: personnel and their responsibilities; work breakdown and project tasks; schedule and milestones; and deliverables and reports. The applicant shall ensure that all activities are performed in accordance with RD-0034 [21]. Compliance with these requirements must also be demonstrated for all subcontracted services such as services sourced from specialist contractors and testing laboratories. Demonstration should be provided in a manner and level of detail that is commensurate with the associated radiological hazard.

7.4 Technical characteristics and attributes of external hazards

Table B1 in Appendix B summarizes the basic characteristics and attributes for the technical elements of hazards analyses for key external events. The method(s) of investigation should be demonstrated to be capable of quantifying the most significant parameters of the hazard, addressing the unique circumstance of the site in which it is applied, and be acceptable or adaptable to achieve the regulatory objectives of the NNR. When such methods involve the examination of available historical records and oral tales for clues on past occurrences of the hazard (and or other phenomena associated with the hazard), the name of the hazard and or all forms of its manifestation should be identified in the languages of past and current communities in the surrounding area. This should include the identification of any sacred symbols and superstitions that may be associated with the hazard. Oral and written folk-history should be treated as a potential avenue for further investigation, but it should only be credited in the event that other solid scientific evidence can be found to back it up.

7.5 Peer review

A peer review of the hazard analysis study should be performed to provide assurance that a proper process has been duly followed in conducting the hazard analysis, that the analysis has addressed and evaluated uncertainties, that the documentation is complete and traceable, and that the requirements and goals of the hazard evaluation process have been met. An acceptable peer review approach is one that is performed according to an established process and by qualified personnel and documents the results and identifies both strengths and weaknesses of the chosen methodology. Table B2 in Appendix B lists the characteristics and attributes expected of a peer review and the peer review process.

7.5.1 Peer review process

Two methods of peer review can be used: (1) participatory peer review; and (2) late stage peer review. A participatory peer review is carried out during the course of the study, allowing the reviewer(s) to resolve comments as the hazard analysis proceeds and as technical issues arise. A late stage and follow-up peer review should be carried out towards the end of the study.

The peer review process should use a documented procedure to direct the analysis team in evaluating the adequacy of a hazard evaluation methodology. It should also compare the hazard evaluation against established criteria (e.g., technical requirements). In addition to reviewing the methods used, the peer review should determine whether the methods were applied correctly. The peer review process should clearly document the scope and extent of the review performed. Limitations of the peer review should be clearly stated.

7.6 Qualifications of analysis team and peer reviewers

The team qualifications determine the credibility and adequacy of the analysis team and peer reviewers. This should be accompanied by a traceable publication history record in peer reviewed scientific and or technical literature and or technical documents. Each member of the peer review team must be a subject matter expect and or have technical expertise in the review areas assigned to him or her, including experience in the specific methods that are used to perform evaluations in that particular review area. Furthermore, each member of the peer review team should be knowledgeable about the peer review process, including the desired characteristics and attributes used to assess the adequacy of the hazard evaluation method. Finally, in order to avoid any perception of a technical conflict of interest, the peer reviewers should not have performed any actual work on the hazard evaluation investigations.

7.7 Documentation

Documentation of the hazard study and the peer review process should provide the necessary information to ensure that the findings and the peer review process are traceable and the bases of the findings are defensible. Descriptions of the qualifications of the peer review team members and the peer review process should be documented. The results of the peer review for each technical element of the hazard evaluation method and update process should be described, including the areas in which the methodology does not meet or exceed the desired characteristics and attributes. This should include an assessment of the importance of any identified deficiencies on the study results and how these deficiencies were addressed and resolved. Documentation should also demonstrate evidence of the use of a suitable data base management system to facilitate storage, retrieval, updating and sharing of gathered data. The use of software must demonstrate compliance with "Requirements for authorization submissions involving computer software and evaluation models" issued by the NNR [**10**]. If a customized hazard-simulation model has been developed to account for site-specific conditions, complete documentation of the technical bases of the customized model should be carried out.

7.8 Use of expert judgment

When expertise on a specific technical issue is not available within the analysis team, suitable provisions should be made for the use of expert judgement outside the analysis team to resolve the given technical issue. The analysis team shall explicitly and clearly define the objective of the information that is being sought through the use of outside expert judgement, and shall explain this objective and the intended use of the information to the expert(s).

7.9 Operating experience

As one of the ways to feedback operating experience to refine risk predictions, industry experience should be taken into account when estimating design basis parameters for external events. For example industry experience has shown that some events have occurrences that place them in categories that are different to those in which they were placed for the original design and or in original licensing considerations [6]. Where it may be shown from experience feedback that certain initiating event frequencies are lower than originally calculated, the NNR may require that these events continue to be treated in the previously established manner. However, for events where it has been shown that the initiating frequency is higher than originally thought, the event will be re-allocated into the appropriate category where the appropriate nuclear safety criteria apply.

7.10 Validity, interpretation and ownership of results and hazard inputs

Circumstances under which the results obtained through the method(s) used can be disputed or rejected should be stated. This should include the main assumptions of the methods followed and any applicable expiry date. The ownership of the inputs and results (and or their interpretation) of the hazard study should be clearly stated.

8 SAFETY GOALS AND LICENSING CRITERIA FOR NUCLEAR POWER PLANTS

One way of quantifying and minimising the negative effect(s) or impact(s) associated with a particular activity is to express its impact(s) in terms of a mortality risk or the years (or the days) of life lost (loss-of-life expectancy) by the affected individuals as a consequence of that activity and to prescribe a safety goal or limit criteria on the mortality risk allowed for the protection of the public and the environment. Probabilistic safety goals that have been progressively introduced by regulatory bodies and utilities can be grouped into three categories, in relation with the tools used for assessing compliance:

- Core Damage Frequency (CDF) – Level 1 PSA
- Releases Frequency (LERF) – Level 2 PSA
- Annual Fatalities, Annual Doses – Level 3 PSA

Tables C1 and C3 of Appendix C show licensing criteria used by the NNR for the protection of plant personnel and the public against nuclear accidents which are extracted from RD-0024 [2]. The criteria limit the mortality risk and dose quantities per year to the values specified in the tables. However, intermediate safety goals in terms core damage frequencies (CDF - Level 1 PSA) and large early release frequencies (LERF - Level 2 PSA) associated with these criteria are not explicitly specified. However, the specification of intermediate safety goals is required for structural design of nuclear installations against external events. For example, if known in advance, the CDF safety goal can be used as direct input in the seismic risk equation to facilitate the estimation of the design basis ground motion and margin of conservatism required for the design of safety related SSCs using the approach recommended in ASCE 43-05 [15]. Appendix C demonstrates the derivation of these intermediate Safety Goals from the licensing criteria used by the NNR. If several risks metrics are used it is important to demonstrate that they are consistent. This is the aim of the analysis presented in Appendix C. Below the resulting Safety Goals have been illustrated symbolically (Table 1).

Table 1: Intermediate Safety Goals for external events

Level 1 PSA Safety Goals (CDF – per annum)	Level 2 PSA Safety Goals (LERF– per annum)	Domain
SG_{CDF} $FDBEE$	SG_{LERF}	Safety Goals for Design Basis External Events
TSG_{CDF}	TSG_{LERF}	Target Safety Goals for Beyond Design Basis External Events
SG_{OBEE} $FOBEE$	(-)	Safety Goals for Operating Basis External Events

where

SG_{CDF} = Safety Goal for Core Damage Frequency

TSG_{CDF} = Target Safety Goal for Core Damage Frequency

$FDBEE$ = Frequency of Design Basis External Event

SG_{LERF} = Safety Goal for Large Early Frequency

TSG_{LERF} = Target Safety Goal for Large Early Frequency

SG_{OBEE} = Safety Goal for Operating Basis External Event

$FOBEE$ = Frequency of Operating Basis External Event

Once intermediate Safety Goals have been established the process of demonstrating compliance can be illustrated schematically (Figure 1).

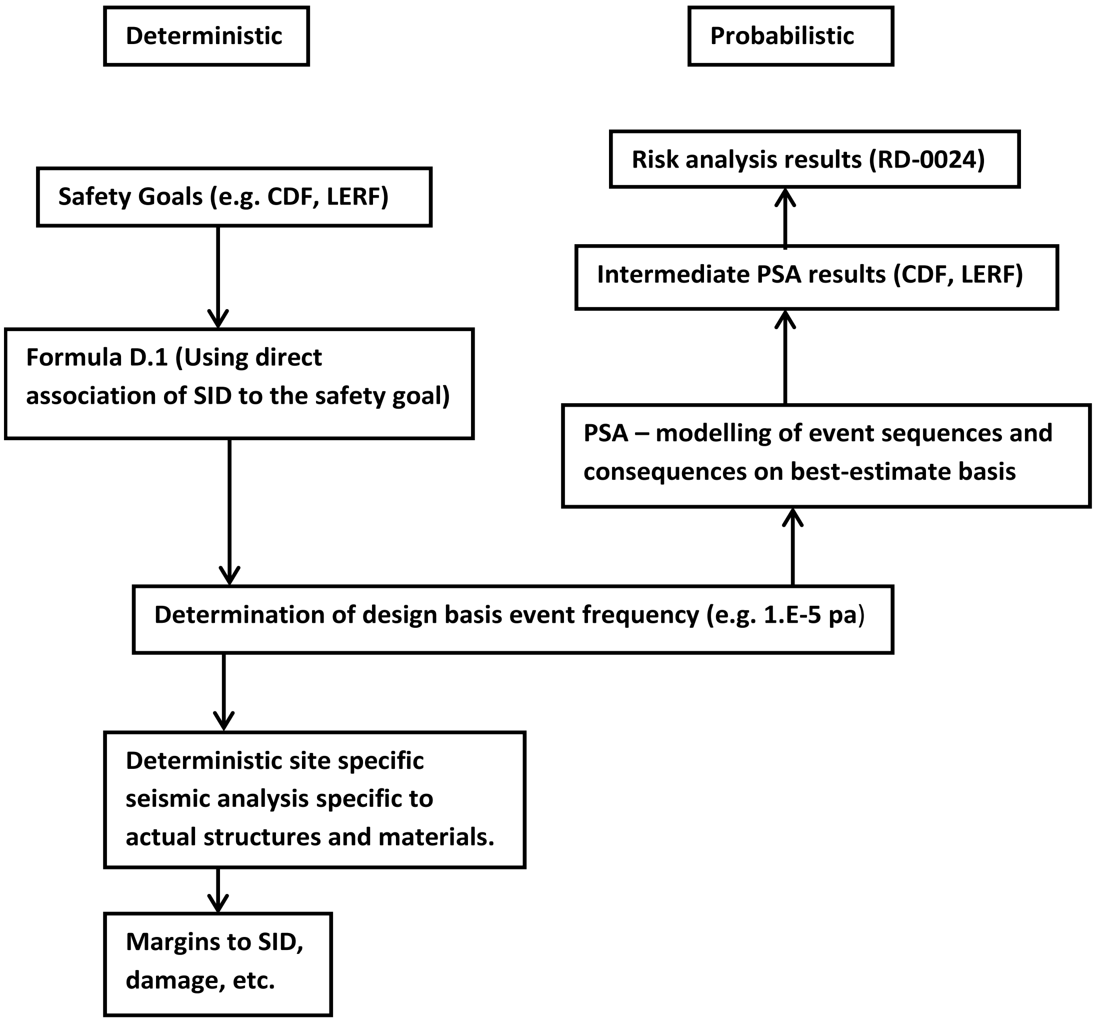

Figure 1: Application process flow chart

The ultimate objective is to demonstrate through PSA results that the Safety Goals do not compromise the annual fatality and dose limits specified in RD-0024 [2] and RD-0018 [22]. The application of the ALARA principle must be demonstrated for the selection of design features that provide for minimisation of radiological doses and thus the optimum level of safety in terms of radiological risks. All beyond design basis conditions have to be considered in the demonstration of compliance with the respective NNR risk criteria. Numerical values for the Safety Goals recommended for demonstrating compliance with the NNR requirements are presented in the following sections.

8.1 Safety Goals for design basis external events

Appendix C demonstrates the derivation of quantitative Safety Goals for design basis events from the licensing Criteria used by the NNR. The derivation leads to the following design basis Safety Goals which are recommended for demonstrating compliance with the NNR requirements:

$SG_{CDF} = 1 \times 10^{-5}$ pa

$SG_{LERF} = 1 \times 10^{-6}$ pa

where

SG_{CDF} = Safety Goal for Core Damage Frequency

SG_{LERF} = Safety Goal for Large Early Frequency

Although derived differently, these Safety Goals are in line with international best practice.

8.2 Safety Goals for beyond design basis external events and consideration of "cliff edge" effects

It is important to make provision for events with hazard levels that exceed the levels considered for design and to prevent the potential for small deviations in plant parameters from giving rise to severely abnormal plant behaviour (cliff edge effects). Appendix C shows that in order to meet the CDF design basis Safety Goal limit with a sufficient safety margin, the applicant needs to aim for a more conservative target Safety Goal as follows:

$TSG_{CDF} = 5 \times 10^{-6}$ pa

As shown later (see Section 10.5), this target Safety Goal allows a seismic margin of approximately 1.7 to be achieved when it is used to specify the target performance goal for seismic design which is in line with international requirements.

Similarly, for the LERF Safety Goal, the applicant needs to aim for a more conservative target Safety Goal whose quantitative value is defined in Appendix C as follows:

$TSG_{LERF} < 1 \times 10^{-6}$ pa

where

TSG_{CDF} = Target Safety Goal for Core Damage Frequency

TSG_{LERF} = Target Safety Goal for Large Early Frequency

Therefore characterization of external events should include frequencies of occurrence below 1×10^{-6} pa.

8.3 Safety Goals for operating basis events

In order to allow evaluation of the frequency of the operating basis event, it is also necessary to establish a Safety Goal that corresponds to the operating basis event. The recommended Safety Goal is defined in Appendix C as follows:

$SG_{OBEE} = 2\times10^{-4}$ pa

where

SG_{OBEE} = Safety Goal for Operating Basis Event

This Safety Goal is chosen to correspond to a value for the frequency of operating basis seismic event of $FOBEE = 2\times10^{-3}$ which is consistent with local seismic requirements for industrial structures.

For anticipated operational occurrences it has to be demonstrated that dose constraints specified for the respective nuclear installation in accordance with RD-0018 [22] are not compromised.

8.4 Evaluation of hazard exceedance frequencies to achieve Safety Goals

If a risk equation that expresses the relationship between the target Safety Goal, the hazard exceedance probability (i.e. the frequency of the design basis event) and other design factors, exists in the literature, and has been fully established in design standards, it could be used to calculate the combination of the design factors and the mean hazard exceedance probability value required to achieve a set Safety Goal subject to NNR acceptance. When it is not possible to relate a Safety Goal to a hazard exceedance probability (for example when the hazard risk equation does not exist) the design basis hazard level shall be obtained from the hazard curve by making a conservative assumption that the hazard exceedance probability is at least equal to the Safety Goal for design basis events. The Safety Goal needs to be increased by a factor of ten to achieve conservatism for operating basis events.

8.5 Minimum requirements for hazard levels

For each external event, the site-specific hazard level selected as a design basis is not expected to fall below the hazard level used in the national code for the appropriate class of the building, facility or structure taking into account the area of location. If the site-specific hazard level chosen as a design basis fall below the national hazard level, a conservative assumption shall be made that the site-specific hazard level is at least equal to the hazard level used in the national code or national hazard map for the appropriate class of the building, facility or structure. However, this requirement only ensures that workers in the nuclear installation are exposed to the same level of risk (death risk due to collapse of a building as a result of a natural hazard natural) as workers in other industrial type facilities. Thus in order to address the additional nuclear risk, the applicant should follow accepted international practice in the selection of appropriate international codes and standards for facilities whose design is governed by minimum requirements, including the combination of such standards with local standards.

9 SAFETY GOALS FOR NON-POWER REACTOR AND NON-REACTOR FACILITIES

The Safety Goals discussed in section 8 and derived in Appendix C1-C4 have been formulated for nuclear power plants as they demand the most stringent criteria to be applied. However, the radiological hazard associated with non-power reactor and non-reactor facilities is significantly less than that expected for power reactor facilities. In this case it is necessary to apply the graded approach [11] and other risk arguments to formulate suitable Safety Goals using the simplified procedure presented in sections C1-C4 of Appendix C. This is done by adjusting the alpha factors $\alpha L1_{xxx}$ and $\alpha L2_{xxx}$ which relate intermediate safety goals to the principal safety criteria. Evaluation of the resulting safety goals is presented in Section C6 of Appendix C for non-power reactor and non-reactor facilities. It is important to recognise that the risk metrics associated with power reactor facilities do not necessarily apply to non-power reactor and non-reactor facilities and thus the resulting safety goals should be viewed as surrogate safety goals (SSG). The derivation further assumes that the radiological hazard associated with non-power reactor facilities is less than that expected for non-reactor facilities. This is an approximate classification and it is expect that applicants will conduct a rigorous classification based on the radiological hazard associated with the facility.

10 REQUIREMENTS FOR SEISMIC EVENTS

The applicant should undertake a site-specific probabilistic seismic hazard assessment (PSHA) study to quantify the ground motion hazard due to the seismicity of the site and the surrounding region using one of a number of evaluation methods accepted for industry practice such as the Senior Seismic Hazard Analysis Committee (SSHAC) process [**12**], the performance-based approach [**13**], etc. The investigations should be consistent with the safety standard issued by the IAEA for acceptable seismic hazard evaluation practice in member states [**14**]. The method must be probabilistic in nature and should take into account both aleatory and epistemic uncertainties. A uniform hazard spectrum (UHRS) should be developed for the site using the chosen PSHA methodology. The PSHA method should specifically address the following areas of investigations:

1. Geologic, seismic, and geophysical investigations
2. Geologic evidence, or absence of evidence, for surface deformation
3. Correlation of earthquakes with capable tectonic sources

4. Ages of most recent deformation
5. Relationship of tectonic structures in the site area to regional tectonic structures
6. Characterization of capable tectonic sources.
7. Designation of zones of quaternary deformation in the site region
8. Potential for surface tectonic deformation of the site
9. The range of seismicity rates and maximum magnitudes for the region around the site
10. Attenuation relations
11. Deaggregation
12. Propagation of aleotory and epistemic uncertainties

Further information on the above listed topics can be found in specialized literature.

Seismic investigations should be based on published and unpublished scientific information derived from various sources that present geologic, geotechnical, seismic, geophysical, and related pertinent data for the site vicinity and site area in which the site is located. These sources should include the Council for Geo-Science (CGS), other provincial and state agencies, academic institutions, national building codes, mining industry, professional organizations, non-governmental organizations and local communities. However, verification and or detailed investigations should be performed by the applicant to support the information and to gather new information. Resolution accuracy of the investigative technique used should be taken into account.

A study of earthquakes affecting the site should include discussions of quaternary tectonics, structural geology, stratigraphy, geochronology methods used for age dating, paleoseismology, and geologic history of the site vicinity, site area, and site location. These should compare well with studies conducted by others in the same area, and be supported by detailed investigations performed by the applicant. Site vicinity, site area, and site location-specific geologic maps and cross-sections constructed at scales adequate to clearly illustrate surficial and bedrock geology, structural geology, topography, and relationship of power plant foundations to these features should be included. For coastal and inland sites near large bodies of water, similar detailed investigations are to be conducted to reveal information regarding onshore and offshore geology and seismicity, and where possible, to identify on shore expression of offshore tectonic structures.

Documentation should include appropriate references to all relevant published and unpublished materials. Illustrations provided to document site characteristics should include structural, tectonic, physiographic, topographic, geologic, gravity, and magnetic maps; geologic cross-sections showing soil horizons, stratigraphy, lithology, and structure; geologic maps of trenches and test pits; seismic reflection or refraction and other geophysical survey profiles; soil and core boring logs; geophysical borehole logs; aerial photographs; and satellite imagery. Some sites may require maps illustrating areas of subsidence, karst features, mechanically weak zones of soil and rock, paleoliquefaction features, sand blow features, irregular weathering conditions and weathering depths, landslide potential, locations of oil and gas wells, faults, and joints. Maps should include superimposed plot plans of plant facilities, and the relationship of all Seismic Category 1 facilities to subsurface geology should be illustrated. Locations of all plant structures, borings, trenches, test pits, seismic and geophysical data collection profiles, and geologic cross-sections should also be included on plot plans.

The PSHA project goal should specify the following as minimum output requirements for the project and should include the desired format for each output:

1. Mean hazard curves
2. Fractile hazard curves
3. Uniform hazard response spectra
4. Magnitude–distance deaggregation
5. Mean and modal magnitude and distance
6. Seismic source deaggregation
7. Aggregated hazard curves
8. Earthquake time histories

10.1 Performance goals for design basis earthquake ground motion

The qualitative description of acceptable performance for Seismic Category 1 SSCs in a nuclear installation is to not exceed an elastic limit state of behavior. Thus, the definition of unacceptable performance is the “onset of significant inelastic deformation”. The qualitative measure represented by “onset of significant inelastic deformation” means that inconsequential and localized inelastic deformation constitutes acceptable performance. The target performance goal for the frequency of onset of significant inelastic deformation (P_{FOSID}) used for seismic design may be defined by:

$$P_{FOSID} = SG_{CDF}$$

In addition to fulfilling the performance goal for seismic-induced core damage, the design may be demonstrated to achieve the following performance goal for seismic-induced large early release frequency (P_{SLERF}):

$$P_{SLERF} = SG_{LERF}$$

The choice of values for the Safety Goal parameters SG_{CDF} and SG_{LERF} is discussed in detail in Appendix C and Section 8.1.

10.2 Performance goal for beyond design basis earthquake ground motion

According to Section 8.2, the design should be carried to provide margins for events with hazard levels that exceed the levels considered for design events and to prevent the potential for small deviations in plant parameters from giving rise to catastrophic plant behaviour (cliff edge effects). Thus in order to meet the CDF design basis Safety Goal limit with a sufficient safety margin, the applicant needs to aim for a more conservative performance goal for seismic core damage frequency (P_{SCDF}) defined as:

$$P_{SCDF} = TSG_{CDF}$$

The choice of the value for the Safety Goal parameter TSG_{CDF} is discussed in detail in Appendix C and Section 8.2.

10.3 Performance goal for operating basis earthquake ground motion

Safety Goals for operating basis events were discussed in Section 8.3. The target performance goal for the operating basis earthquake ground motion (P_{OBEGM}) corresponds to the Safety Goal for operating basis external events as shown below:

$$P_{OBEGM} = SG_{OBEE}$$

where the quantitative Safety Goal parameter SG_{OBEE} is defined in Appendix C and Section 8.3.

10.4 Surface-Fault rupture and criteria for a capable tectonic source

Sites that have a potential for fault rupture at or near the ground surface and associated deformation should be avoided. The potential for surface fault rupture should be adequately characterized using acceptable methods and evaluation approaches. A capable tectonic source is a tectonic structure that can generate both vibratory ground motion and tectonic surface deformation such as faulting or folding at or near the earth's surface in the present seismotectonic regime. It is defined by at least one of the following criteria:

1. presence of surface or near-surface deformation of landforms or geologic deposits of a recurring nature within the last approximately T1 years or at least once in the last approximately T2 years (see Appendix E for the definition of T1 and T2),
2. a reasonable association with one or more moderate to large earthquakes or sustained earthquake activity that are usually accompanied by significant surface deformation,
3. a structural association with a capable tectonic source that has characteristics of either item 1 or 2 such that movement on one could be reasonably expected to be accompanied by movement on the other.

10.5 Estimation of the mean frequency used to define the design basis seismic hazard

The design basis earthquake (DBE) ground motion and site-specific response spectrum (SSRS) for future nuclear facilities can be established following the performance-goal based approach defined in the ASCE Standard 43-05 [**15**] to meet the target performance goals in Section 10.1, 10.2 and 10.3 which are based on the NNR licensing criteria. The ASCE Standard 43-05 is formally constructed to produce designs aimed at achieving a target acceptable seismic risk goal which is defined as the annual probability of seismic-induced unacceptable performance. However, alternate methods are also allowed, with the provision that such methods must explicitly justify and properly incorporate into reliability calculations appropriate site-specific hazard curves, proper demands, realistic capacity estimates, and due consideration of the uncertainties in the estimation of hazard curves, demands, and capacities, and achieve the target performance goals in Section 10.1, 10.2 and 10.3.

The SSRS defined in the ASCE Standard 43-05 is calculated by:

$$SSRS = DF \times UHRS$$

where *DF* is the design factor and *UHRS* is the uniform hazard response spectrum calculated at the reference mean hazard exceedance frequency, H_D.

The reference mean hazard exceedance frequency, H_D, used to define the reference UHRS used for design can be calculated using the Simplified Seismic Risk Equation (D1) such that the performance goals (P_{FOSID} and P_{SCDF}) specified in Sections 10.1 and 10.2 are satisfied. Two approaches can be followed for determining the mean hazard exceedance frequency H_D that meet the P_{FOSID} and P_{SCDF} performance goals, namely, the facility can be designed for the P_{FOSID} performance goal but with sufficient conservatism to meet the P_{SCDF} performance goal. Alternatively, the facility can be designed to meet the P_{SCDF} performance goal directly. The reference mean hazard exceedance frequency corresponding to the performance goal for seismic-induced large early release frequency (P_{SLERF}) or the performance goal for the operating basis earthquake ground motion (P_{OBEGM}) and can also be evaluated from the Simplified Seismic Risk Equation (D1).

For illustrative purposes, Table D1 demonstrates the calculation of the H_D parameter (i.e H_D = H_{FOSID}) that meets the FOSID performance goal defined in Section 10.1 using the simplified seismic risk equation (D1). Table D2 demonstrates the calculation of the H_D parameter (i.e H_D = H_{SCDF}) that meets the SCDF performance goal defined in Section 10.2. Table D3 demonstrates the calculation of margin of conservatism if the H_D parameter is selected to satisfy the FOSID performance goal defined in Section 10.1 but with sufficient conservatism to meet the SCDF performance goal specified in Section 10.2. As Table D3 in Appendix D shows, this allows a seismic margin of approximately 1.7 to be achieved which is in line with international requirements. The latter approach is advantageous as it avoids the use of two different H_D values for the same design and leads to the use of one uniform hazard response spectrum in satisfying the FOSID and SCDF performance goals. Furthermore, using the FOSID performance goal as a basis for calculating the H_D parameter leads to a higher value for H_D. This means that the reference UHRS is estimated in the domain where the seismic data may be reasonably well constrained. If the SCDF performance goal is used instead, a lower value for H_D is obtained (compare Table D1 and D2), which may occur in the domain where the seismic data is not reasonably well constrained. Finally, Tables D4 and D5 demonstrate the calculation of H_D parameters that directly meet the performance goal for the operating basis earthquake ground motion (P_{OBEGM}) and the performance goal for seismic-induced large early release frequency (P_{SLERF}), respectively.

It is important to note that while the combination of the design factor *DF* and the hazard exceedance frequency H_D is important in obtaining the achieved performance goal, the particular choice of H_D and *DF* values is rather arbitrary. Many other combinations that essentially give the same results for any H_D and *DF* pair exist. Therefore the reason for a particular choice of H_D and *DF* is practical convenience. The advantage of the flexibility in the choice of H_D and *DF* pair is that, where possible, it allows the reference UHRS to be estimated in the domain where the seismic data may be reasonably constrained.

Note that the achieved target performance goal values that are listed in Tables D1-D5 for illustrative purposes are defined relative a design assumed to be characterised by fragilities values: β = 0.3; 0.4; 0.5; 0.6 and located on a site which is characterized by seismic hazard curve slopes: A_R = 2.0; 2.25, 2.5 …6.0. No weights were applied to favour the most probable fragility values and hazard slope values. Shallow seismic hazard curve slopes ($A_R < 2$) are not included as these can be dealt with by introducing a conservative bias.

It is also important to note that each target performance goal in Tables D1-D5 is achieved with a significant degree of variability. This degree of variability in achieved target performance goal values cannot be avoided for any simple criteria that are independent of β because target performance goal values vary by about a factor of two as a function of β. However, the main objective is achieved by specifying *DF* values that accurately achieve the target performance goal for low variability failure modes (β between 0.3 and 0.4) while accepting increased conservatism for larger variability failure modes (β larger than 0.4). The inherent variability in the values of the achieved performance goal means that the overall performance goal achieved can be represented by a median and or mean value μ and a standard deviation σ. These statistical parameters are summarized at the bottom of each table.

The calculations in Appendix D are based on the assumption that inelastic deformation directly causes the associated hazard, i.e. SID (significant inelastic deformation) leads to Core Damage, and/or Large Early Release. On this basis the analysis shows that the seismic design basis would have to take into account seismic events of frequency higher than the corresponding Safety Goal by a factor of ten. In reality the frequency of SID does not correlate to (public or operator) fatality frequencies or doses directly. Therefore in terms of PSA, which explicitly models the event sequences and phenomena on a best-estimate basis, the seismic core damage frequency (CDF) and large early release frequency (LERF) would be somewhat lower than the original safety goals, which are based on SID. Similarly the deterministic seismic and structural analysis, using site-specific and plant-specific data on a conservative basis would show that there is a margin to SID and between SID and actual plant damage (including safety system failure, CDF, LERF, etc.).

Finally, seismic hazard levels selected for design cannot be lower than the values provided by the national seismic hazard map [**16**] or the national seismic design code [**17**] for the same region. A seismic hazard map of South Africa which shows peak ground acceleration with a probability of exceedance of 10 % in 50 years can be found in Appendix F. The national seismic hazard map is produced by the Council for Geo-Science and includes both natural and mining-induced seismicity [**16**]. Therefore it is important that mining-induced seismicity is taken into account in the evaluation of the seismic hazard.

11 REQUIREMENTS FOR EXTERNAL EVENTS OTHER THAN SEISMIC EVENTS

General requirements in the treatment of other external events are given below. It is not possible to exhaustively discuss all external events within this position paper and the material below should be regarded as a description of general principles some of which are based on the recommendations of the International Atomic Energy Agency for estimation of the design-basis hazards in its member States. The licensee should consult relevant guidelines, standards and specialist literature for detailed technical guidelines used in addressing probabilistic and deterministic analysis. There is a general lack of industry guidelines dealing with probabilistic techniques for most external events. However, all external events, including those that cannot be dealt with using conventional or established methods should be considered, characterized and used as input into the design process. Such events may include coastal erosion, exposure to corrosive environment, oil spills, jelly fish ingress, biological infestation, etc.

11.1 Geological and geotechnical hazards

Geological and geotechnical investigations at and around the site need to be performed with the following objectives:

1. The assessment of possible geological and/or geotechnical problems involving surface rupture due to faulting, liquefaction, collapse and slope instability as a consequence of an earthquake. A fault is considered capable on the basis of geological, geophysical, geodetic, or seismological data (refer to section 10.4).
2. The assessment of the potential for liquefaction and soil capacity loss needs to be evaluated for site peak ground accelerations, magnitudes, and source characteristics consistent with the design earthquake ground motions. The value of peak ground acceleration to be used for liquefaction studies needs to be evaluated based on a site-specific study
3. The evaluation of the soil characteristics (static and dynamic) so that reasonable soil characterization can be achieved in the modeling of soil structure interaction, mainly in seismic analysis. For this, it is necessary to determine depth to competent bedrock or firm bearing strata, shear wave velocity variation and average shear wave velocity
4. The evaluation of geotechnical parameters to be used in the design of the foundation for static and dynamic loads and for radiological dispersion studies through groundwater. The stability of the foundation material under dynamic, static, and seismic loading should be assessed, with a detailed description of surface and subsurface conditions (including hydrogeochemical effects) being incorporated into a geotechnical investigation program for the purposes of hazard determination and mitigation.
5. Uncertainties in the mechanical properties of the site materials need to be taken into account through appropriate studies

A number of other forms of ground failure or ground settlements should be investigated by following the guidance found in specialist literature.

11.2 External flooding

All hazards associated with external flooding events that may affect the site should be evaluated by performing a site-specific flood hazard assessment and should consider all potential sources of flooding (see for example Table G1 in Appendix G). The design input parameters should be established by deterministic methods or probabilistic methods or using a combination of the two methods. Estimated flood hazards should be compared to historical data to verify that the specified design basis conservatively exceeds the historical extreme.

The design-basis flood parameters should be defined in terms of:

— A deterministic peak flood level or a probabilistic peak-flood level corresponding to the mean hazard annual exceedance probability including the combination of flood hazards
— Estimated duration of the flood level and applicable flood combinations
— Corresponding loads associated with the design basis peak-flood level and applicable load combination (e.g. hydrostatic and/or hydrodynamic forces, debris loads, sedimentation, erosion and scour phenomenon)
— Estimated duration of loads associated with the design basis peak-flood level and applicable load combinations

11.3 Wind

11.3.1 Straight winds

Wind characteristics should be investigated by conducting regional and site-specific studies to establish design basis parameters for wind. In general, the effects of wind depend on site-specific parameters such as wind characteristics prevailing at the site, topography and plant layout. The effects of wind on plant structures are generally grouped into two different types:

— Effect of extreme values of wind pressure that can induce high forces in excess of the load carrying capacity of the structure
— Effect of moderate but quasi constant values that can induce resonance effects through the mechanism of Karman turbulence and or earoelastic flutter.

The first effect mainly depends on the general layout of buildings and structures. The results of the investigations should allow the estimation of over pressures and under pressures that can be simultaneously induced on different parts of buildings and structures. Since these effects also depend on wind direction, the investigations should show wind direction(s) prevailing at the site.

The second effect depends on the shape of the structure and generally appears only on tall and slender structures (such as stacks, poles, cooling towers, utility bridges, and relatively light-weight structures with large smooth surfaces) perpendicular to the wind direction. Thus the results of the investigations should allow the dynamic behaviour of slender structures to be evaluated to assess the potential for wind induced-resonance including the effects aerodynamic flow of wind. To accomplish this it is important that site statistics of wind speed and direction are well characterized (even in the low speed range) during investigations.

In general, the frequency and intensity of winds and pressure-loading effects, including gusts, should be considered in the assessment. Wind-propelled missiles that could have an impact on SSCs should also be considered.

Typically, extreme, normal and frequent values of wind speed and direction will be estimated from site and regional monitoring data (50 year regional data where possible but not less than 10 years). Wind speed needs to be measured at 10 m height above ground. The extreme value cannot be lower than the value provided by the national design code [**18**] for the same region. According to the national design code [**18**] the highest wind speeds occur in Beaufortwest in the Western Cape Province. The national design code gives over and under pressure distribution including variation with the height of the considered point above ground and relative values with respect to the building geometry, the wind speed and wind direction and can be used provided site effects are evaluated. In case site effects are expected to be significant, a monitoring system has to be installed and operated for a significant time period for comparison with regional data.

The frequency and intensity of winds and pressure-loading effects, including gusts, should be considered in the assessment.

11.3.2 Rotational winds due to tornadoes and missile effects

An evaluation of regional meteorological data should be carried out to assess the potential for rotational winds due to tornadoes and hurricanes at the site. Historical data and probabilistic models for the occurrence tornadoes in South Africa are presented in [**19**]. However, this data is limited by lack of historical data for tornadoes in other parts of South Africa. Therefore it is important to consult all available sources of information including oral tales, superstitions and belief systems of local communities when conducting site-specific studies. If rotational winds cannot be ruled out, standard procedures as for nuclear power plants needs to be followed for estimating design basis parameters. Wind borne missiles, tornado-induced atmospheric pressure drop and loads induced by a combination of wind and atmospheric pressure drop and tornado-induced flooding should be taken into account in the derivation of design basis parameters. The potential for wide and rapid dispersion of radionuclides by tornado type wind action should be considered.

11.4 Precipitation (rain, ice and snow)

All types of precipitation should be assessed on the basis of historic and recorded data for the region. The assessment should take into account the potential effects on amongst others:

1. Structural loading, including acute impact from heavy precipitation such as hail;
2. Cooling air or water intakes;
3. Drainage systems
4. Off-site power supplies to the site;
5. Dispersion of releases from the NPP through surface or groundwater;
6. Possibility of affecting releases from the NPP into the environment.

11.5 Abnormal temperatures and humidity

Thermal actions on buildings due to abnormal temperature changes (i.e. freezing) and humidity should be determined by considering local meteorological data, regional data, experience and national codes. Evaluation of abnormal thermal effects should take into account all possible extreme temperature conditions to which the facility may be subjected during its design life. Extreme changes in, for example, shade air temperature, solar radiation, and re-radiation, will result in variations of the temperature distribution which will induce thermal stresses within individual elements of a structure. In general, the magnitude of the thermal effects will depend on local climatic conditions, orientation of the structure, its overall mass, finishes, thermal insulation, ambient heating, ventilation and coefficient of thermal expansions of different materials. Specialist literature should be consulted for the effect of different aggregate types on the coefficient of thermal expansions of concrete.

The following potential factors should be included in the assessment of temperature and humidity on the facility:

1. Effects of sudden or prolonged extreme temperatures on plant SSCs that are important to safety;
2. Effects of condensation and evaporation on plant SSCs that are important to safety (e.g., electronic components);

The following parameters need to be considered when gathering extreme temperature data in order to derive design data:

— Maximum shade air temperature
— Minimum shade air temperature

The maximum and minimum values should not be lower and higher than the values used in the national standard for the appropriate region [**20**]. The temperature need to be monitored after construction of the facility in order to check periodically the validity of design data.

11.6 Design basis for external explosion

External explosion hazard may be related to the presence of other plants in the vicinity of the facility using or storing explosive materials such as gas, oil, chemical products or transport of such materials. There are three main types of explosion sources:

— Clouds of explosive gas
— Tanks full of gas
— Solid explosive materials.

A complete study of surrounding industrial activity and transportation by road, river, sea, train or pipe lines should be made in order to identify chemical nature and quantity of the transported substances, geographical location, frequency of occurrence of relevant accidents, storage or transport conditions and eventually protection against explosions. The approach for quantifying hazard levels can follow the guidance found in specialized literature. A general approach usually involves expressing the hazard in terms of an equivalent explosion of trinitrotoluene (TNT). This requires the estimation of equivalent

TNT mass, distance from the facility, pressure wave and duration. When applying the pressure wave to the building, it is important to take into account reflection effects on walls depending on the relative direction of walls and pressure wave propagation as well as dynamic effects due to the time variability of the pressure wave.

11.7 Aircraft crash

A design-specific assessment of the effects on the installation of the impact of a large, commercial or military aircraft is required.

11.7.1 Design Basis Aircraft

For the design basis analysis (down to 10^{-6}/annum), a representative design basis aircraft crash should be postulated. The design basis aircraft impact loads should also be conservatively selected from the aircraft considered in the hazard study undertaken for the specific site. As a minimum a representative military aircraft should be considered. The design should make some provision (based on current knowledge) to account for future air traffic developments in the vicinity of the specific site.

The nuclear installation should be designed to withstand the impact of this design basis aircraft crash (including the potential aircraft fuel ignition) without loss of any safety function. This requirement applies to power reactors and critical facilities where the crash frequency is greater than 10^{-6}/annum.

11.7.2 Beyond design basis aircraft

For the beyond design basis aircraft analysis (below 10^{-6}/annum), a representative beyond design basis aircraft crash should be postulated. Aircraft impact loads will be based on aircraft crashes into a critical building/facility, identified in the hazard study as having a probability of occurrence less than 10^{-6} per annum. The design should be based on updated data and should therefore also take into account future developments in aircraft design and air travel movements.

The postulated beyond design basis aircraft should considered representative large commercial, and military aircraft. The analysis of this accident should demonstrate that, even though the building may be damaged, the structural integrity will be maintained and so ensure continued compliance the NNR risk criteria.

Using realistic analyses, the identification and incorporation into the design of those features and functional capabilities are required such that,

— the event does not cause damage which would lead to an immediate release of significant amounts of radioactive substances to the environment

— In spite of later consequences of the event (e.g. fire at the plant site), the most important safety functions can be maintained with adequate certainty for such a long time that the consequences of the crash can be repaired without release of significant amounts of radioactive substances to the environment.

and with reduced use of operator actions:

— in spite of the direct consequences of the event the most important safety functions can be started with adequate certainty; and the reactor core remains cooled,
— Spent fuel cooling and spent fuel pool integrity is maintained.

11.8 Missiles

Investigations should be undertaken according to appropriate procedures to derive design basis parameters for resistance against other missiles not addressed by the design basis events discussed in Section 8 (i.e. explosive generated missiles). The response of a structure or barrier to missile impact depends largely on the location of impact (e.g. midspan of a slab or near a support), on the dynamic properties of the target and missile, and on the kinetic energy of the missile. Therefore this hazard can only be analyzed when some level of details about the design exist including the layout of plant structures.

Analysis procedures selected for conducting investigations should be adequately justified. In general, the assumption of plastic collisions is acceptable, where all of the missile's initial momentum is transferred to the target and only a portion of its kinetic energy is absorbed as strain energy within the target. However, where elastic impacts are expected, the additional momentum transferred to the target by missile rebound should be considered in the analyses. After it has been demonstrated that the missile will not penetrate the barrier, an equivalent static load concentrated at the impact area should then be determined, from which the structural response, in conjunction with other design loads, can be evaluated using conventional design methods.

11.9 Meteorological conditions

Meteorological conditions at the site and in the surrounding area should be considered in determining the acceptability of a site to:

a) ensure that these conditions will not compromise the plant's safety,

b) provide descriptions of meteorological characteristics at or near the site to facilitate making atmospheric dispersion estimates for both postulated accidental and expected routine airborne releases of effluents, and

c) compare offsite data sources for determining the appropriateness of climatological data considered during the plant phase.

Meeting these requirements provides assurance that severe weather conditions will not compromise the safety of the proposed nuclear power plant and that sufficient meteorological data are available to make representative estimates of atmospheric dispersion.

At least one cycle of onsite meteorological data (and preferably more whole years) should be provided. This requires the applicant to establish an onsite meteorological monitoring program and a database collection and management system to handle the resulting database. The onsite data should provide an acceptable basis for:

(1) making estimates of atmospheric dispersion for design basis accident, and

(2) the long-term atmospheric dispersion estimates for routine releases from a nuclear installation or nuclear installations that might be constructed on the proposed site.

The description of onsite meteorological data submitted to the NNR should also include the description of the monitoring programme established to gather and monitor the data. The monitoring programme description should cover the following items:

1. a site map (drawn to scale) that shows tower location and true north with respect to man-made structures, topographic features, and other features that may influence site meteorological measurements
2. distances to nearby obstructions of flow in each downwind sector
3. measurements made
4. elevations of measurements
5. exposure or instruments
6. instrument descriptions
7. instrument performance specifications
8. calibration and maintenance procedures and frequencies
9. data output and recording systems
10. data processing, archiving, and analysis procedures

Guidance on a suitable onsite meteorological monitoring program to provide the required meteorological data can be found in specialized literature.

12 CONCLUSIONS

The purpose of this document was to outline requirements for conducting site investigations for external events, demonstrate the derivation of target safety goals which are required when establishing the design basis parameters for the design of nuclear installations against external events using performance-goal based approach and to clarify the NNR position on the selection of design basis hazard levels applicable to new nuclear installations.

13 REFERENCES

[1] Licensing of sites for new nuclear installations, Regulation R.927 published in Government Gazette 34735, 11 November 2011

[2] Requirements on Risk Assessment and Compliance with Principal Safety Criteria for Nuclear Installations, RD-0024, SA National Nuclear Regulator, 2008

[3] Site Evaluation for Nuclear Installations, Safety Series No. NS-R-3, IAEA, Vienna, 2003

[4] Authorisations for nuclear installation, National Nuclear Regulator, Position paper PP-0009, 2011

[5] External Human Induced Events in Site Evaluation for Nuclear Power Plants, Safety Guide No. NS-G-3.1, IAEA, Vienna, 2002

[6] External Events Excluding Earthquakes in the Design of Nuclear Power Plants, Safety Series No. NS-G-1.5, IAEA, Vienna, 2003

[7] Meteorological Events in Site Evaluation for Nuclear Power Plants, Safety Guide No. NS-G-3.4, IAEA, Vienna, 2003

[8] Flood Hazard for Nuclear Power Plants on Coastal and River Sites, Safety Guide No. NS-G-3.5, IAEA, Vienna, 2003

[9] Extreme External Events in the Design and Assessment of Nuclear Power Plants, IAEA-TECDOC 1341, Vienna, 2003

[10] Requirements for authorization submissions involving computer software and evaluation models, RD-0016, SA National Nuclear Regulator, 2006

[11] Consideration of external events in the design of facilities other than nuclear power plants, with emphasis on earthquakes, IAEA TECDOC 1347, Vienna, 2003

[12] Recommendations for Probabilistic Seismic Hazard Analysis: Guidance on Uncertainty and the Use of Experts, NUREG/CR 6372, US NRC, 1997

[13] A performance-based approach to define the site-specific earthquake ground motion, RG 1.208 US NRC, 2007

[14] Seismic hazards in site evaluation for nuclear installations, Safety Series No. SSG-9, IAEA, Vienna, 2010

[15] Seismic Design Criteria for Structures, Systems, and Components in Nuclear Facilities, American Society of Civil Engineers/Structural Engineering Institute, ASCE/SEI 43-05, 2005

[16] Probabilistic seismic-hazard maps for South Africa. Version 1, Council for Geoscience. Pretoria, 2003

[17] Basis of structural design and actions for buildings and industrial structures, Part 4: Seismic actions and general requirements for buildings, SANS 10160-4, SABS, Pretoria, 2011

[18] Basis of structural design and actions for buildings and industrial structures, Part 3: Wind actions, SANS 10160-3, SABS, Pretoria, 2011

[19] Inkanyamba: Tornado activity in South Africa, A. M. Goliger, R.V. Milford, B. F. Adam, M. Edwards, CSIR, 1997

[20] Basis of structural design and actions for buildings and industrial structures, Part 7: Thermal actions, SANS 10160-7, SABS, Pretoria, 2011

[21] Quality and Safety Management Requirements for Nuclear Installations, RD-0034 Rev 0, SA National Nuclear Regulator

[22] Basic Licensing requirements for the PBMR, RD-0018 Rev 1, SA National Nuclear Regulator

APPENDIX A – HAZARD EXCEEDANCE PROBABILITY AND EXPOSURE TIME

The relationship between the probability of exceedance, the duration of exposure and the average return period (or recurrence interval) is given by Equation A1. Typical values of the exceedance probability for different exposure times are listed in Table A1.

$$p_0 = 1 - e^{-\frac{t}{T}} \qquad \text{A1}$$

where t is the design life or exposure time, p_0 is the probability of occurrence, and T is the return period.

Table A1: Typical values of the probability of exceedance for different exposure times

Probability of exceedance p_0 in a given exposure time t	approximate average return period T [years]	approximate average frequency H_D [per year]
50% in 50 years	70	$1.4x10^{-2}$
75% in 100 years	70	$1.4x10^{-2}$
39.3% in 50 years	100	$1x10^{-2}$
63.2% in 100 years	100	$1x10^{-2}$
10% in 50 years	500	$2x10^{-3}$
19% in 100 years	500	$2x10^{-3}$
5% in 50 years	1000	$1x10^{-3}$
10% in 100 years	1000	$1x10^{-3}$
2.5% in 50 years	2000	$5x10^{-4}$
5% in 100 years	2000	$5x10^{-4}$
0.5% in 50 years	10 000	$1x10^{-4}$
1% in 100 years	10 000	$1x10^{-4}$
0.25% in 50 years	20 000	$5x10^{-5}$
0.5% in 100 years	20 000	$5x10^{-5}$
0.1% in 50 years	50 000	$2x10^{-5}$
0.2% in 100 years	50 000	$2x10^{-5}$
0.05% in 50 years	100 000	$1x10^{-5}$
0.1% in 100 years	100 000	$1x10^{-5}$
0.025% in 50 years	200 000	$5x10^{-6}$
0.05% in 100 years	200 000	$5x10^{-6}$
0.005% in 50 years	1 000 000	$1x10^{-6}$
0.01% in 100 years	1 000 000	$1x10^{-6}$

APPENDIX B – TECHNICAL ATTRIBUTES FOR EXTERNAL EVENTS

Table B1: Summary of technical characteristics and attributes of External events

External event	Technical characteristics and attributes
Seismic activity	Probabilistic seismic analysis Establishes the frequency of earthquakes at the site Examines all credible sources Includes current information[1] Based on comprehensive data including: -Geological, seismological and geophysical -Local site topography -Historical information Reflects the composite distribution of the informed technical community Level of analysis depends on application and site complexity Aleatory and epistermic uncertainties in characterising seismic sources Aleatory and epistermic uncertainties in characterising ground motion propagation Allow estimates of: -median and mean hazard curves -fractile hazard curves -uniform hazard response spectra
High winds	Probabilistic high wind analysis Results in frequency of high winds at the site Based on site-specific data Reflects historical and recent information Uncertainties in the model and parameter values: -properly accounted for -fully propagated -allow estimates of mean hazard curve
External Flooding	Deterministic (based on probable maximum flood) or probabilistic external flooding analysis or combination of both Probabilistic results in frequency of external flooding at the site Based on site-specific data Reflects historical and recent information Uncertainties in the model and parameter values: -properly accounted for -fully propagated -allow estimates of mean hazard curve
Other	Results in frequency of occurrence at the site Based on site-specific data Reflects recent information Uses historical data or a phenomenological model or combination

[1] use of new data and speculative models not fully established in the hazard literature should be treated with caution as these may not have been sufficiently interrogated by experts in the field.

Table B2: Summary of characteristics and attributes expected for a Peer Review

Element	Characteristics and attributes
Peer Review Process	-Uses documented process -Uses as a basis for review a set of desired characteristics and attributes for the hazard evaluation method -Uses a minimum list of review topics to ensure coverage, consistency, and uniformity -Reviews other methods -Reviews application of methods -Reviews assumptions and assesses their validity and appropriateness -Reviews the result of each technical element of the method for reasonableness -Reviews modification of hazard evaluation method attributable to use of different model, techniques or tools -Reviews database, maintenance and update process
Team qualifications	-Independent with no conflicts of interest -Collectively represent expertise in all the technical elements -Expertise in the technical elements assigned to review including a traceable publication history record in peer reviewed scientific and or technical journals -Knowledge of the peer review process
Documentation	-Describes the peer review team qualifications -Describes the peer review process -Documents where hazard analysis study method does not meet desired characteristics and attributes -Assesses and documents significance of deficiencies -Describes the scope of the peer review performed -Describes all computer calculations and simulation models used to establish the design bases of safety-related SSCs -The use of software used must be demonstrated to comply with “Requirements for authorization submissions involving computer software and evaluation models” issued by the NNR -If a customized hazard-simulation model has been developed to account for site-specific conditions, a complete documentation of the technical bases of the customized model should be carried out

APPENDIX C – DERIVATION OF SAFETY GOALS FROM LICENSING CRITERIA

This Appendix demonstrates the derivation of target Safety Goals which are required when establishing the design basis parameters for the structural design of nuclear installations against external events.

C-1 Safety Goals for Fatality risk limits

Table C1 shows licensing criteria used by the NNR for the protection of plant personnel and the public against nuclear accidents (see RD-0024). The criteria are given in terms of Level 3 PSA Safety Goals to limit the death risk per year or annual number of fatalities to the values specified in the table. However, intermediate Safety Goals (in terms of Level 1 and Level 2 PSA) associated with these criteria are not explicitly specified. Intermediate target Safety Goals are required for structural design of nuclear installations against external events. For example, if known in advance, the CDF safety goal can be used as direct input in the seismic risk equation to facilitate the estimation of the design basis ground motion and margin of conservatism required for the design of safety related SSCs using the approach recommended in ASCE 43-05 [15].

Table C1: Probabilistic Licensing Criteria of the NNR

Worker or Public Risk	**Level 3 PSA Safety Goals (fatalities/annum)**	**Level 2 PSA Safety Goals (LERF - pa)**	**Level 1 PSA Safety Goals (CDF - pa)**
Worker Peak Risk (WPR)	$SGL3_{WPR} = 5 \times 10^{-5}$ fatalities/annum	$SGL2_{WPR}$	$SGL1_{WPR}$
Worker Average Risk (WAR)	$SGL3_{WAR} = 1 \times 10^{-5}$ fatalities/annum	$SGL2_{WAR}$	$SGL1_{WAR}$
Citizen Peak Risk (CPR)	$SGL3_{CPR} = 5 \times 10^{-6}$ fatalities/annum	$SGL2_{CPR}$	$SGL1_{CPR}$

In order to derive intermediate target Safety Goals based on the licensing criteria in Table C1, it is reasonable to assume that the annual death risk is proportional to the required target Safety Goal (which is represented by an annual probability of unacceptable safety or annual probability of exceeding acceptable behaviour limits). This is similar to defining a 'probability ratio[2]' between the death risk per year and the

[2] The use of probability ratios can also be found in ASCE 43-05 [15]. However, the Safety Goals recommended in ASCE 43-05 are based on PRA applications derived from operating experience but this standard gives no guidance on how safety goals should be specified in the absence of operating experience.

target Safety Goal per year and interpreting the resulting number as a factor of safety to be used in the design basis. Equations (C1-C6) show six probability ratios between the death risk per year and the target Safety Goal per year which can be defined based on the NNR criteria using the probability ratio approach.

$$\alpha L1_{WPR} = SGL3_{WPR} / SGL1_{WPR} \quad (C1)$$
$$\alpha L1_{WAR} = SGL3_{WAR} / SGL1_{WAR} \quad (C2)$$
$$\alpha L1_{CPR} = SGL3_{CPR} / SGL1_{CPR} \quad (C3)$$

$$\alpha L2_{WPR} = SGL3_{WPR} / SGL2_{WPR} \quad (C4)$$
$$\alpha L2_{WAR} = SGL3_{WAR} / SGL2_{WAR} \quad (C5)$$
$$\alpha L2_{CPR} = SGL3_{CPR} / SGL2_{CPR} \quad (C6)$$

For brevity, equations C1-C3 and C4-C6 will be represented as follows:

$$\alpha L1_{xxx} = SGL3_{xxx} / SGL1_{xxx} \quad (C7)$$
$$\alpha L2_{xxx} = SGL3_{xxx} / SGL2_{xxx} \quad (C8)$$

where $SGL1_{xxx}$ and $SGL2_{xxx}$ are the desired target Safety Goals that need to be established in order to meet the annual fatality frequency limits, $SGL3_{xxx}$. The symbols $\alpha L1_{xxx}$ and $\alpha L2_{xxx}$ represent the respective proportionality constants whose quantitative value and meaning can be chosen to satisfy two criteria. Firstly, the quantitative values for the parameters $\alpha L1_{xxx}$ and $\alpha L2_{xxx}$ can be chosen such that the annual fatality frequency requirements $SGL3_{xxx}$ are satisfied with suitable margins of conservatism. Secondly, the meaning or the units for $\alpha L1_{xxx}$ and $\alpha L2_{xxx}$ can be chosen to ensure equality between the left hand and the right hand side of Equations (C1-C6). For example, since the target Safety Goals $SGL1_{xxx}$ and $SGL2_{xxx}$ have units 'number of core damages per year' and 'number large early releases per year', and the units for the annual fatality frequency limits $SGL3_{xxx}$ are known (i.e. number of fatalities per year), one suitable definition of the units (for the parameters $\alpha L1_{xxx}$ and $\alpha L2_{xxx}$) that ensures consistency of units between the left hand and the right hand side of Equations (C1-C6) is given by the choice: $\alpha L1_{xxx}$ = number of fatalities per unit core damage and $\alpha L2_{xxx}$ = number of fatalities per unit core large early release. Thus physically, the constants $\alpha L1_{xxx}$ and or $\alpha L2_{xxx}$ can be viewed as factors of safety which represents the number of fatalities assumed (for design purposes) to occur as a result of exceeding an acceptable structural damage level leading to core damage and or large early release. This implies that a design assuming 2 fatalities per core damage is more conservative than a design assuming 1 fatality per core damage. Similarly, an assumption of 1 fatality per large early release is more conservative than an assumption of zero fatalities per large early release. The choice(s) of quantitative values for the ratios $\alpha L1_{xxx}$ and $\alpha L2_{xxx}$ and the Safety Goals $SGL1_{xxx}$ and $SGL2_{xxx}$ required to fulfil the annual fatality frequency requirements with suitable margins of conservatism are explained further below.

If the 'death risk to Safety Goal ratio' is viewed as a factor of safety as explained in the previous paragraph, the scenario $\alpha L1_{xxx} = \alpha L2_{xxx} = 1$, requires that the numerical value of the target Safety Goal is exactly equal to the numerical value of the annual fatality frequency (i.e. $SGL1_{xxx} = SGL3_{xxx}, SGL2_{xxx} = SGL3_{xxx}$). This represents a factor of safety of unity or a limiting scenario. On the other hand, the scenario $\alpha L1_{xxx} = \alpha L2_{xxx} < 1$ means that the value of the target Safety Goal is greater than the value of the annual fatality frequency (i.e. $SGL1_{xxx} > SGL3_{xxx}, SGL2_{xxx} > SGL3_{xxx}$). This scenario leads to a factor of safety that is less than unity which implies less conservatism. Conversely, the scenario $\alpha L1_{xxx} = \alpha L2_{xxx} > 1$ means that the value of the target Safety Goal is less than the value of annual fatality frequency (i.e. $SGL1_{xxx} < SGL3_{xxx}, SGL2_{xxx} < SGL3_{xxx}$). This scenario implies a factor of safety greater than unity which is conservative. Thus the desired criteria for specifying target Safety Goals are given by the following equations:

$$SGL1_{xxx} = SGL3_{xxx} / \alpha L1_{xxx}; \; \alpha L1_{xxx} \geq 1 \qquad \text{(C9)}$$

$$SGL2_{xxx} = SGL3_{xxx} / \alpha L2_{xxx}; \; \alpha L2_{xxx} \geq \alpha L1_{xxx} \geq 1 \qquad \text{(C10)}$$

Substituting the choice $\alpha L1_{WPR} = \alpha L1_{WAR} = \alpha L1_{CPR} = 1$ (i.e. $\alpha L1_{xxx} = 1$), in Equations C1-C3, leads to PSA Level 1 Safety Goals shown in the first column of Table C2. Similarly, substituting the choice $\alpha L2_{WPR} = \alpha L2_{WAR} = \alpha L2_{CPR} = 5$ (i.e. $\alpha L2_{xxx} / \alpha L1_{xxx} = 5$) leads to PSA Level 2 Safety Goals shown in the second column of Table C2. Both sets of values lie within the range of values used by most international nuclear regulatory bodies.

Table C2: Safety goal criteria for design basis and beyond design basis conditions

Level 1 PSA Safety Goals (CDF/annum) $\alpha L1_{WPR} = \alpha L1_{WAR} = \alpha L1_{CPR} = 1$	**Level 2 PSA Safety Goals (LERF/annum)** $\alpha L2_{WPR} = \alpha L2_{WAR} = \alpha L2_{CPR} = 5$
$SGL1_{WPR} = 5 \times 10^{-5}$	$SGL2_{WPR} = 1 \times 10^{-5}$
$SGL1_{WAR} = 1 \times 10^{-5}$	$SGL2_{WAR} = 2 \times 10^{-6}$
$SGL1_{CPR} = 5 \times 10^{-6}$	$SGL2_{CPR} = 1 \times 10^{-6}$

Note that this choice of safety factors or ratios is not unique and many other combinations can be chosen to achieve the same Safety Goals. This non-uniqueness can be exploited to express each set of Safety Goals in Table C2 in terms of a single goal as discussed further below.

C-2 Design basis Safety Goals

The set of PSA Level 1 Safety Goals can be reduced further and written in terms of a single goal $SGL1 = 1 \times 10^{-5}$ by noting that the choice $\alpha L1_{WPR} = 5, \alpha L1_{WAR} = 1, \alpha L1_{CPR} = 0.5$ reproduces the PSA Level 1 Safety Goals shown in the first column of Table C2 (this is similar to normalizing all the Level 1 Safety Goals by the value in the second row of Table C2). Similarly, the set of PSA Level 2 Safety Goals can be written in terms of a single goal $SGL2 = 1 \times 10^{-6}$ by making the choice $\alpha L2_{WPR} = 50, \alpha L2_{WAR} = 10, \alpha L2_{CPR} = 5$ (this is similar to normalizing all the Level 2 Safety Goals by the value in the third row of Table C2). Thus the design basis Safety Goals recommended for demonstrating compliance with the NNR requirements are:

$$SG_{CDF} = SGL1 = 1 \times 10^{-5}$$
$$SG_{LERF} = SGL2 = 1 \times 10^{-6}$$

Although derived differently, these Safety Goals are in line with international best practice.

If a risk equation that expresses target Safety Goal as a function of the hazard exceedance probability (i.e. the frequency of the design basis external event - FDBEE) and other design factors does exists in the literature, and has been fully established in design standards, it could be used to calculate the combination of the design factors and the FDBEE required to achieve a set Safety Goal (subject to NNR review and acceptance). When it is not possible to relate a Safety Goal to a hazard exceedance probability (for example when the hazard risk equation does not exist) the design basis hazard level can be obtained from the hazard curve by making a conservative assumption that the hazard exceedance probability is at least equal to the Safety Goal for design basis events as follows:

$$FDBEE = SG_{CDF}$$

C-3 Safety Goals for beyond design basis conditions and consideration of "cliff edge" effects

Since the PSA Level 1 Safety Goals listed in Table C2 have been derived based on the limiting criteria $\alpha L1_{WPR} = \alpha L1_{WAR} = \alpha L1_{CPR} = \alpha L1_{CAR} = 1$, it is evident from Equations (C2-C3) that in order to meet the CDF Safety Goal ($SG_{CDF} = 1\times10^{-5}$) with a sufficient safety margin and to avoid "cliff edge effects", the applicant needs to aim for a more conservative target Safety Goal lower than $SG_{CDF} = 1\times10^{-5}$. The recommended target Safety Goal is specified as follows:

$$TSG_{CDF} = 5\times10^{-6}$$

This target Safety Goal allows a seismic margin of approximately 1.7 to be achieved when it is used to specify the target performance goal for seismic design (for confirmation of this see Table D3 in Appendix D) which is in line with international requirements.

Similarly, for the LERF Safety Goal, the applicant needs to aim for a more conservative target Safety Goal as follows:

$$TSG_{LERF} < 1\times10^{-6}$$

The Safety Goals stated above can be stated equivalently as follows:

$$SG_{CDF} = Min(SGL1_{WPR}, SGL1_{WAR}) = 1\times10^{-5}$$
$$SG_{LERF} = Min(SGL2_{WPR}, SGL2_{WAR}, SGL2_{CPR}) = 1\times10^{-6}$$
$$TSG_{CDF} = Min(SGL1_{WPR}, SGL1_{WAR}, SGL1_{CPR}) = 5\times10^{-6}$$
$$TSG_{LERF} < Min(SGL2_{WPR}, SGL2_{WAR}, SGL2_{CPR}) < 1\times10^{-6}$$

C-4 Safety Goal for operating basis external event

In order to allow evaluation of the frequency of the operating basis event, it is also necessary to establish a Safety Goal that corresponds to the operating basis external event. The recommended Safety Goal is defined as follows:

$$SG_{OBEE} = Max(SGL1_{WPR}, SGL1_{WAR}, SGL1_{CPR}); \alpha L1_{WPR} = \alpha L1_{WAR} = \alpha L1_{CPR} = \alpha L1_{CAR} = 0.25$$
$$SG_{OBEE} = 2\times10^{-4}$$

This Safety Goal is chosen to correspond to a value for the frequency of operating basis seismic event of $FOBEE = 2 \times 10^{-3}$ which is consistent with local seismic requirements for industrial structures. The latter value is derived differently below.

C-5 Safety Goals for Dose risk limits

In addition to annual fatality limits, RD-0024 also specifies safety criteria in terms annual dose limits (Column 2 of Table C3). To derive quantitative Safety Goals based on these criteria, the annual dose limits are first expressed in terms of equivalent fatality risk limits (Re) by using a suitable conversion factor. For example, the conversion factor 1Sv = 0.04 fatalities or 1 fatality = 25 Sv (UKHSE, 2006) leads to the set of values shown in Column 3 of Table C3.

After performing the conversion calculations, the same derivation procedure described in the previous section can be applied. However, it is sufficient to note that none of the resulting values is less than values considered in the previous section and thus the corresponding Safety Goals will be enveloped by the Safety Goals derived previously based on Table C1. This is confirmed in Table C4.

The frequency of the operating basis external event can be defined from Table C4 as:

$$FOBEE = Max(SGL1_{WP\,\mathrm{Re}}, SGL1_{WA\,\mathrm{Re}}, SGL1_{CP\,\mathrm{Re}}) = 2 \times 10^{-3}$$

As noted above, this value is in line with local seismic requirements for industrial structures.

Table C3: Annual dose limits used by the NNR for licensing of nuclear installations

Worker or personnel	Dose limit (Sv/annum)	Equivalent Risk (Re) (fatalities/annum)	Equivalent Level 1 PSA Safety Goals (CDF - pa)	Equivalent Level 2 PSA Safety Goals (LERF - pa)
Worker Peak Dose (WPD)	$D_{WPD} = 50 \times 10^{-3}$	$SGL3_{WP\,\mathrm{Re}} = 2 \times 10^{-3}$	$SGL1_{WP\,\mathrm{Re}}$	$SGL2_{WP\,\mathrm{Re}}$
Worker Average Dose (WAD)	$D_{WAD} = 20 \times 10^{-3}$	$SGL3_{WP\,\mathrm{Re}} = 8 \times 10^{-4}$	$SGL1_{WA\,\mathrm{Re}}$	$SGL2_{WA\,\mathrm{Re}}$
Citizen Peak Dose (CPD)	$D_{CPD} = 25 \times 10^{-5}$	$SGL3_{CP\,\mathrm{Re}} = 1 \times 10^{-5}$	$SGL1_{CP\,\mathrm{Re}}$	$SGL2_{CP\,\mathrm{Re}}$

Table C4: Safety goal criteria for design basis and beyond design basis conditions

Equivalent Level 1 PSA Safety Goals (CDF - pa) $\alpha L1_{WP\mathrm{Re}} = \alpha L1_{WA\mathrm{Re}} = \alpha L1_{CP\mathrm{Re}} = 1$	Equivalent Level 2 PSA Safety Goals (LERF - pa) $\alpha L2_{WP\mathrm{Re}} = \alpha L2_{WA\mathrm{Re}} = \alpha L2_{CP\mathrm{Re}} = 5$
$SGL1_{WA\mathrm{Re}}$ = 2 x 10^{-3}	$SGL2_{WA\mathrm{Re}}$ = 4 x 10^{-4}
$SGL1_{WP\mathrm{Re}}$ = 8 x 10^{-4}	$SGL2_{WP\mathrm{Re}}$ = 1.6 x 10^{-4}
$SGL1_{CP\mathrm{Re}}$ = 1 x 10^{-5}	$SGL2_{CP\mathrm{Re}}$ = 2 x 10^{-6}

C-6 Surrogate Safety Goals for non-power reactor and non-rector facilities

The Safety Goals derived and discussed in the previous sections (C1-C4) have been formulated for nuclear power plants as they demand the most stringent criteria to be applied. However, the radiological hazard associated with non-power reactor and non-reactor facilities is significantly less than that expected for power reactor facilities. In this case it is necessary to apply the graded approach [11] and other risk arguments to formulate suitable Safety Goals using the simplified procedure discussed in the previous sections (C1-C4). This is done by adjusting the alpha factors $\alpha L1_{xxx}$ and $\alpha L2_{xxx}$ which relate intermediate safety goals to the principal safety criteria. It is important to recognise that the risk metrics associated with power reactor facilities do not necessarily apply to non-power reactor and non-reactor facilities and thus the resulting safety goals should be viewed as surrogate safety goals (SSG). The following sub-sections deal with the derivation of surrogate safety goals for 1) non-power reactor and 2) non-reactor facilities. Below it is assumed that the radiological hazard associated with non-power reactor facilities is less than that expected for non-reactor facilities. This is an approximate classification and it is expect that applicants will conduct a rigorous classification based on the radiological hazard associated with the facility.

C-6.1 Surrogate Safety Goals for non-power reactor facilities

Suitable surrogate safety goals for non-power reactor facilities can be evaluated by adjusting the alpha factors $\alpha L1_{xxx}$ and $\alpha L2_{xxx}$ which relate intermediate safety goals to the principal safety criteria. For example, substituting $\alpha L2_{xxx} / \alpha L1_{xxx} = 5$ and $\alpha L2_{xxx} = 1$ (i.e. $\alpha L1_{WPR} = \alpha L1_{WAR} = \alpha L1_{CPR} = 0.2$ and $\alpha L2_{WPR} = \alpha L2_{WAR} = \alpha L2_{CPR} = 1$) in Equations C1-C6 leads to the following surrogate safety goals (SSG) which can be shown to be suitable safety goals for non-power reactor facilities:

$$SSG_{CDF} = Min(SGL1_{WPR}, SGL1_{WAR}) = 5\times10^{-5}$$
$$SSG_{LERF} = Min(SGL2_{WPR}, SGL2_{WAR}, SGL2_{CPR}) = 5\times10^{-6}$$
$$TSSG_{CDF} = Min(SGL1_{WPR}, SGL1_{WAR}, SGL1_{CPR}) = 2.5\times10^{-5}$$
$$TSSG_{LERF} < Min(SGL2_{WPR}, SGL2_{WAR}, SGL2_{CPR}) < 5\times10^{-6}$$

The first goal is approximately in line with the quantitative performance goal requirement for Seismic Design Category 4 structures specified in [15]. The rest of the goals have been defined to address beyond design basis events.

C-6.2 Surrogate Safety Goals for non-reactor facilities

Substituting $\alpha L2_{xxx} / \alpha L1_{xxx} = 5$ and $\alpha L2_{xxx} = 0.5$ (i.e. $\alpha L1_{WPR} = \alpha L1_{WAR} = \alpha L1_{CPR} = 0.1$ and $\alpha L2_{WPR} = \alpha L2_{WAR} = \alpha L2_{CPR} = 0.5$) in Equations C1-C6 leads to the following surrogate safety goals which can be shown to be suitable safety goals for non-reactor facilities:

$$SSG_{CDF} = Min(SGL1_{WPR}, SGL1_{WAR}) = 1\times10^{-4}$$
$$SSG_{LERF} = Min(SGL2_{WPR}, SGL2_{WAR}, SGL2_{CPR}) = 1\times10^{-5}$$
$$TSSG_{CDF} = Min(SGL1_{WPR}, SGL1_{WAR}, SGL1_{CPR}) = 5\times10^{-5}$$
$$TSSG_{LERF} < Min(SGL2_{WPR}, SGL2_{WAR}, SGL2_{CPR}) < 1\times10^{-5}$$

It can be shown that the first goal is in line with the quantitative performance goal requirement for Seismic Design Category 3 structures specified in [15].

Notes on Appendix C:

In this appendix it is attempted to find a link between the risk limits specified in RD-0024 as principal safety criteria, and intermediate safety goals (i.e. CDF and LERF for power reactor facilities and surrogate safety goals for non-power reactor and non-reactor facilities). This is done by means of simple proportionality, which is clearly an oversimplification. Conceptually, a hypothetical Level 3 PSA is being replaced by a small set of proportionality constants with assumed values. However, it is possible to justify these assumptions as conservative because the alpha factors assumed are conservative compared to those that would be obtained in a real PSA. Therefore the simplified approach employed is sufficient for the present purpose and for establishing a link between the IAEA-style design goals for CDF and LERF and the NNR risk-based criteria.

APPENDIX D – SIMPLIFIED SEISMIC RISK EQUATION

The Simplified seismic risk equation is given in ref [**15**] as equation D1.

$$P_F = H_D e^{-f}[DF \times F_P]^{-K_H} \qquad \text{(D1)}$$

$$f = -X_P(K_H\beta) - \frac{1}{2}(K_H\beta)^2$$

$$K_H = \frac{1}{\log(A_R)}$$

$$DF = Max(1, 0.6 \times A_R^{0.8})$$

where

P_F = Target annual frequency of unacceptable seismic performance
H_D = Annual exceedance frequency at which the UHRS is defined
DF = Design factor expression chosen to achieve an H_D / P_F ratio equal to 10
F_P = Seismic margin factor of safety between the DBE ground motion input and the component seismic capacity, associated with the conditional failure probability
X_P = Standardized normal variant associated with the failure probability
A_R = Seismic hazard slope ratio
β = component fragility

Table D1: Achieved performance goal calculated from Eq. D1 to satisfy P_{FOSID} by selecting $H_D = 1x10^{-4}$

Slope Ratio A_R	Design Factor $DF = 0.6(A_R)^{0.8}$	Achieved performance goal (APG) (per year)			
		APG for β = 0.3	APG for β = 0.4	APG for β = 0.5	APG for β = 0.6
2	1.045	1.02E-05	9.51E-06	7.21E-06	6.11E-06
2.25	1.148	1.02E-05	9.18E-06	6.81E-06	5.49E-06
2.5	1.249	1.04E-05	9.15E-06	6.78E-06	5.35E-06
2.75	1.348	1.05E-05	9.23E-06	6.86E-06	5.38E-06
3	1.445	1.07E-05	9.35E-06	7.00E-06	5.47E-06
3.25	1.540	1.08E-05	9.48E-06	7.14E-06	5.59E-06
3.5	1.635	1.10E-05	9.60E-06	7.29E-06	5.73E-06
3.75	1.727	1.11E-05	9.73E-06	7.44E-06	5.86E-06
4	1.819	1.12E-05	9.84E-06	7.57E-06	5.99E-06
4.25	1.909	1.13E-05	9.95E-06	7.70E-06	6.12E-06
4.5	1.999	1.14E-05	1.01E-05	7.83E-06	6.24E-06
4.75	2.087	1.15E-05	1.02E-05	7.94E-06	6.35E-06
5	2.174	1.16E-05	1.02E-05	8.05E-06	6.46E-06
5.25	2.261	1.17E-05	1.03E-05	8.15E-06	6.56E-06
5.5	2.347	1.18E-05	1.04E-05	8.25E-06	6.66E-06
5.75	2.432	1.18E-05	1.05E-05	8.34E-06	6.76E-06
6	2.516	1.19E-05	1.05E-05	8.43E-06	6.84E-06
		Target Performance Goal = P_{FOSID} = 1.0E-05 Maximum APG = APG_{Max} = 1.19E-05 Mean APG = μ_{APG} = 8.65E-06 Median APG = μ_{APG} = 8.79E-06 Standard deviation APG = σ_{APG} =2.04E-06 Margin of conservatism = $(P_{FOSID}-\mu_{APG})/P_{FOSID}$ =14%			

Table D2: Achieved performance goal calculated from Eq. D1 to satisfy P_{SCDF} by selecting $H_D = 5x10^{-5}$

Slope Ratio A_R	Design Factor $DF = 0.6(A_R)^{0.8}$	Achieved performance goal (APG) (per year)			
		APG for β = 0.3	APG for β = 0.4	APG for β = 0.5	APG for β = 0.6
2	1.045	5.10E-06	4.75E-06	3.61E-06	3.06E-06
2.25	1.148	5.11E-06	4.59E-06	3.41E-06	2.74E-06
2.5	1.249	5.18E-06	4.58E-06	3.39E-06	2.67E-06
2.75	1.348	5.26E-06	4.62E-06	3.43E-06	2.69E-06
3	1.445	5.34E-06	4.67E-06	3.50E-06	2.74E-06
3.25	1.540	5.42E-06	4.74E-06	3.57E-06	2.80E-06
3.5	1.635	5.49E-06	4.80E-06	3.65E-06	2.86E-06
3.75	1.727	5.56E-06	4.86E-06	3.72E-06	2.93E-06
4	1.819	5.61E-06	4.92E-06	3.79E-06	3.00E-06
4.25	1.909	5.67E-06	4.98E-06	3.85E-06	3.06E-06
4.5	1.999	5.72E-06	5.03E-06	3.91E-06	3.12E-06
4.75	2.087	5.76E-06	5.08E-06	3.97E-06	3.18E-06
5	2.174	5.80E-06	5.12E-06	4.03E-06	3.23E-06
5.25	2.261	5.84E-06	5.16E-06	4.08E-06	3.28E-06
5.5	2.347	5.88E-06	5.20E-06	4.13E-06	3.33E-06
5.75	2.432	5.91E-06	5.24E-06	4.17E-06	3.38E-06
6	2.516	5.94E-06	5.27E-06	4.21E-06	3.42E-06
		Target Performance Goal = P_{SCDF} = 5.0E-06 Maximum APG = APG_{Max} = 5.94E-06 Mean APG = μ_{APG} = 4.32E-06 Median APG = μ_{APG} = 4.39E-06 Standard deviation APG = σ_{APG} =1.02E-06 Margin of conservatism = $(P_{SCDF}-\mu_{APG})/P_{SCDF}$ =14%			

Table D3: Achieved performance goal calculated from Eq. D1 to satisfy P_{SCDF} by selecting $H_D = 1x10^{-4}$ and an additional safety margin = 1.7

Slope Ratio A_R	Design Factor $DF = 1.7 \times 0.6(A_R)^{0.8}$	**Achieved performance goal (APG) (per year)**			
		APG for β = 0.3	APG for β = 0.4	APG for β = 0.5	APG for β = 0.6
2	1.045	2.40E-06	1.63E-06	1.24E-06	1.05E-06
2.25	1.148	2.97E-06	2.03E-06	1.51E-06	1.22E-06
2.5	1.249	3.47E-06	2.41E-06	1.79E-06	1.41E-06
2.75	1.348	3.91E-06	2.76E-06	2.05E-06	1.61E-06
3	1.445	4.29E-06	3.07E-06	2.30E-06	1.80E-06
3.25	1.540	4.63E-06	3.36E-06	2.53E-06	1.98E-06
3.5	1.635	4.93E-06	3.62E-06	2.75E-06	2.16E-06
3.75	1.727	5.20E-06	3.86E-06	2.95E-06	2.32E-06
4	1.819	5.45E-06	4.08E-06	3.14E-06	2.48E-06
4.25	1.909	5.67E-06	4.28E-06	3.31E-06	2.63E-06
4.5	1.999	5.87E-06	4.46E-06	3.47E-06	2.77E-06
4.75	2.087	6.06E-06	4.63E-06	3.63E-06	2.90E-06
5	2.174	6.22E-06	4.79E-06	3.77E-06	3.02E-06
5.25	2.261	6.38E-06	4.94E-06	3.90E-06	3.14E-06
5.5	2.347	6.53E-06	5.08E-06	4.03E-06	3.25E-06
5.75	2.432	6.66E-06	5.21E-06	4.15E-06	3.36E-06
6	2.516	6.95E-06	5.33E-06	4.26E-06	3.46E-06
		Target Performance Goal = P_{SCDF} = 5.0E-06 Maximum APG = APG_{Max} = 6.95E-06 Mean APG = μ_{APG} = 3.60E-06 Median APG = M_{APG} = 3.41E-06 Standard deviation APG = σ_{APG} =1.49E-06 Margin of conservatism = $(P_{SCDF}-\mu_{APG})/P_{SCDF}$ =28%			

Table D4: Achieved performance goal calculated from Eq. D1 to satisfy P_{OBEGM} by selecting $H_D = 2x10^{-3}$

Slope Ratio A_R	Design Factor $DF = 0.6(A_R)^{0.8}$	Achieved performance goal (APG) (per year)			
		APG for β = 0.3	APG for β = 0.4	APG for β = 0.5	APG for β = 0.6
2	1.045	2.039E-04	1.902E-04	1.443E-04	1.222E-04
2.25	1.148	2.044E-04	1.835E-04	1.363E-04	1.097E-04
2.5	1.249	2.072E-04	1.830E-04	1.355E-04	1.069E-04
2.75	1.348	2.105E-04	1.846E-04	1.373E-04	1.075E-04
3	1.445	2.138E-04	1.870E-04	1.399E-04	1.094E-04
3.25	1.540	2.168E-04	1.895E-04	1.429E-04	1.119E-04
3.5	1.635	2.196E-04	1.921E-04	1.458E-04	1.145E-04
3.75	1.727	2.222E-04	1.946E-04	1.487E-04	1.172E-04
4	1.819	2.246E-04	1.969E-04	1.515E-04	1.198E-04
4.25	1.909	2.267E-04	1.991E-04	1.541E-04	1.223E-04
4.5	1.999	2.286E-04	2.011E-04	1.566E-04	1.247E-04
4.75	2.087	2.304E-04	2.031E-04	1.589E-04	1.270E-04
5	2.174	2.321E-04	2.049E-04	1.610E-04	1.292E-04
5.25	2.261	2.336E-04	2.065E-04	1.631E-04	1.313E-04
5.5	2.347	2.350E-04	2.081E-04	1.650E-04	1.332E-04
5.75	2.432	2.363E-04	2.096E-04	1.668E-04	1.351E-04
6	2.516	2.376E-04	2.110E-04	1.685E-04	1.369E-04
		Target Performance Goal = P_{OBE} = 2 E-04 Maximum APG = APG_{Max} = 2.376E-04 Mean APG = μ_{APG} = 1.730E-04 Median APG = M_{APG} = 1.758E-04 Standard deviation APG = σ_{APG} = 4.090E-05 Margin of conservatism = $(P_{OBE}-\mu_{APG})/P_{OBE}$ =14%			

Table D5: Performance goal calculated from Eq. D1 to satisfy P_{SLERF} by selecting $H_D = 1x10^{-5}$

Slope Ratio A_R	Design Factor $DF = 0.6(A_R)^{0.8}$	Achieved performance goal (APG) (per year)			
		APG for β = 0.3	APG for β = 0.4	APG for β = 0.5	APG for β = 0.6
2	1.045	1.02E-06	9.51E-07	7.21E-07	6.11E-07
2.25	1.148	1.02E-06	9.18E-07	6.81E-07	5.49E-07
2.5	1.249	1.04E-06	9.15E-07	6.78E-07	5.35E-07
2.75	1.348	1.05E-06	9.23E-07	6.86E-07	5.38E-07
3	1.445	1.07E-06	9.35E-07	7.00E-07	5.47E-07
3.25	1.540	1.08E-06	9.48E-07	7.14E-07	5.59E-07
3.5	1.635	1.10E-06	9.60E-07	7.29E-07	5.73E-07
3.75	1.727	1.11E-06	9.73E-07	7.44E-07	5.86E-07
4	1.819	1.12E-06	9.84E-07	7.57E-07	5.99E-07
4.25	1.909	1.13E-06	9.95E-07	7.70E-07	6.12E-07
4.5	1.999	1.14E-06	1.01E-06	7.83E-07	6.24E-07
4.75	2.087	1.15E-06	1.02E-06	7.94E-07	6.35E-07
5	2.174	1.16E-06	1.02E-06	8.05E-07	6.46E-07
5.25	2.261	1.17E-06	1.03E-06	8.15E-07	6.56E-07
5.5	2.347	1.18E-06	1.04E-06	8.25E-07	6.66E-07
5.75	2.432	1.18E-06	1.05E-06	8.34E-07	6.76E-07
6	2.516	1.19E-06	1.05E-06	8.43E-07	6.84E-07
		Target Performance Goal = P_{SLERF} = 1.0E-06 Maximum APG = APG_{Max} = 1.19E-06 Mean APG = μ_{APG} = 8.65E-07 Median APG = μ_{APG} = 8.79E-07 Standard deviation APG = σ_{APG} =2.04E-07 Margin of conservatism = $(P_{SLERF}-\mu_{APG})/P_{SLERF}$ =14%			

APPENDIX E – CAPABLE FAULT PARAMETERS

This Appendix contains equations for the evaluation of the parameters T_1 and T_2 which are needed in the first definition among the criteria for a capable fault.

Evaluation of T_1

T_1 is defined and computed from the Nyquist frequency formula [E1] such that overall consistency is achieved with the NNR definition of the frequency limit for design basis events.

$$T_1 = \frac{1}{2 \times f} \qquad \text{(E1)}$$

where f = frequency limit for design basis events = 1×10^{-6}

Evaluation of T_2

T_2 is defined to achieve consistency with performance goal for the frequency of onset of significant inelastic deformation (FOSID) as well as the performance goal for seismic core damage frequency (SCDF). Therefore, given two frequencies f_1 and f_2 which correspond to the frequency of onset of significant inelastic deformation and the seismic core damage frequency performance goals, respectively, T_2 is computed from the minimum value yielded by the Nyquist frequency formula [E1] in the following expression [E2].

$$T_2 = Min\left[\frac{1}{2 \times f_1}, \frac{1}{2 \times f_2}\right] \qquad \text{(E2)}$$

where $f_1 = P_{FOSID}$ and $f_2 = P_{SCDF}$

APPENDIX F – SEISMIC HAZARD MAP OF SOUTH AFRICA

A seismic hazard map of South Africa which shows peak ground acceleration with a probability of exceedance of 10 % in 50 years is presented below (Figure F1). The map includes both natural and mining-induced seismicity.

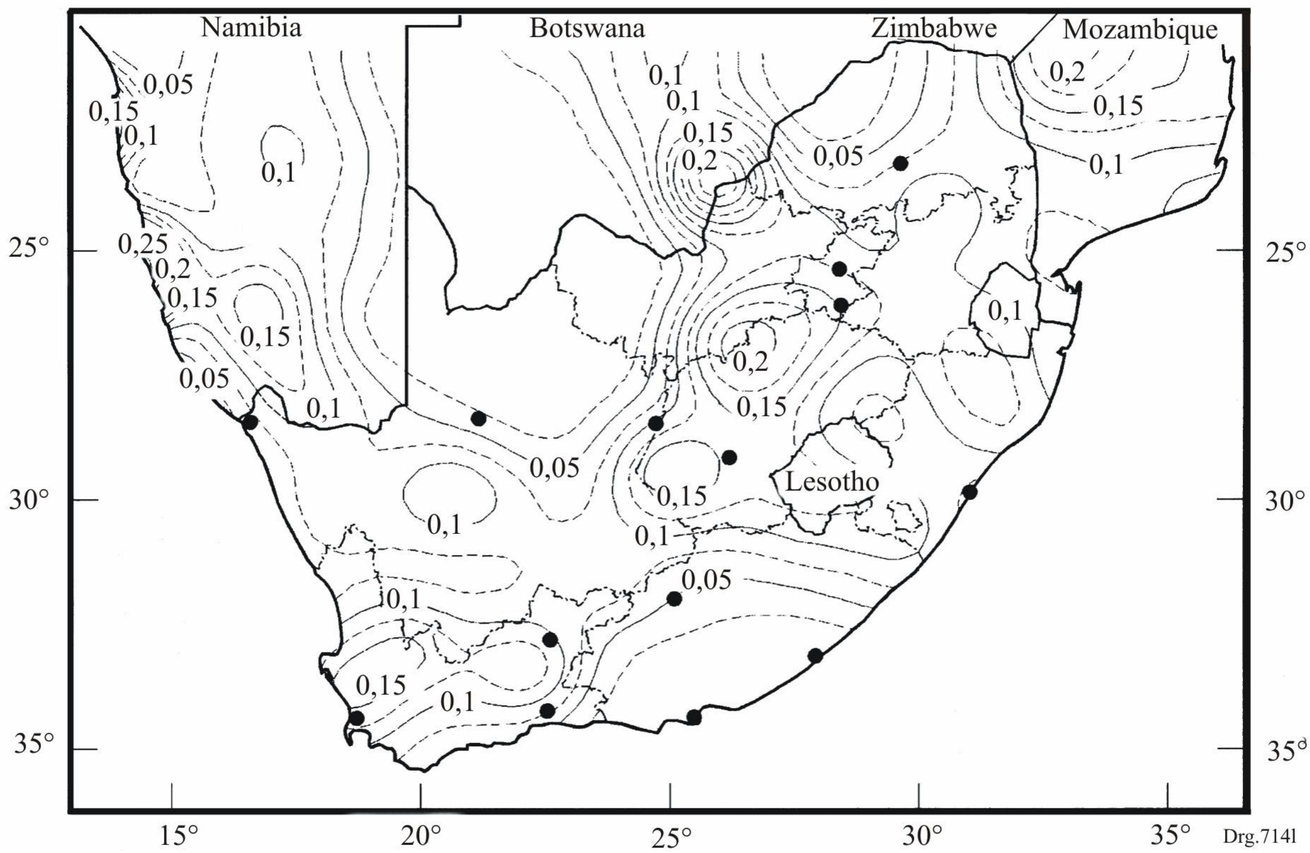

Figure F1: Seismic hazard map of South Africa

APPENDIX G – EXAMPLES OF FLOODING SOURCES

Table G1: Possible sources of flooding

Event	Sources
River flooding	Precipitation, snow melt, debris jam, ice jam, rapid sedimentation
Dam failure	Earthquake, flood, volcano, landslide, static failure
Levee or dike failure	Earthquake, flood, static failure, upstream dam failure, landslide, volcano
Flood run-off/drainage	Precipitation, ponding, drainage capacity
Tsunami	Earthquake
Seiche	Earthquake, wind
Storm surge	Hurricane
Wave	Wind, Tsunami
Groundwater	Precipitation, ponding, flooding, drought and over-pumping
Mudflows	Volcano, earthquake
Subsidence-induced flooding	Fluid extraction