Eskom

ESKOM HOLDINGS LIMITED
GENERATION DIVISION

ENVIRONMENTAL IMPACT ASSESSMENT FOR A PROPOSED NUCLEAR POWER STATION AND ASSOCIATED INFRASTRUCTURE

Seismic Hazard Environmental Impact Report

OCTOBER 2009

EXECUTIVE SUMMARY

In general the impact of a Nuclear Power Plant Station (NPS) on the geo-scientific environment is insignificant compared to the potential impact that the geo-scientific environment may have on the proposed NPS. Geo-scientific investigations are guided by Nuclear Regulatory Codes, especially U.S. Nuclear Regulations, which comprises some of the most rigorous and conservative international regulatory requirements, and requires geological and geophysical investigations of increasing resolution in concentric radii of 320, 40 and 8 km around each proposed site.

The primary hazard considered here is 'Local vibratory ground motion' resulting from geological-related seismic events (fault rupture), which, in terms of potential consequences, constitutes the most serious geo-scientific threat to a NPS. Mitigation for this hazard entails various engineering mitigation steps regarding NPS seismic design. The geo-scientific assessment that forms part of the Environmental Impact Assessment (EIA) must therefore provide evaluations to obtain an estimate of the seismic hazard including safe shutdown earthquake ground motion, the hazard for deformation at or near the surface and permit adequate engineering solutions to actual and potential geologic and seismic effects at the three proposed sites.

Seismic Hazard Analysis (SHA) entails estimating the expected level of ground motion at the site during the active and decommissioned life of the plant, based on a model of the regional and local seismicity (size and locations of recorded and potential earthquakes). All seismic hazard analyses require the same fundamental input data; a model for the occurrence of earthquakes (seismicity model) and a model for the estimation of the ground motions at a given location as a result of each earthquake scenario (ground-motion model). The seismicity and ground-motion models are combined, either probabilistically and/or deterministically, to obtain the ground motions to be considered for design. Probabilistic Seismic Hazard Analysis (PSHA) uses advanced statistical methodologies which enable the consideration of uncertainties

Seismic Hazard Analysis was previously undertaken for the three sites by the Council for Geoscience, employing a probabilistic SHA (PSHA) methodology called the Parametric-Historic PSHA. The development of the Parametric-Historic PSHA methodology by the CGS was motivated by the uncertainty and incompleteness of the seismic catalogue. In November 2000 this methodology was accepted as a valid approach to PSHA by the NNR. By December 2006 the NNR required additional international involvement and review of the existing PSHAs. Consequently the CGS PSHAs were reviewed by international experts familiar with PSHA for NPSs. Following this review, it was pointed out that the Parametric-Historic SHA methodology used to calculate these baseline figures does not fully conform to the latest guidelines set out by the US Nuclear Regulatory Commission (USNRC). One of the key reasons for this is that the way the method treats aleatory and epistemic uncertainties in seismic hazard analysis, is not consistent with current approaches for nuclear facilities. They indicated the requirement that an appropriate PSHA be carried out using expert opinion, as defined by the Senior Seismic Hazard Analysis Committee (SSHAC) in the United States. After the conclusion of a SSHAC Level 3 study the results will form the new baselines in an updated Chapter of a Site Safety Report (SSR).

The baseline values that are presently available to rank the sites for suitability, are the results obtained from the Parametric-Historic methodology, with the following PGA values calculated for each locality:

- Thyspunt 0.16g
- Bantamsklip 0.23g
- Duynefontein 0.30g

None of these exceed the PGA of 0.3g typically used in the seismic design of NPSs, although the values for the Bantamsklip and Duynefontein sites are close, or at this threshold. This will necessitate additional geological investigations and implementation of an advanced PSHA that will follow internationally accepted practice, and in particular, will conform to the requirements of a Level 3 study as defined in the SSHAC Guidelines. The above will not only confirm the reliability of the above results, but may increase or decrease these values. However, the available data indicate that the Thyspunt site has the lowest seismic risk of the three proposed NPS sites, and from a seismic point of view, Thyspunt is the preferred site of the three proposed NPS sites. Furthermore, in the light of the uncertainty as to whether the revised PSHA will result in significantly different PGA values, Thyspunt is the site with the biggest seismic margin to accommodate changes to this value.

NUCLEAR 1 ENVIRONMENTAL IMPACT ASSESSMENT AND ENVIRONMENTAL MANAGEMENT PROGRAMME

SPECIALIST STUDY FOR INCEPTION REPORT

SPECIALIST STUDY: SEISMIC HAZARD

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LIST OF ABBREVIATIONS

Abbreviation	**Description**
AEC	Atomic Energy Corporation
ARS	Acceleration Response Spectra
CFB	Cape Fold Belt
CFR	Code of Federal Regulations
CGS	Council for Geoscience
EIA	Environmental Impact Assessment
GIS	Geographic Information System
GMPE	Ground-Motion Prediction Equation
IAEA	International Atomic Energy Association
Ma	Million years before present
NECSA	Nuclear Energy Corporation of South Africa
NNR	National Nuclear Regulator
NPP	Nuclear Power Plant
NPS	Nuclear Power Station
NSIP	Nuclear Siting Investigation Programme
PGA	Peak Ground Acceleration
PNI	Palaeoseismic-Neotectonic Investigations
PNI&I	Palaeoseismic-Neotectonic Investigations and Integration
PSHA	Probabilistic Seismic Hazard Analysis
RS	Remote Sensing
SA	Site Area (< 8 km radius)
SHA	Seismic Hazard Analysis
SSE	Safe Shutdown Earthquake
SSHAC	Senior Seismic Hazard Analysis Committee
SRAFA	Safety Report And Final Assessment
SSEGM	Safe Shutdown Earthquake Ground Motion
USNRC	US Nuclear Regulatory Commission
WWSSN	World-Wide Standard Seismic Network

GLOSSARY OF TERMS

Term	Description
Annual Frequency of Exceedance (AFE)	Rate at which a given level of ground motion is exceeded. This rate results from consideration of the seismicity model (location and frequency of earthquakes of a given size) and the ground-motion model (distribution of ground motions expected at a given site conditional on a given earthquake scenario defined by the earthquake magnitude and distance from the site).
Aleatory Uncertainty	Uncertainty related to the inherent or apparent randomness of the physical processes associated with the generation and propagation of seismic waves.
Capable Fault	A capable fault" is defined (Council for Geoscience, 2004a, RGEOL/QA02/S01) as a fault exhibiting one or more of the following characteristics: • Movement at or near the ground surface at least once within the past 35,000 years or movement of a recurring nature within the past 500,000 years. • Macro-seismicity instrumentally determined with records of sufficient precision to demonstrate a direct relationship with the fault. • A structural relationship to a capable fault according to characteristics in the two foregoing criteria such that movement on one could be reasonably expected to be accompanied by movement on the other.
Catalogue	A chronological listing of earthquakes. Early catalogues were purely descriptive, i.e. they gave the date of each earthquake and some descriptions of its effect. Modern catalogues are usually quantitative, i.e. earthquakes are listed as a set of numerical parameters describing origin time, hypocenter location, magnitude, focal mechanism, moment tensor etc.
Cenozoic	An era of geologic time that spans the last 65.5 Ma.
Design Spectrum	A set of curves for design purposes that gives the spectral acceleration of a single degree of freedom oscillator as a function of natural period of vibration and damping.
Deterministic Seismic Hazard Analysis (DSHA)	Prediction of the level of ground-motion expected for a given earthquake scenario, defined by the location and size of the causative earthquake.
Earthquake	Ground shaking and radiated seismic energy caused most commonly by a sudden slip on a fault, volcanic or magmatic activity, or other sudden stress changes in the Earth.
Epicenter	The point on the earth's surfaces vertically above the hypocenter (or focus).
Epistemic uncertainty	Uncertainty related to the lack of knowledge and data limitations regarding the physical processes associated with the generation and propagation of seismic waves.
Fault	A rock fracture along which two sides show displacement relative to one another.

Ground Motion	The movement of the earth's surface from earthquakes or explosions. Ground Motion is generated by sudden slip on a fault or sudden pressure at the explosive source and travel through the earth and along its surface.
Ground Motion Parameter	Parameter characterizing the level of ground shaking at a given site. Commonly used ground-motion parameters include peak parameters (peak ground acceleration, PGA; peak ground velocity, PGV), spectral parameters (Fourier amplitude spectrum, FAS), energy-related parameters (Housner intensity, Arias intensity), duration and response ordinates (see Response spectrum).
Ground Motion Prediction Equation	Equation relating an independent variable representing the level of ground shaking (generally, the logarithm of a ground-motion parameter) to a number of explanatory variables characterizing the physical processes associated with the generation and propagation of seismic waves. Explanatory variables commonly include magnitude, source-to-site distance and a parameter characterizing local site conditions. Modern equations also include additional paramers such as style-of-faulting, hanging-wall factor and depth-to-top-of-rupture. GMPEs are derived through regression on instrumentally recorded (empirical) data or data obtained from numerical simulations. A GMPE should include a measure of the variability associated with the prediction (see Sigma).
Hazard Curve	A plot of the expected frequency of exceedance over some specified time interval of various levels of some characteristic measure of an earthquake, as magnitude or peak ground acceleration. The time period of interest is often taked as a year, in which case the curve is called the annual frequency of exeedance.
Hypocenter	The hypocenter is the point within the earth where and earthquake rupture starts. Also commonly referred to as the focus.
Local Magnitude (ML)	Local magnitude scale, also known as the Richter magnitude scale that set out to quantify the amount of seismic energy released by an earthquake. It is a logarithmic scale of the maximum amplitude in micrometres of seismic waves in a seismogram written by a standard Wood-Anderson seismograph at a distance of 100 km from the epicentre. Empirical tables were constructed to reduce measurements to the standard distance of 100 km, and the zero of the scale was fixed arbitrarily to fit the smallest earthquake then recorded. The word "magnitude" or the symbol M, without a subscript, is sometimes used when the specific type of magnitude is clear from the context, or is not really important.
Magnitude	A quantity intended to measure the size of an earthquake and is independent of place of observation. Richter magnitude or local magnitude (ML)
Magmatism	The formation of igneous rock from magma.
Mesozoic	An era of geologic time that spans the interval 251 – 65.5 Ma.
m_{max}	The maximum regional earthquake that can be generated by a seismogenic source.
Quaternary	A period in the Cenozoic era that cover the last 2.6 million years.
Peak Ground Acceleration (PGA)	The maximum acceleration amplitude measured (or expected) of an earthquake.

Pleistocene	A period in the Cenoizoic era that cover the interval between 2.6 Ma and 11,000 years before present.
Pliocene	A period in the Cenoizoic era that cover the interval between 5.3 – 2.6 Ma.
Pluton	A body of igneous rock that formed through crystallization from molten magma below the earth's surface.
Probabilistic Seismic Hazard Analysis (PSHA)	Combining available information on earthquake sources in a given region with theoretical and empirical relations among earthquake magnitude, distance from the source and local site conditions to evaluate the exceedance probability of a certain ground motion parameter at a given site during a prescribed period.
Recurrence Interval	Time interval separating, on average, the reoccurrence of earthquakes of a given size (magnitude) at a given location or on a given seismic source.
Recurrence Parameters	Parameters characterising the distribution in time of earthquakes over a given geographic region or associated with a specific seismic source, as well as their relative sizes.
Response Spectral Ordinate	Maximum response of a single-degree-of-freedom oscillator (defined by its natural period and damping level) to a given ground-motion input (generally, an acceleration time-series).
Response Spectrum	Envelope of a given response spectral ordinate (e.g., spectral acceleration) against period.
Return Period	Reciprocal of the annual frequency of exceedance of a ground motion. Not to be confused with recurrence interval, which characterises earthquakes, but not the resultant ground motion.
Seismic Hazard	The probable level of ground shaking occurring at a given point within a certain period of time. It is also used to refer to any physical phenomena associated with an earthquake and their effects on land use, man-made structure and socio-economic systems that have the potential to produce a loss.
Seismic Source	An area of seismicity probably sharing a common cause. General term used to define faults or area sources.
Seismogenic	Capable of generating earthquakes.
Shear Zone	Zone of ductile deformation between two undeformed geological blocks or bodies.
SH_{max}	Maximum horizontal stress.
Sigma	Aleatory ground-motion variability, taken equal to the standard deviation (scatter) associated with ground-motion prediction equations. Sigma has a strong influence on the shape of hazard curves derived in PSHA.
Uniform Hazard Spectrum (UHS)	Spectrum constituted by the response ordinates corresponding to the same annual frequency of exceedance or return period

1 INTRODUCTION

1.1 Background

1.1.1 General

This report is a specialist assessment of relevant palaeoseismic and seismological data for inclusion in the Environmental Impact Assessment (EIA) Report to be compiled by ARCUS GIBB (Pty) Ltd. The report describes and assesses the scope of available data and investigations and outlines the uncertainties related to available data.

The seismological assessment forms part of the Environmental Impact Assessment (EIA) and must provide evaluations to obtain an estimate of the seismic hazard including the safe shutdown earthquake ground motion, the risk for deformation at or near the surface and to permit adequate engineering solutions to actual and potential geologic and seismic effects at the proposed site.

Since the regulatory guidance set out in the US Nuclear Regulatory Commission (USNRC) Standard Review Plan NUREG-0800 is favoured by Eskom (as it is the most conservative and detailed regulatory guidance available internationally) geo-scientific information is provided with specific reference to Chapters 2.5.1 to 2.5.5 of the NUREG-0800 for a Site Safety Report (SSR). Ground motion investigations will follow NUREG 1.208.

1.1.2 Site Location and Physiography

Following a lengthy Nuclear Siting Investigation Programme (NSIP) and environmental scoping process, Eskom identified three localities along the South African south and west coast as preferred sites for Nuclear 1. They are: Duynefontein, which is located about 25 km N of Cape Town in the SW Cape at latitude 33.675° S and longitude 18.433°E (WGS84); Bantamsklip located at latitude 34.707°S and longitude 19.553°E (WGS84), about 25 km SE of Gansbaai along the SW Cape coastline; and Thyspunt, approximately 14 km west of Cape St. Francis along the Eastern Cape coastline, at latitude 34.192°S and longitude 24.715°E (WGS84) (Figure 1).

The coastline at Duynefontein is dominated by sandy beaches with intermittent ragged outcrops and gullies in quartzitic greywacke of the Tygerberg Formation of the Malmesbury Group. About 20 m of sand belonging to the Cenozoic Sandveld Group covers the bedrock at the site terrace. Light grey calcified dune sand and calcarenite crops out amongst the generally white to light grey calcareous sand of the Witzand Formation (De Beer et al., 2008).

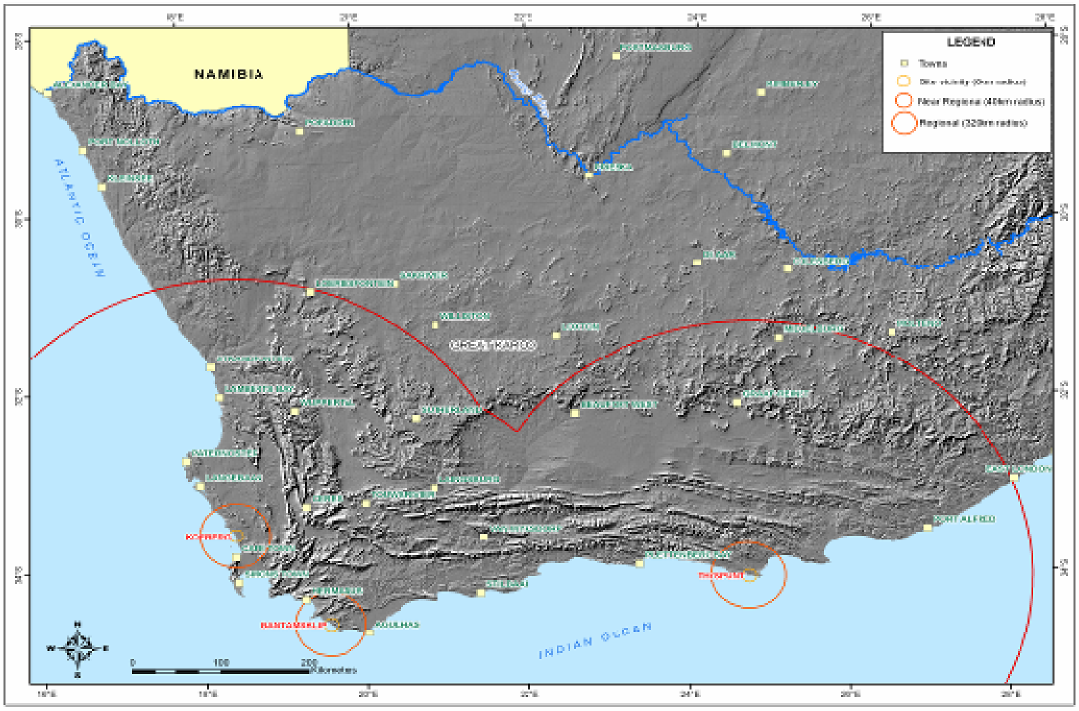

Figure 1: *The location of the three proposed sites for Nuclear 1 and regulatory radii that guide geological investigations.*

A much more rugged coastline is found at Bantamsklip dominated by ragged outcrops and gullies developed on fractured and faulted, well-bedded quartz arenites of the Peninsula Formation. A flat coastal terrace covered with white sand and grassy vegetation occurs between the rocky coastline and first dunes at Bantamsklip. Semi-consolidated, vegetated dunes persist to the road between Gansbaai and Buffelsjags, north of which lie an extensive flat sandy plain with fynbos and local wetlands. The plain ends against a relatively straight 50 m Late Pliocene shoreline eroded into hills composed of calcarenite, and laterally against promontories of resistant rocks of the Table Mountain Group.

The Thyspunt area is characterized by a relatively flat to gently seaward-sloping coastal platform. Near the coastline, this platform is covered by a remnant thin veneer of weathered Cenozoic marine and aeolian sediments, and buried by modern linear E-W dunes forming headland bypass dunefields. The landward extremity of the transgressive Miocene marine planation event that lead to the development of the platform is indicated by a palaeo-sea cliff developed along the southern foot of the fold-belt mountains.

Several headlands and small embayments dominate the coastline at Thyspunt. This is due mainly to the underlying anticlinal and synclinal fold structures. Headlands are related to the more resistant lithological units in the Table Mountain Group (e.g. Peninsula and Skurweberg Formations) and the embayments correspond to softer, more easily eroded stratigraphy in this Group (e.g. Cedarberg, Goudini and Baviaanskloof Formations), or the overlying Bokkeveld Group (e.g. Gydo Formation at the base of the Ceres Subgroup).

1.2 Study Approach

1.2.1 Regulatory Framework

The project concerns a range of proposed activities that have been identified in the schedule of activities listed in terms of section 24(4)(a) and (d) of the National Environmental Management Act, 1998 (No. 107 of 1998, as amended) in Government Notice No R 386 and R387 of 2006. Investigations required before environmental authorization of these activities can be considered must follow the procedure outlined in regulations 26 to 27 of the Environmental Impact Assessment Regulations.

The National Nuclear Regulator Act, 1999 (No. 47 of 1999) regulates the construction and running of NPSs in South Africa. In addition geological and geophysical investigations done for the siting of a new NPS are subject to international regulatory requirements (IAEA, 2002). At present there are no specific South African regulations for seismic and geological issues related to the licensing of NPS sites, and thus Eskom decided to follow the US Regulations for the probabilistic part of the Seismic Hazard Assessment (SHA) and that US Standards and practice be applied to the palaeoseismic-neotectonic investigations as well. This is because the US nuclear industry is considered to reflect the state-of-the-art and its regulations are the most conservative as well as the most readily understandable, tried and tested.

The Nuclear Regulatory Codes form the basis of all work conducted to date; therefore, compliance with these Codes and Regulations is essential. Geological and geophysical investigations are a requirement in all international regulations controlling the siting of new NPS's (see Regulatory Guide 1.208, USNRC, 2007). The necessity for such data arises in the first place from the need to identify seismic sources and to assess the potential for tectonic deformation at or near the surface, and secondly, to provide information that is necessary to calculate the local ground motions that can be expected at the site. It is a specific condition of the International Atomic Energy Agency (IAEA, 2002) that geological and geophysical studies for coastal sites should include offshore investigations of adequate size to decrease uncertainties with regard to potentially hazardous features.

The following US Nuclear Regulatory Commission codes provide regulatory guidelines for seismic and geological investigations:

- NUREG 0800 – Standard Review Plan (Revision 2 – July 1981). This Standard Review Plan is intended to guide the U.S. Office of Nuclear Reactor Regulation staff responsible for the review of applications to construct and operate NPPs. "Standard Review Plans are not substitutes for regulatory guides or the U.S. Nuclear Regulatory Commission's (NRC) regulations and compliance with them are not required". The applicable rules and basic acceptance criteria pertinent to the areas of the Standard Review Plan are set out in greater detail in:

  - 10 CFR (Code of Federal Regulations) Part 50, Appendix A, "General Design Criteria for Nuclear Power Formerly NUREG-75/087 Plants", General Design Criterion 2 – "Design Bases for Protection Against Natural Phenomena

  - 10 CFR Part 100, "Reactor Site Criteria";

  - 10 CFR100, Appendix A, "Seismic and Geologic Siting Criteria for Nuclear Power Plants".

  The following regulatory guides provide information, recommendations and guidance and in general describe a basis acceptable for implementing the requirements General Design Criterion 2, Part 100, and Appendix A to Part 100:

  - Regulatory Guide 1.132, "Site Investigations for Foundations of Nuclear Power Plants";

  - Regulatory Guide 4.7, "General Site Suitability Criteria for Nuclear Power Stations".

- Regulatory Guide 1.165 – Identification and characterization of seismic sources and determination of safe shutdown earthquake ground motion (1997)

  - This guide has been developed to provide general guidance on procedures acceptable to the USNRC for (1) conducting geological, geophysical, seismological, and geotechnical investigations, (2) identifying and characterising seismic sources, (3) conducting probabilistic seismic hazard analyses, and (4) determining the SSE for satisfying the requirements of 10 CFR 100.23 (i.e. 10 CFR 100 paragraph 23). The information collections contained in this regulatory guide are covered by the requirements of 10 CFR Part 50.

- NUREG/CR-6372 Guide – Recommendations for Probabilistic Seismic Hazard Analysis: Guidance on Uncertainty and Use of Experts, Main Report (April 1997)

  - The project resulting in this document was directed towards providing methodological guidance on how to perform a PSHA, and was prepared by the Senior Seismic Hazard Analysis Committee (SSHAC), supported by a large number of other experts working under the Committee's guidance, under contract to Lawrence Livermore National Laboratory. It was cosponsored by the U.S. Nuclear Regulatory Commission, the U.S. Department of Energy, and the Electric Power Research Institute.

- RG-1.208 A Performance-Based Approach to Define the Site-Specific Earthquake Ground Motion (2007)
    - The purpose of this regulatory guide is to provide guidance on the development of the site-specific ground motion response spectrum. This represents the first part of the assessment of the Safe Shutdown Earthquake (SSE) for a site as a characterization of the regional and local seismic hazard. It provides an alternative to using the requirements of NUREG 1.165.

1.2.2 Prescribed Study Area

For the purpose of complying with U.S. Nuclear Regulations, the area that has to be included in investigations for a NPS, is bound by concentric regulatory radii of 320, 40 and 8 km around the proposed site. The following acceptance criteria and compliance was applicable to the studies:

- **Acceptance and compliance of regions (320 km radius).** Regional geological and seismological investigations are not expected to be extensive or carried out in great detail, but should include literature reviews, the study of maps and remote sensing data, and if, necessary, ground truth reconnaissance conducted within a radius of 320 km of the site to identify seismic sources (which include both currently seismogenic and potentially capable tectonic sources).

- **Acceptance criteria and compliance of areas (40 km radius).** Geological seismological and geophysical investigations should be carried out within a radius of 40 km in greater detail than the regional investigations to identify and characterize the seismic and surface deformation potential of any capable tectonic sources and the seismic potential of seismogenic sources, or to demonstrate that such structures are not present. Sites with capable tectonic or seismogenic sources within a radius of 40 km may require more extensive geological and seismological investigations and analysis.

- **Acceptance criteria and compliance of sites (8 km radius).** Detailed geological, seismological, geophysical and geotechnical investigations should be conducted within a radius of 8 km of the site, as appropriate, to evaluate the potential for tectonic deformation at or near the ground surface and to assess the ground motion transmission characteristics of soils and rocks in the site vicinity.

1.2.3 Investigation Background

All three sites under review were the subject of geological and geophysical investigations during the Nuclear Site Investigation Programme (NSIP) performed by the AEC (now NECSA) team and its consultants for Eskom in the 1980's. During this time the AEC team produced a number of 1:50,000 scale geological maps which, together with several published (and digitally available) 1:250,000 scale CGS geological maps form the basis of the existing geological database. The CGS has been involved in seismic monitoring for Eskom since 1994. Between 1995 and 2002 the CGS also undertook micro-seismic monitoring around the sites on Eskom's behalf.

A summary of the work done up to 2002, including outcomes of audits, quality assurance, international reviews etc. is given in the Summary Report and Final Assessment (SRAFA, 2004).

Palaeoseismic investigations were carried out by the CGS between November 2003 and June 2006 (also referred to as the Palaeoseismic-Neotectonic Investigations and Integration or PNI&I). Three projects were undertaken, namely a study of coastal warping, a palaeoseismic trenching study of Quaternary reactivation along the Ceres-Kango-Baviaanskloof-Coega fault system, and an investigation into the potential for neotectonic reactivation along known and any new faults identified in the intervening coastal region (see geology section for more detail).

The work of the PNI&I project was followed by onshore and offshore geophysical investigations for the Thyspunt, Bantamsklip and Duynefontein sites, which comprised of airborne magnetic surveys aided by ground follow-up methods. These included EM, resistivity and gravity surveys, whereas offshore investigations included multibeam, side-scan sonar and magnetic surveys. None of the surveys covered the full extent of the Site Vicinity areas. The aeromagnetic survey for Thyspunt extended 25 km inland, and 2 km offshore; the latter was done to ensure overlap with the marine magnetic surveys. Both aeromagnetic and marine-magnetic surveys completely covered the 8 km Site Area of Thyspunt and providing high resolution geophysical information.

The result of the above work, including location of all geophysical anomalies, has been incorporated in the seismic hazard assessment, which has not changed from the former PNI&I investigations.

The aeromagnetic survey for Bantamsklip extended inland to 25 km from the site and covered only a narrow, less than 3 km wide offshore strip, whereas the offshore survey was limited to the Site Area.

The "regional" aeromagnetic survey for Duynefontein extended inland to 25 km from the site and in addition covered an almost 10 km wide offshore strip. The initial offshore surveys were limited to the Site Area, but this was later on expanded to include an area up to Milnerton. Marine surveys inside the Site Area were shared amongst the CGS and Fugro, whereas the whole of the Duynefontein extended marine area was surveyed by Fugro at a later stage.

The addition of as much as possible (interpretative) geophysical data to the current geological knowledge of the site as defined in the PNI&I investigations, is unable to provide definitive solutions to problems like a lack of information about the timing of last movement along faults and can only expand knowledge of the spatial distribution of potential hazards. The presentation of a revised geological model therefore does not eliminate the need for detailed palaeoseismic investigations within the SV (Site Vicinity) and the SA (Site Area), and where necessary, further afield as dictated by the complexity of the geological situation (USNRC, 2007).

During the course of 2008 detailed geological investigations (De Beer et al., 2008; Goedhart et al., 2008; Siegfried et al., 2008) were undertaken by the CGS in the 8km Site Area and 40km Site Vicinity areas of all three proposed sites. These investigations focused on geological features in order to improve the understanding of the potential geo-hazards within the respective Site Vicinity areas, but especially in terms of possible sources of seismicity and surface or near-surface deformation. The resultant data enabled the compilation of maps at 1:5,000 scale in the Site Area and 1:50,000 scale in 40km Site Vicinity.

1.2.4 Seismic Hazard Analysis Methodology

One of the most serious threats to the safe operation of a nuclear facility is caused by the vibratory motions that could be generated at the site as the result of an earthquake. In view of the severity of the potential consequences of a nuclear plant being exposed to such ground shaking, seismic ground-shaking hazard impacts both on the location and design of the plant. Therefore, substantial efforts have to be devoted to assessing this hazard by carrying out a Seismic Hazard Analysis (SHA). SHA entails calculating the level of ground motion expected at the site, based on a model of the regional and local seismicity (size and locations of earthquakes). An important consideration in the SHA is the incorporation of all identified uncertainties.

All seismic hazard analyses require the same fundamental input data; a model for the occurrence of earthquakes (seismicity model) and a model for the estimation of the ground motions at a given location as a result of each earthquake scenario (ground-motion model). The seismicity and ground-motion models are combined, either probabilistically and/or deterministically, to obtain the ground motions to be considered for design. Whilst deterministic approaches consider only a few earthquake scenarios, probabilistic analyses endeavour to consider the range of all possible scenarios, and are therefore increasingly preferred over deterministic methodologies for the assessment of seismic hazard at the sites of critical facilities.

The development of a seismicity model requires the identification and description of active seismic sources. A seismo-tectonic model integrating information from geological and geophysical investigations described previously with the information contained in the regional earthquake catalogue forms the basis for the definition of seismic sources within a region. An earthquake catalogue must list the locations, times of occurrence and magnitudes (sizes) of earthquakes together with their uncertainties.

In view of the fact that the period of time over which instrumental recordings of earthquake occurrences is extremely short compared to the typical recurrence time of the geological processes involved, it is extremely important to supplement information from instrumental recordings with historical data such as reports of felt effects from past earthquakes, as well as the often costly and time-consuming study of palaeoseismic (fossil seismic) movements along specific structures. This is particularly important for regions of low seismicity, where the infrequent occurrence of larger earthquakes limits the information content from instrumental recordings even more.

Both the deterministic and the probabilistic SHA approaches rely on a catalogue that is known to be incomplete, and it is therefore crucial that the completeness of the catalogue (in both space and time) is assessed before any conclusions are reached regarding the size of the maximum earthquake (m_{max}) or the recurrence of earthquakes of a given size. The integration of historical and paleoseismic information can improve the completeness of the catalogue and therefore significantly improve estimates of the earthquake recurrence parameters. In particular, the integration of such information can considerably increase the level of confidence attached to the value of m_{max}.

For the hazard calculations, it is customary to define seismic source zones delineating areas within which the seismicity can be considered uniform in terms of the tectonic regime, maximum earthquake size m_{max} and earthquake recurrence parameters. The latter describe the overall level of seismic activity as well as the relative frequency of occurrence of earthquakes of different sizes within a specific region.

Whilst the seismicity model describes the distribution of earthquakes in space and time, the ground-motion model describes the level of ground-motion expected at the site for a given earthquake scenario, i.e., an earthquake of a given size occurring at a given distance from the site. The ground-motion parameters most commonly used in seismic hazard calculations are peak ground acceleration (PGA) and 5%-damped elastic spectral response ordinates, generally also expressed in terms of acceleration. The spectral response ordinate at a given period represents the maximum response of a single-degree-of-freedom system to a given ground acceleration time-series. The range of response periods considered for a given project will reflect the range of fundamental periods of the various structural components and systems exposed to seismic shaking.

The level of ground motion expected at the site for a given earthquake scenario is calculated using ground-motion prediction equations (GMPEs), also known in the past as attenuation relations. These equations relate a predicted variable characterizing the level of shaking to a set of explanatory variables describing the earthquake source, wave propagation path and site conditions. GMPEs are generally specific to a given tectonic setting. In regions of low seismicity where empirical recordings of strong ground-motion data are scarce, GMPEs are generally derived from the results of numerical simulations calibrated using information retrieved from the inversion of weak-motion data

While recent equations include a number of additional terms, some factors that are known to influence the motion (and many others that are not yet known) are not included in the equations because the information is not readily available or not predictable in advance. Even for the factors that are considered in the equation, the representation of the ground motion is very simple compared to the complexity of the physical processes involved in ground-motion generation and propagation.

For regions of low seismicity such as South Africa, for which little or no indigenous strong ground-motion data exist, GMPEs from other, tectonically compatible regions need to be adopted. In previous SHA calculations carried out by CGS, the GMPEs derived for Eastern North America by Atkinson and Boore (1995, 1997) were used. Since these equations did not adequately match the shape of the attenuation curve derived from data recorded from small to moderate earthquakes, the coefficients of the original equation were adjusted by the CGS in order to improve the fit to the values of PGA and response spectra for small-to-moderate events in the Atkinson & Boore (1995) dataset.

In modern SHA, several GMPEs are generally considered in order to capture the epistemic uncertainty regarding the most appropriate GMPE to use. The selection and ranking of candidate GMPEs is a key challenge for future SHA efforts in South Africa, as it represents one of the principal sources of uncertainty in the hazard calculations (e.g., Sabetta et al., 2005). As a result of recent efforts, techniques have been derived to develop a rational framework for this selection and ranking procedure (e.g. Cotton et al., 2006).

The identification and quantification of uncertainties is an essential component of any SHA. The distinction between aleatory variability (randomness) and epistemic uncertainty (uncertainty related to the incomplete knowledge of the nature of seismicity and earthquake ground-motion prediction) is important, as these two types of uncertainty are handled differently from a formal point of view. Aleatory variability is represented using continuous probability distributions. The established tool for handling epistemic uncertainties is the logic tree, a methodology wherein branches are formed, representing the alternative models or values for each input parameter (Kulkarni et al., 1984; Scherbaum et al., 2005). Weights are assigned to the branches that reflect the relative confidence in each being the most appropriate model for the application. The hazard calculations are then performed following all the possible branch combinations in the tree, with the total weight associated with each hazard estimate being the product of the weights on the branches followed through the logic tree. This results in a distribution of weighted hazard estimates.

As a result of the numerous methodological issues encountered in early Probabilistic Seismic Hazard Analysis (PSHA) studies for nuclear facilities in the eastern United States, the Senior Seismic Hazard Analysis Committee (SSHAC) was established. The recommendations of this committee are summarised in Budnitz et al. (1997) and are hereafter referred to as the "SSHAC Guidelines". In recognition of the fact that PSHAs are conducted for a wide range of public and private facilities and that most PSHAs will be conducted with limited resources, the SSHAC Guidelines identified four different PSHA study levels, based primarily on the level of complexity of the study and the resources dedicated to it by the project sponsor. Level 1 is the simplest and least resource intensive, and Level 4 is the most complex and resource intensive. For the higher levels of study (Levels 3 and 4), the insight gained from practical applications that have been undertaken since the publication of the SSHAC Guidelines has recently been summarised in Hanks et al. (2009).

The CGS previously employed a probabilistic SHA (PSHA) methodology called the Parametric-Historic PSHA. This methodology is based predominantly on statistical inference from seismicity catalogues. The development of the Parametric-Historic PSHA methodology by the CGS was motivated by the uncertainty and incompleteness of the seismic catalogues (which is often the case). The Parametric-Historic PSHA methodology employed by the CGS was peer-reviewed internationally and accepted. It was also accepted by the NNR as a valid approach, as well as the results and the NNR accordingly stated that the approach should be applied to all Eskom nuclear sites. The NNR would only change their position after significantly new SHA methodologies became available, locally and/or internationally. Following the publication of the USNRC draft regulation DG-1146 in October 2006 (superseded by NUREG 1.208 in 2007), the NNR reviewed their earlier position in December 2006 and required additional international involvement and review of the existing PSHAs.

Subsequently, CGS engaged international experts in the conduct of PSHA for NPSs, which highlighted that the way uncertainties are treated in the Parametric Historic approach is not consistent with current global practice. A key shortcoming of the Parametric-Historic PSHA is that it does not properly address the uncertainties related to the prediction of the ground motion expected at the site: whilst the seismicity is characterised probabilistically in the Parametric-Historic PSHA, the ground-motion model is *de facto* treated in a deterministic manner. Moreover, in addition to a methodology that clearly distinguishes between aleatory variability and epistemic uncertainty and their influences on the seismic hazard estimation, the consultants recommended the adoption of a formal procedure for multiple expert assessments to capture the epistemic uncertainty. These reviewers proposed that an appropriate PSHA, such as is defined by SSHAC, be carried out. The various investigations prescribed by the SSHAC Guidelines offer an internationally accepted approach to achieve expert solicitation, with Level 3 and Level 4 studies preferred for critical facilities. The US Nuclear Regulatory Commission (US NRC) as outlined in RG 1.208 also recommends a SSHAC Level 3 or Level 4 PSHA for nuclear facilities. Details of what a Level 3 (or 4) investigation encompasses may be found in the SSHAC

Guidelines (Budnitz et al., 1997) published as NUREG/CR-6372 and in Hanks et al. (2009), but, in brief, a Level 3 investigation requires the use of multiple experts and logic-trees to assist the decision-making process when completing a PSHA.

As a result of the adoption of a standard approach to PSHA and the fundamental differences with that previously used at CGS, the ground-motion values calculated using the Parametric-Historic PSHA are not directly comparable in a meaningful manner to those calculated using a PSHA as defined in RG 1.208. Following the conclusion of a SSHAC Level 3 study, the results will be presented in an updated relevant Chapter of a Site Safety Report (SSR). However, the results obtained using the Parametric-Historic method are considered acceptable for ranking purposes and are presented in this report. The reliability of the seismic scenarios calculated using the Parametric-Historic approach, will be confirmed through further geological investigations and the information utilized in a PSHA, following internationally accepted SSHAC methodology described above.

1.2.5 Assumptions and Limitations

The descriptions and facts given here stem from published data and work undertaken by the CGS. In terms of the identification of faults and seismic risk the information represents the current knowledge and understanding based on a regional picture. New evidence of neotectonic movements may be discovered in the more detailed investigations that still have to be undertaken to look for evidence of palaeo-seismicity and can alter the understanding of the tectonics of the area as well as influence the seismic hazard and ultimately the seismic risk estimation. The assumptions and limitations applicable are:

- The current national seismic network is inadequate to reliably associate specific seismic epicentres with specific geological structures. This applies to the NSIP seismic monitoring project as well. Technically both projects have probably run long enough to satisfy standard regulatory requirements, but as southern Africa is considered to be a stable continental region, with low levels of seismicity and only a brief documented seismic history, it is important to continue seismic monitoring to increase the existing seismic database.
- Determination of the associations between geological features and seismicity will require extensive revision of the seismic catalogue, as well as palaeoseismic investigations. Assessment of the regional or local stress fields require extensive research which has not yet been undertaken; interpretation of fault capability in terms of regional stress directions can therefore at best be qualitative, having to rely on data of uncertain quality in published papers and unpublished geotechnical reports.
- One of the major uncertainties in the seismic hazard calculations concerns the most appropriate ground motion prediction equations to be used, which remain to be identified through extensive and thorough comparisons of the locally available information with the ground-motion levels predicted by the candidate equations.
- The environmental impact assessment is based on the current state of knowledge without making provision for results of the regulatory required detailed investigations for siting. The findings presented here still needs to be confirmed by a more rigorous PSHA and may increase or decrease these values.

2 DESCRIPTION OF SITES AND SURROUNDING ENVIRONMENT

The discussion in this section is not intended as an exhaustive treatise on the relevant seismic data, but rather to summarise the available data and then focus on features that may change our current view of geological hazards. The tectonic setting of the sites and presence of faults or other potentially seismogenic sources in the 320 km radii from the sites are covered.

2.1 Thyspunt

The baseline description of the geology and tectonics (both regionally and locally) relating the Thyspunt site has been discussed in greater detail in the geology section.

2.1.1 Palaeoseismicity

Within the framework of seismic hazard analysis, the “capability” of a fault is established through an analysis of its movement history within the Late Quaternary. In more specific terms, a “capable fault” is defined (10CFR100 Appendix A) as a fault exhibiting one or more of the following characteristics:

- Movement at or near the ground surface at least once within the past 35,000 years or movement of a recurring nature within the past 500,000 years.
- Macro-seismicity instrumentally determined with records of sufficient precision to demonstrate a direct relationship with the fault.
- A structural relationship to a capable fault according to characteristics in the two foregoing criteria such that movement on one could be reasonably expected to be accompanied by movement on the other.

No palaeoseismic investigations have been conducted in the immediate vicinity of the Thyspunt site. Further afield Goedhart (2006) established that the reactivation of a major Mesozoic fault occurred east of Oudtshoorn during early Holocene times.

Data indicates that the offshore Plettenberg fault has been inactive since the so-called ‘6At11 unconformity’ formed in the offshore Pletmos Basin around 117.5 Ma (million years before present). A review of the Soekor seismic profile closest to the Thyspunt site, suggests that this fault may extend into younger strata (and therefore suggest more recent activity), but it still fails to cut the much younger 15At1 regional unconformity found across the Pletmos, Gamtoos and Algoa Basins, which indicates an absence of tectonic activity since 92 Ma ago. The fault position is, however, uncertain and the possibility for Quaternary activity along the Plettenberg fault should be considered in the seismic hazard analyses. A brief review of the existing Petroleum Agency seismic reflection data shows that the offshore Plettenberg fault may have been active in the late Tertiary, and possibly even the late-Quaternary to Holocene. This is based upon the observation that the fault extends up to the sea floor, forming a significant fault scarp along two separate segments of the fault trace; at its western end and a ~60km long segment showing a sea-floor scarp occurs along the fault trace south-west of Thyspunt, where it extends SE into the NW-SE bend in the fault trace some 18km from the site. It is evident however, that the sea floor between the Plettenberg fault and the coastline south of Thyspunt is highly erosive, suggesting the scarps may also arise from differential erosion of tilted lithologies across the fault (i.e. a non-tectonic scarp).

Little evidence has hitherto been found of Cenozoic reactivation along the landward part of the Gamtoos fault, although an offshore segment has been reactivated in the Tertiary.

The small Cape St. Francis fault is known to extend to about 16 km from the site and there is secondary evidence that the offshore Cape St. Francis fault may extend into the Site Area if extended landward; its SSW dip would imply that it could be present at some depth under the site. However the AEC map for this area (AEC, 1987) does not show any on-land continuation of this fault and neither do any existing CGS maps. Subsequent geophysical and geological work could not establish the presence of this structure onshore (Goedhart et al., 2008).

The PNI&I investigation inferred an age of 126 Ma for the last movement on this fault, and found no neotectonic activity or seismicity associated with it. They therefore concluded it was an old fault with low capability for generating a significant surface rupturing seismic event. Brief review of this offshore fault during the NSIP investigation suggests that the southern NNW-SSE striking segment was last active at 116Ma, since younger overlying sediments, dated between 109.5 and 108 Ma, are not faulted (Goedhart, 2007). While this new information indicates the fault is slightly younger than initially estimated, it is not significantly so with respect to the definition of a capable fault in US regulatory Guide 10CFR 100, Appendix A. Of possible concern though, is that further NW, towards Thyspunt, younger sediments have been removed by erosion down to, and past, the 1At1 boundary. Further investigations are therefore recommended.

2.1.2 Seismic Hazard

Previously maximum possible magnitude was obtained for the background seismicity restricted to the Plettenberg, Gamtoos and Kouga/Paul Sauer Faults, following the parametric-historic approach. In addition earlier estimates of the earthquake magnitude resulting from the formation of the fault scarp along the Kango–Baviaanskloof fault was reassessed following a detailed palaeoseismic trench investigation, which suggested that fault reactivation was associated with a large earthquake (Goedhart, 2006). Using the Parametric-Historic method, a PGA of 0.16g has been calculated which forms the baseline value (SRAFA, 2004) for the Thyspunt site. While this is still to be confirmed and may change (increase or decrease), it is noteworthy that this is well below the PGA of 0.3g typically used in the seismic design of NPSs.

In the future SSHAC Level 3 PSHA study, additional information will be gathered to assign ranges of slip rates to these faults. The data in the instrumental and historical catalogues are then re-appraised, and these catalogues subsequently used to define activity rates in broad area sources of floating earthquakes that account for seismicity not directly linked to these faults. Advanced studies need to be carried out to determine a set of appropriate ground-motion prediction equations (GMPEs), using inversions of weak-motion data, stochastic simulations, and selection and ranking tools based on maximum-likelihood and information-theory approaches. The shear-wave velocity profile at the site is being determined from surface-wave measurements, to be used in site response calculations based on state-of-the-art methodologies. The hazard calculations are to be carried out using the internationally accepted Cornell-McGuire approach, and including full consideration of all epistemic and aleatory uncertainties within a rational framework.

2.1.3 Impact of Climate Change

Climate change is not expected to have any impact on the seismic risk at the proposed NPS locality.

2.2 Bantamsklip

The baseline description of the geology and tectonics (both regionally and locally) relating the Bantamsklip site has been discussed in greater detail in the geology section.

2.2.1 Palaeoseismicity

The definition of capable faults provided in section 2.1.1 is also applicable here. There is currently no evidence available of Quaternary activity and large (M>6) events on any of the above faults. This statement should, however, be seen in the following context:

- The area is located on a Mesozoic rifted margin. Quaternary deformation in this intraplate setting is therefore expected to be very slow, with seismic events that are clustered at sources that happen to be active at this point in time;
- The rate of Quaternary tectonic activity in South Africa that may form and preserve surface evidence of seismic events is much lower (possibly by several orders of magnitude) than the rate of geomorphic evolution (especially erosion) experienced by the landscape. That means that the surface evidence of such events are destroyed at a much faster rate than they are formed and their preservation potential are therefore extremely small;
- As a result of the rarity for seismogenic events to leave evidence of recent tectonic activity, determination of fault capability has to be based largely upon associations between well-located seismic events and geological structures; and
- There is a lack of a dedicated network with ample stations and the required sensitivity to monitor the smaller seismic events in the area.

No observations of evidence for strong ground motion during the latest Pleistocene and Holocene could be made because of the absence of suitable riverbank exposures. There is no primary evidence of the most recent movement of all the faults within the 40 km radius around the site. This is to a large extent the result of a lack of exposures of contacts between faulted pre-Cenozoic rocks and Cenozoic formations. It is therefore inferred that they are all geologically old faults with no Pleistocene movement history.

A WNW striking fault with the characteristics of a pre-Cenozoic fault and a damage zone some 50 m wide and 80 degrees SSW dip occurs at Celt Bay, some 3 km SE of the site (De Beer, 2007a; Siegfried et al., 2008). There is at present no evidence that the fault is capable, and there is presently no evidence that it is a risk for surface faulting. No evidence of Pleistocene activity along the Worcester fault has yet been found, but that may also be the result of high erosion rates which could remove any available evidence .

There is no evidence that any of the faults in the offshore Bredasdorp Basin have been active subsequent to the 93 Ma 15At1 unconformity. There is evidence of Late Cretaceous to early Cenozoic volcanic activity on the offshore Alphards Bank some 50 km SE from the site, and this area has only produced one M 2.2 event in 1997. Events between M 2.2 and 3.9 near Robertson may be associated with magmatism of the same general age in that area, and the proximity of the Worcester fault line.

Recent slumping in aeolianites of the area has been found to be minimal. The only large-scale palaeo-slumping detected was found to occur in the Pliocene to Early Pleistocene Wankoe Formation. Fracturing in the Cenozoic aeolianites and limited exposures of marine calcarenites have been found to be of a very limited extent and explainable in terms of generally minor epeirogenic movements, perhaps aided by seismicity. Brecciation is a common result of the calcretization of such lithological types as exposed along the whole of the South Coast; it would therefore be extremely difficult to demonstrate its relationships towards local faults in the absence of good vertical exposure.

WNW-ESE to E-W trending offshore faults on the NE margin of the Columbine-Agulhas arch, which bound the Bredasdorp Basin on its western side, may pose a larger risk to the site (although they do not seem to be currently seismically active) than NE-SW striking faults. The presence of Early Cenozoic mafic intrusive rocks on the Alphards Bank (Dingle et al., 1983) along the southeastward continuation of the WNW-ESE faults suggests that they may represent important lines of weakness in this area.

The presence of young mafic intrusive rocks SE of Cape Agulhas introduce some uncertainty regarding seismic risk in the western Bredasdorp Basin, since the Early Cretaceous Koegelfontein Complex and associated Early Cenozoic olivine melilitites on the Namaqualand coast, as well as the alkaline Gamoep Suite at Kliprand have been shown to be most probably responsible for increased seismicity in those areas.

2.2.2 Seismic Hazard

The Bantamsklip site region is characterised by a lack of recorded seismicity. The maximum earthquake for each seismogenic zone in the Cape Low province formed part of the seismic hazard for Bantamsklip and shows that the dominant source of seismic hazard is the background seismicity of the Cape Low. In the SSHAC Level 3 study, additional information is being gathered to assign ranges of slip rates to earthquakes on known faults, and the instrumental and historical earthquake catalogues are being used to define activity rates in broad area sources of floating earthquakes that account for seismicity not directly linked to these faults. Advanced studies are being carried out to determine a set of appropriate ground-motion prediction equations (GMPEs), using inversions of weak-motion data, stochastic simulations, and selection and ranking tools based on maximum-likelihood and information-theory approaches. The shear-wave velocity profile at the site needs to be determined from surface-wave measurements, and will eventually be used in site response calculations based on state-of-the-art methodologies. The hazard calculations will be carried out using the internationally accepted Cornell-McGuire approach, and including full consideration of all epistemic and aleatory uncertainties within a rational framework.

However, to date, the results yielded by the Parametric-Historic methodology represent the only values available to rank the sites for suitability. Using this method, a PGA of 0.23g has been calculated (SRAFA, 2004) for Bantamsklip, which is close to, but still below the PGA of 0.3g typically used in the seismic design of a NPS.

2.2.3 Impact of Climate Change

Climate change is not expected to have any impact on the seismic risk at the proposed NPS.

2.3 Duynefontein

The baseline description of the geology and tectonics (both regionally and locally) relating the Duynefontein site has been discussed in greater detail in geology section.

2.3.1 Palaeoseismicity

A definition for capable faults is provided in section 2.1.1. Liquefaction and intense ground deformation in the area between Melkbosstrand and Cape Town during the 1809 event are well known from historical data, but the cause of the earthquake remains un-investigated to this day. No new information could be acquired during the regional investigations.

Apart from the confirmation of a dolerite dyke displacement of unknown post-Cretaceous age no new data on this hazard were acquired during previous investigations. Reliable evidence for a large earthquake with an intensity of VIII, and ML 6.3 (Brandt *et al*., 2005) having occurred in 1809 within 25 km of Duynefontein comes from historical records of its secondary effects. The closest position to Duynefontein where liquefaction features were reported is at Bloubergsvlei (De Beer, 2007b).

Dames and Moore (1976) concluded that enough circumstantial evidence exists for the presence of a NW striking fault offshore of Duynefontein but that it does not come closer than 8 km to the site. It is however possible that such a fault could pass anywhere between 7 and 10 km offshore of Duynefontein (the inferred Melkbos Ridge fault passes 7.5 from the Koeberg NPS). No new research has been performed to confirm or refute the presence of the fault or its point of closest approach to the site. The inference that the event happened closer to Milnerton than to Duynefontein is based on the reported damage to the farmhouse at Jan Biesjes Kraal.

The Vredenburg–Stellenbosch fault zone occurs within 25 km of the site and although there is currently no evidence of it having been active in Quaternary times. The presence of extensive sand cover and intense cultivation in the area hampers the further investigation of this feature.

The only other evidence of palaeoseismic importance to the Duynefontein site is minor faulting in Pleistocene aeolianites at Saldanha which is both too far away from Duynefontein and too difficult to interpret with confidence. There is no evidence of substantial tectonic deformation in available exposures of the post-Early Pliocene to pre-Late Pleistocene Springfontyn Formation west of Duynefontein (3.6 Ma–0.2 Ma, Roberts, 2006) but exposures are discontinuous and uncertainties therefore exist as to how representative this evidence is.

2.3.2 Seismic Hazard

Previous results obtained through the Parametric-Historic method represent the baseline values that can be used to rank the sites for suitability, even though their validity will be reconfirmed through the more rigorous SSHAC approach. Based on the Parametric-Historic methodology, a PGA of 0.30g has been calculated and forms the baseline (SRAFA, 2004) for Duynefontein, which is the standard earthquake design basis used for a NPS. This value will be reconfirmed, and may decrease or increase following the conclusion of a more rigorous PSHA using the SSHAC Level 3 methodology. This study will require additional information to be gathered in order to assign ranges of slip rates to known faults. The data in the instrumental and historical catalogues will be reappraised, and these catalogues subsequently used to define activity rates in broad area sources of floating earthquakes that account for seismicity not directly linked to these faults. Advanced studies are being carried out to determine a set of appropriate ground-motion prediction equations (GMPEs), using inversions of weak-motion data, stochastic simulations, and selection and ranking tools based on maximum-likelihood and information-theory approaches. The shear-wave velocity profile at the site need to be determined from surface-wave measurements, to be used in site response calculations based on state-of-the-art methodologies. The hazard calculations are carried out using the internationally accepted Cornell-McGuire approach, and including full consideration of all epistemic and aleatory uncertainties within a rational framework.

2.3.3 Impact of Climate Change

Climate change is not expected to have any impact on the seismic risk at the proposed NPS.

2.4 Summary of Seismic Data

The most important factor that has to be considered in the seismic design of an NPS and for which various engineering mitigation steps needs to be considered, is the level of ground motion (or shaking) experienced at any given location. This is directly influenced by the two primary elements contained within a SHA; i.e. a model describing the occurrence of earthquakes in the region (the seismicity model) and a model used to estimate the resulting ground motion. The estimation of the ground motion additionally needs to account for the nature of near-surface geo-materials, which are being characterised by shear-wave velocities through in situ measurements. The models for seismic sources and ground-motion prediction will then be combined through standard PSHA calculations, and the design level of motion in terms of PGA and spectral accelerations at several response periods will be determined following the procedures outlined in RG 1.208.

3 IMPACT IDENTIFICATION AND ASSESSMENT

The assessment of potential impacts related to seismic risk is significantly interrelated to other areas of impact assessment, particularly geology. Seismic effects may differ from those of other disciplinary areas of assessment because the proposed projects or actions will not actually cause effects *on* the seismicity of an area. Rather, environmental effects are normally associated *with* seismic activity.

This section identifies and evaluates seismic conditions at the project site that could affect, or be affected by implementation of the proposed project and recommends mitigation measures to avoid or lessen potential impacts.

The proposed project could have a significant environmental impact if it would expose people or structures to potential adverse effects, involving:

- Substantial vibratory ground motion resulting from a seismic event.

3.1 Impact 1. Vibratory Ground Motion.

Stress release causes movement along known or new faults at surface or rock stress release at depth resulting in earthquakes with noticeable to severe ground movement especially in unconsolidated media, resulting in seismic shockwaves and aftershocks being transmitted with velocities and amplitudes dependent on the rock media through which they travel. They are natural phenomena, impossible to predict. The impacts of this hazard varies between the three sites and are discussed separately for each.

3.1.1 Thyspunt

Results indicate that, at this stage of the geo-scientific investigations, the seismic hazard does not preclude a standard export NPS at the proposed Thyspunt site. The most important geologic structure to consider is the offshore Plettenberg Bay Fault, and perhaps an onshore extension of the Cape St. Francis fault. Geological information along a number of existing faults has been updated, and several new and inferred faults have been identified, but to date none of them have been demonstrated to be capable.

The ground-motion hazard calculations carried out to date were conducted prior to the publication of the current industry standards such as RG 1.208 and will be replaced by the results of a standard PSHA carried out within a SSHAC Level 3 framework. These results will take the form of sets of hazard curves showing the relation of annual frequency of exceedance to the expected level of ground motion for a number of ground-motion parameters including PGA and spectral accelerations at several response periods. These hazard curves will then be used to determine design levels of motion, following the procedures outlined in RG 1.208.

With the current state of knowledge there are no disqualifiers for this site. This includes consideration of the Plettenberg and Cape St. Francis faults, although this needs to be confirmed by additional studies. The seismic hazard will be reconfirmed through implementation of the more rigorous SSHAC approach.

3.1.2 Bantamsklip

The existing geo-scientific surveys served to largely confirm the position of several known faults, and delineate some new features within the Site Region area, Site Vicinity area or the Site Area, some of which should now be added to the fault database.

The results of the surveys confirmed most of the positions of the major faults and added a better understanding of the exact position of some, e.g. the Groenkloof fault. It was concluded from extensive ground follow-up work that the “Blomerus fault” does not exist, and that this feature merely represents a Pliocene 50 m palaeo-shoreline. Evidence for the north-westward continuation for the Celt Bay fault was difficult to interpret due to possibly little lithological contrast. The Bantamsklip site is situated approximately 4.5 km away and exactly in the middle between the Mesozoic-aged Groenkloof and Elim faults. Although no evidence could be found that indicates fault activity since the Late Cretaceous, their relationships to the Miocene-Quaternary sediments of this area have never been investigated in sufficient detail.

The results of the multibeam and side-scan sonar surveys were very efficient in pointing out underwater fractures in the basement and Table Mountain Group rocks on the Bantamsklip promontory. To date no evidence of prehistoric strong ground motion could be found in this area, which presently displays very subdued seismicity, but this needs to be confirmed by future onland palaeoseismic investigations.

As noted for the Thyspunt site, the ground-motion hazard calculations carried out to date will be replaced by the results of a standard PSHA carried out within a SSHAC Level 3 framework. These results will take the form of sets of hazard curves showing the annual frequency of exceedance to the expected level of ground motion for a number of ground-motion parameters including PGA and spectral accelerations at several response periods. These hazard curves will then be used to determine design levels of motion, following the procedures outlined in RG 1.208.

Based on available data at this stage of the geo-scientific investigations, the seismic hazard does not preclude a standard export NPS at the proposed Bantamsklip site. However, this still needs to be reconfirmed by a more comprehensive PSHA.

3.1.3 Duynefontein

The recent geo-scientific surveys served to largely confirm the position of known faults, and delineate some new features within the Site Region area, Site Vicinity area or the Site Area, some of which should now be added to the fault database.

A prime objective of the surveys around Duynefontein was to find evidence of a fault that could have been responsible for the 4 December 1809 event. Several candidates have been identified in the offshore, but the onshore extension of these structures remains uncertain. The multibeam echo-sounder surveys resulted in a more accurate position for the fault scarp known to have been located by Dames and Moore (1976) about 8 km from Duynefontein. A number of additional fault features have been identified that should be included in sensitivity analyses for the seismic hazard analysis.

The ground-motion hazard calculations will be replaced by the results of a standard PSHA carried out within a SSHAC Level 3 framework. These results will take the form of sets of hazard curves showing the annual frequency of exceedance to the expected level of ground motion for a number of ground-motion parameters including PGA and spectral accelerations at several response periods. These hazard curves will then be used to determine design levels of motion, following the procedures outlined in RG 1.208.

With the current state of knowledge there are no disqualifiers for this site. This includes consideration of features possibly associated with the 1809 event. The seismic hazard will be reconfirmed by following a complete SSHAC Level 3 PSHA study.

3.2 Cumulative Impacts

Geological impacts related to the proposed development would involve hazards associated with site-specific soil conditions, erosion, and ground shaking during earthquakes. Since hazardous events of this type, as well as seismological activity, occur infrequently in this region and are separated by long periods of inactivity, the cumulative, incremental impact resulting from geological, tectonic and seismological environment is expected to be low.

When considering the three sites together, the impact on each site would be specific to that site and would not be common or contribute to (or shared with, in an additive sense) the impacts on other sites. This is because each development site has unique geologic considerations that would be subject to uniform site development and construction standards. In this way, potential cumulative impacts resulting from geological, seismic, and soil conditions would be reduced to insignificant on a site-by-site basis by construction methods and code requirements. In addition, development on the site would be subject to uniform site development and construction standards that are designed to protect public safety.

The size and nature of the geological and seismological environment is such that it is not spatially localised. This is important in cases where more than one nuclear facility may be built and operated at a specific locality. While some variation in the impact a geological hazard on individual facilities may occur, such a hazard will have an impact on all facilities present at an affected locality.

Based on current knowledge, the three localities under review are considered suitable locations for standard export NPS's following the extensive Nuclear Siting Investigation Programme (NSIP). To date no geological evidence has been found that would halt the development of a NPS at any these sites. However, a definitive statement regarding the hazard from surface fault rupture cannot be made until the foundations are excavated at the site. The final level of design ground motion has yet to be determined, but this will influence the design of the plants rather than be a site disqualifier.

4 ENVIRONMENTAL ASSESSMENT

The objective of the assessment of impacts is to identify and assess all the significant impacts that may arise as a result of the NPS. The assessment of potential impacts related to geology is significantly interrelated to other areas of impact assessment. Geology and soils effects may differ from those of other disciplinary areas of assessment because many proposed projects or actions will not actually cause effects *on* the geology of soils of an area. The existing and potential future impacts of the geological environment on the proposed development for each of the three main project phases (construction, operation, decommissioning) is listed and described below. The geological environment differs from other disciplinary areas of assessment because the proposed projects will not actually cause effects *on* the geology of soils of an area. Instead the geo-scientific environment may pose a risk to a proposed development. Also, given the long return periods employed in geo-scientific studies, the geological risk remains constant throughout the construction, operational and decommissioning phases of the project.

4.1 Impact 1. Vibratory Ground Motion

4.1.1 Thyspunt

(a) Nature of the impact

Movement along known or new faults at surface or rock stress release at depth resulting in earthquakes with noticeable to severe ground movement especially in unconsolidated media, resulting in seismic shockwaves and aftershocks being transmitted with velocities and amplitudes dependent on the rock media through which they travel. They are natural phenomena, with long return periods and can potentially occur at any time during construction, operation or decommissioning.

Criteria	***Rating Scales***	***After Mitigation***
Cumulative impacts	• Low	• Low
Nature	• Negative	• Negative
Extent (the spatial limit of the impact)	• Local to Regional.	• Local to Regional.
Intensity (the severity of the impact)	• Vary from Low – High	• Vary from Low – Medium
Duration (the predicted lifetime of the impact)	• Permanent	• Permanent
Probability (the likelihood of the impact occurring)	• Improbable	• Improbable
Reversibility (ability of the impacted environment to return to its pre-impacted state once the cause of the impact has been removed)	• Low	• Medium
Impact on irreplaceable resources (is an irreplaceable resource impacted upon)	• Yes	• Yes
Confidence level (the specialist's degree of confidence in the predictions and/or the information on which it is based)	• Medium - High	• High

(b) Intensity
The severity of ground movement can vary from Very Low to Very High.

(c) Consequence
Low - High: The intensity of this risk factor can vary from low to high, causing a resulting variation in consequence.

(d) Legal requirements
The seismic and geological investigations that assess this risk factor should follow the regulations stipulated in the National Nuclear Act and the directives of the National Nuclear Regulator.

(e) Significance
High: High and improbable

(f) Cumulative Impacts
Since this type of event is expected to occur very infrequently the cumulative impact at one locality is expected be very low. However in the case of a seismic event the effect will not be spatially localised and will impact all facilities at a specific locality (in the case where more than one facility is built and operated). However variation in the impact of a geological hazard on individual facilities may occur for a range of reasons (including engineering design).

(g) Mitigation measures

- The geotechnical and structural civil engineer shall assign the appropriate “seismic design criteria” for the design of utilities, including on-site and off-site water reservoirs.

- To provide the expected ground motions and seismic design parameters derived therefrom based on geologic, seismotectonic, palaeoseismic and instrumentally recorded events.

- Perform additional geologic investigations, aimed at reducing the uncertainties regarding the geological model for the Site Vicinity area, which represent important data that will inform the seismic design parameters used by the structural and geotechnical engineers.

4.1.2 Bantamsklip

(a) Nature of the impact
Movement along known or new faults at surface or rock stress release at depth resulting in earthquakes with noticeable to severe ground movement especially in unconsolidated media, resulting in seismic shockwaves and aftershocks being transmitted with velocities and amplitudes dependent on the rock media through which they travel. They are natural phenomena, with long return periods and can potentially occur at any time during construction, operation or decommissioning.

Criteria	*Rating Scales*	*After Mitigation*
Cumulative impacts	• Low	• Low
Nature	• Negative	• Negative
Extent (the spatial limit of the impact)	• Local to Regional.	• Local to Regional.
Intensity (the severity of the impact)	• Vary from Low – High	• Vary from Low – Medium
Duration (the predicted lifetime of the impact)	• Permanent	• Permanent
Probability (the likelihood of the impact occurring)	• Improbable	• Improbable
Reversibility (ability of the impacted environment to return to its pre-impacted state once the cause of the impact has been removed)	• Low	• Medium
Impact on irreplaceable resources (is an irreplaceable resource impacted upon)	• Yes	• Yes
Confidence level (the specialist's degree of confidence in the predictions and/or the information on which it is based)	• Medium	• High

(b) Intensity
The severity of ground movement can vary from very low to very high.

(c) Consequence
Low - High: The intensity of this risk factor can vary from low to high, causing a resulting variation in consequence.

(d) Legal requirements
The seismic and geological investigations that assess this risk factor should follow the regulations stipulated in the National Nuclear Act and the directives of the National Nuclear Regulator.

(e) Significance
High: High and improbable

(f) Cumulative Impacts
Since this type of event is expected to occur very infrequently the cumulative impact at one locality is expected be very low. However in the case of a seismic event the effect will not be spatially localised and will impact all facilities at a specific locality (in the case where more than one facility is built and operated). However variation in the impact of a geological hazard on individual facilities may occur for a range of reasons (including engineering design).

(g) Mitigation measures

- The geotechnical and structural civil engineer shall assign the appropriate "seismic design criteria" for the design of utilities, including on-site and off-site water reservoirs.

- To provide the expected maximum capable frequency dependent Peak Ground Acceleration (PGA) seismic design parameters based geologic, seismotectonic, palaeoseismic and recorded events.

- Additional geologic investigations, aimed at reducing the uncertainties regarding the geological model for the Site Vicinity area, which will provide important input informing the seismic design parameters used by the structural and geotechnical engineers.

4.1.3 Duynefontein

(a) Nature of the impact

Movement along known or new faults at surface or rock stress release at depth resulting in earthquakes with noticeable to severe ground movement especially in unconsolidated media, resulting in seismic shockwaves and aftershocks being transmitted with velocities and amplitudes dependent on the rock media through which they travel. They are natural phenomena, with long return periods and can potentially occur at any time during construction, operation or decommissioning.

Criteria	***Rating Scales***	***After Mitigation***
Cumulative impacts	• Low	• Low
Nature	• Negative	• Negative
Extent (the spatial limit of the impact)	• Local to Regional.	• Local to Regional.
Intensity (the severity of the impact)	• Vary from Low – High	• Vary from Low – Medium
Duration (the predicted lifetime of the impact)	• Permanent	• Permanent
Probability (the likelihood of the impact occurring)	• Improbable	• Improbable
Reversibility (ability of the impacted environment to return to its pre-impacted state once the cause of the impact has been removed)	• Low	• Medium
Impact on irreplaceable resources (is an irreplaceable resource impacted upon)	• Yes	• Yes
Confidence level (the specialist's degree of confidence in the predictions and/or the information on which it is based)	• Medium - High	• High

(b) Intensity

The severity of ground movement can vary from very low to very high.

(c) Consequence

Low - High: The intensity of this risk factor can vary from low to high, causing a resulting variation in consequence.

(d) Legal requirements

The seismic and geological investigations that assess this risk factor should follow the regulations stipulated in the National Nuclear Act and the directives of the National Nuclear Regulator.

(e) Significance

High: High and improbable

(f) Cumulative Impacts

Since this type of event is expected to occur very infrequently the cumulative impact at one locality is expected be very low. However in the case of a seismic event the effect will not be spatially localised and will impact all facilities at a specific locality (in the case where more than one facility is built and operated). However variation in the impact of a geological hazard on individual facilities may occur for a range of reasons (including engineering design).

(g) Mitigation measures

- The geotechnical and structural civil engineers shall assign the appropriate "seismic design criteria" for the design of utilities, including on-site and off-site water reservoirs.

- To provide the expected ground motions and seismic design parameters derived therefrom based on geologic, seismotectonic, palaeoseismic and instrumentally recorded events.

- Additional geologic investigations, aimed at reducing the uncertainties regarding the geological model for the Site Vicinity area, which will provide important input informing the seismic design parameters used by the structural and geotechnical engineers.

5 MITIGATION MEASURES

5.1 Impact 1. Vibratory Ground Motion

5.1.1 Thyspunt

Mitigation measures include:

- The geotechnical and structural civil engineers shall assign the appropriate “seismic design criteria” for the design of utilities, including on-site and off-site water reservoirs.

- To provide the expected ground motions and seismic design parameters derived therefrom based on geologic, seismotectonic, palaeoseismic and instrumentally recorded events.

- The ground motion and seismic design parameters are to be used as design input for determining the Safe Shutdown Earthquake Ground Motion (SSEGM) while the site is active as well the regulatory period after its decommissioning.

- Additional geologic investigations aimed at providing more data, will reduce the uncertainties regarding the geological model for the Site Vicinity area. This includes the finalization of outstanding issues related to fault characterization, followed by the compilation of potential source models to be from existing information, with the purpose to build a suite of alternative models that reflect the uncertainty that exists regarding the activities of identified sources. This information will then be utilized in a comprehensive PSHA that will follow internationally accepted practice.
- Continued microseismic monitoring. Compared to global seismicity southern Africa is a stable continental region, with natural earthquakes occurring sporadically in time and space. Owing to the relatively short documented seismic history of the southern African sub-continent most of the available information relates to instrumental data acquired since 1971, with data predating 1971 based on macroseismic observations.

  The US Code of Federal Regulations recommends the installation of micro-seismic monitoring networks at NPSs. Local networks should be deployed during the siting process to rate sites according to their seismic hazard potential. After the siting process, monitoring should continue so as to re-confirm the suitability of the selected site. Seismic monitoring should also continue during operation of the NPS, and even after decommissioning re-use of the site is considered.

  A single short-period seismograph should be installed on a rock outcrop in the vicinity of the Thyspunt site, thereby improving coverage of the current seismograph network and providing weak-motion data at the site that can be used to infer site response characteristics. It is also recommended that strong-motion accelerographs be installed on rock outcrops at the site.

5.1.2 Bantamsklip

Mitigation measures include:

- The geotechnical and structural civil engineers shall assign the appropriate "seismic design criteria" for the design of utilities, including on-site and off-site water reservoirs.
- To provide the expected ground motions and seismic design parameters derived therefrom based on geologic, seismotectonic, palaeoseismic and instrumentally recorded events.
- The ground motion and seismic design parameters are to be used as design input for determining the Safe Shutdown Earthquake Ground Motion (SSEGM) while the site is active as well the regulatory period after its decommissioning.
- Additional geologic investigations aimed at reducing the uncertainties regarding the geological model for the Site Vicinity area. This includes the finalization of outstanding issues related to fault characterization, followed by the compilation of potential source models to be derived from the existing information, with the purpose to build a suite of alternative models that reflect the uncertainty that exists regarding the activities of identified sources. This information will then be utilized in a full-blown PSHA that will follow internationally accepted practice.
- Continued microseismic monitoring. Compared to global seismicity southern Africa is a stable continental region, with natural earthquakes occurring sporadically in time and space. Owing to the relatively short documented seismic history of the southern African sub-continent most of the available information relates to instrumental data acquired since 1971, with data predating 1971 based on macroseismic observations.

  The US Code of Federal Regulations recommends the installation of micro-seismic monitoring networks at NPSs. Local networks should be deployed during the siting process to rate sites according to their seismic hazard potential. After the siting process, monitoring should continue so as to re-confirm the suitability of the selected site. Seismic monitoring should also continue during operation of the NPS, and even after decommissioning re-use of the site is considered.

  The CGS's Elim seismograph station will continue to monitor seismic activity in the vicinity of the Bantamsklip site. It is also recommended that strong-motion accelerographs be installed on rock outcrops at the site.

5.1.3 Duynefontein

Mitigation measures include:

- The geotechnical and structural civil engineers shall assign the appropriate "seismic design criteria" for the design of utilities, including on-site and off-site water reservoirs.
- To provide the expected ground motions and seismic design parameters derived therefrom based on geologic, seismotectonic, palaeoseismic and instrumentally recorded events.

- The ground motion and seismic design parameters are to be used as design input for determining the Safe Shutdown Earthquake Ground Motion (SSEGM) while the site is active as well the regulatory period after its decommissioning.

- Additional geologic investigations aimed at reducing the uncertainties regarding the geological model for the Site Vicinity area. This includes the finalization of outstanding issues related to fault characterization, followed by the compilation of potential source models to be derived from the existing information, with the purpose to build a suite of alternative models that reflect the uncertainty that exists regarding the activities of identified sources. This information will then be utilized in a full-blown PSHA that will follow internationally accepted practice.

- Continued microseismic monitoring. Compared to global seismicity southern Africa is a stable continental region, with natural earthquakes occurring sporadically in time and space. Owing to the relatively short documented seismic history of the southern African sub-continent most of the available information relates to instrumental data acquired since 1971, with data predating 1971 based on macroseismic observations.

  The US Code of Federal Regulations recommends the installation of micro-seismic monitoring networks at NPSs. Local networks should be deployed during the siting process to rate sites according to their seismic hazard potential. After the siting process, monitoring should continue so as to re-confirm the suitability of the selected site. Seismic monitoring should also continue during operation of the NPS, and even after decommissioning re-use of the site is considered.

  CGS will continue to monitor macro seismic activity in the vicinity of the Duynefontein using the existing seismograph network.

Impact	Extent	Intensity	Duration	Consequence	Probability	Significance	Nature	Confidence	Cumulative impact	Reversibility	Impact on irreplaceable resources
Impact 1: Vibratory Ground Motion	Local - Regional	Low - High	Permanent	Low - High	Improbable	High	-ve	High	Low	Low	Yes
With Mitigation	Local - Regional	Low - High	Permanent	Low - Medium	Improbable	High	-ve	High	Low	Medium	Yes

Table 5.1: Impact and Mitigation Table for Thyspunt.

Impact	Extent	Intensity	Duration	Consequence	Probability	Significance	Nature	Confidence	Cumulative impact	Reversibility	Impact on irreplaceable resources
Impact 1: Vibratory Ground Motion	Local - Regional	Low - High	Permanent	Low - High	Improbable	High	-ve	Medium	Low	Low	Yes
With Mitigation	Local - Regional	Low - High	Permanent	Low - Medium	Improbable	High	-ve	High	Low	Medium	Yes

Table 5.2: Impact and Mitigation Table for Bantamsklip.

Impact	Extent	Intensity	Duration	Consequence	Probability	Significance	Nature	Confidence	Cumulative impact	Reversibility	Impact on irreplaceable resources
Impact 1: Vibratory Ground Motion	Local - Regional	Low - High	Permanent	Low - High	Improbable	High	-ve	Low	Low	Low	Yes
With Mitigation	Local - Regional	Low - High	Permanent	Low - Medium	Improbable	High	-ve	Medium	Low	Medium	Yes

Table 5.3: Impact and Mitigation Table for Duynefontein.

6 CONCLUSION AND RECOMMENDATIONS

The report describes and assesses the scope of published data and investigations and outlines the uncertainties related to available data. The scope of investigations that must still be undertaken to give a meaningful input into the full seismic Hazard studies (to be incorporated into the Site Safety Report) for the different sites along the South African coastline was described above and mainly requires additional investigations at each site with respect to tectonics, palaeoseismicity, continued monitoring of current seismicity.

6.1 Thyspunt

At Thyspunt the onshore regional pre-Quaternary geology and tectonics are well understood. Seven fault sources (or fault systems) were identified as being potentially capable of generating significant seismic events. Some of the key sources are located offshore, which complicates characterization of these structures. Some of these are only inferred from geophysical exploration, while none of these faults have any correlation with seismicity nor any evidence for reactivation. Fortunately information regarding offshore structures obtained from geophysical surveys may aid in the characterisation of these structures.

Based on the current state of knowledge there are no disqualifiers for this site, but this still needs to be reconfirmed though the more rigorous SSHAC Level 3 PSHA. The implementation of the mitigation measures listed above and compliance with applicable regulations would reduce the potential impact of uncertainty on the geological and seismological risk.

6.2 Bantamsklip

At Bantamsklip the onshore regional pre-Quaternary geology and tectonics are well understood. The airborne, ground, and marine geophysical surveys conducted by the Council for Geoscience and Fugro within the Site Area (8 km radius) and part of the Site Vicinity area (40 km radius) to a large extent complimented the known onshore and offshore geology at Bantamsklip. The results of the surveys confirmed most of the positions of the major faults and added a better understanding of the exact position of some, e.g. the Groenkloof fault. From extensive ground follow-up work the “Blomerus fault” was reinterpreted as a Pliocene 50 m palaeo-shoreline.

Many faults have been identified in the region surrounding Bantamsklip, but the site is located in an area of very subdued seimicity with no evidence of prehistoric strong ground motion. Surface deposits makes the characterisation of fault capability of the numerous faults located in relatively close proximity to the proposed site location exceedingly difficult. There is consequently significant uncertainty regarding the seismotectonic model for Bantamsklip.

Based on the current state of knowledge there are no disqualifiers for this site, but this still needs to be reconfirmed though the more rigorous SSHAC Level 3 PSHA. The implementation of the mitigation measures listed above and compliance with applicable regulations would reduce the potential impact of uncertainty on the geological and seismological risk.

6.3 Duynefontein

At Duynefontein the onshore regional pre-Quaternary geology and tectonics are well understood. The airborne, ground, and marine geophysical surveys conducted by the Council for Geoscience and Fugro within the Site Area (8 km radius) and part of the Site Vicinity area (40 km radius) to a large extent complimented the known onshore and offshore geology.

A prime objective of the surveys around Duynefontein was to find evidence of a fault that could have been responsible for the 4 December 1809 Milnerton event. Several candidate structures have been identified in the offshore, but the onshore extension of these remain uncertain. The multibeam surveys resulted in a more accurate position for the fault scarp known to have been located by Dames and Moore (1976) about 8 km from Duynefontein.

Based on the current state of knowledge there are no disqualifiers for this site, but this still needs to be reconfirmed though the more rigorous SSHAC Level 3 PSHA. The implementation of the mitigation measures listed above and compliance with applicable regulations would reduce the potential impact of uncertainty on the geological and seismological risk.

6.4 Conclusion

The ground shaking hazard from earthquakes represents the most serious geological hazard impacting on the location and design of a new NPS site. Mitigation for this hazard entails definition of the seismic hazard and associated ground motion aided by appropriate geologic/seismic investigations and monitoring. As a result, hazard studies have to provide estimates of the Safe Shutdown Earthquake Ground Motion and the hazard for deformation at or near the surface.

Results indicate that, at this stage of the geo-scientific investigations, the seismic hazard does not preclude a standard export NPS at any of the proposed sites. However additional studies will still need to be completed during the course of the siting process, which may impact and even change conclusions reached to date.

International review of the Parametric-Historic methodology previously employed for SHA of these sites, does not include all the aspects recommended in the latest regulatory guides for NPPs. As a result, the ground-motion values calculated using the Parametric-Historic PSHA are not directly comparable in a meaningful manner to those calculated using a PSHA as defined in RG 1.208 and needs to be confirmed. A new and advanced Probabilistic Seismic Hazard Analysis (PSHA) will therefore be undertaken, that will follow the latest internationally accepted practice, and in particular, will conform to the requirements of a Level 3 study as defined in the SSHAC Guidelines (Budnitz et al., 1997). The results of these analyses will form the new baselines for Safe Shutdown Earthquake Ground Motions in an updated Chapter of a Site Safety Report (SSR).

The results obtained using the Parametric-Historic method represent the data that are used to inform the EIA and ranking processes. Based on the data collected from various geological investigations, including airborne, ground, and marine geophysical surveys the following PGA values were calculated for each locality using the

Parametric-Historic methodology:

- Thyspunt 0.16g
- Bantamsklip 0.23g
- Duynefontein 0.30g

None of these exceed the PGA of 0.3g typically used in the seismic design of standard export NPSs. The available data and work to date indicate that the Thyspunt site has the highest seismic margin and the lowest seismic risk of the three proposed NPS sites. In addition, in the light of the uncertainty of whether a revised PSHA, following SSHAC procedure, will result in PGA values below 0.3g, it is suggested that the site with the biggest margin to change (viz. Thyspunt) be selected as the preferred site.

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