ENVIRONMENTAL IMPACT ASSESSMENT FOR THE PROPOSED NUCLEAR POWER STATION (“NUCLEAR-1”) AND ASSOCIATED INFRASTRUCTURE

Seismic Hazard Environmental Impact Report

March 2011

Prepared by: Council for Geoscience (CGS)

Prepared for: Arcus GIBB Pty Ltd

On behalf of: Eskom Holdings Ltd

Council for Geoscience

Private Bag X 112 Pretoria 0001 SOUTH AFRICA 280 Pretoria Street Silverton Pretoria
Reception: +27 (0) 12 841 1911 Internet: http://www.geoscience.org.za

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DECLARATION OF INDEPENDENCE

We, **Erna Hattingh** and **Johann Neveling**, as duly authorised representatives of the **Council for Geoscience**, hereby confirm our independence (as well as that of the **Council for Geoscience**) as specialists and declare that neither of us or the **Council for Geoscience** have any interest, be it business, financial, personal or other, in any proposed activity, application or appeal in respect of which Arcus GIBB was appointed as environmental assessment practitioner in terms of the National Environmental Management Act, 1998 (Act No. 107 of 1998), other than fair remuneration for work performed, specifically in connection with the Environmental Impact Assessment for the proposed conventional nuclear power station ('Nuclear 1'). We further declare that we are confident in the results of the studies undertaken and conclusions drawn as a result of it – as is described in our attached report.

Full Name:	Erna Hattingh	Full Name:	Johann Neveling
Title / Position:	Project Manager	Title / Position:	Assistant Project Manager
Qualification(s):	B.Sc. (Hons.), M.Sc.	Qualification(s):	B.Sc. (Hons.), Ph.D., M.B.A.
Experience:	25 yrs	Experience:	16 yrs
Registration(s):	Pr. Sci. Nat.	Registration(s):	Pr. Sci. Nat.

EXECUTIVE SUMMARY

In general the impact of a Nuclear Power Station on the geo-scientific environment is insignificant compared to the potential impact that the geo-scientific environment may have on the proposed Nuclear Power Station. Geo-scientific investigations for nuclear sites are guided by Nuclear Regulatory Codes, especially U.S. Nuclear Regulations, which are regarded as the most comprehensive international regulatory framework, and requires geological and geophysical investigations of increasing resolution in concentric regulatory radii of 320, 40 and 8 km around each proposed site.

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 earthquakes). All seismic hazard analyses require the same fundamental input data; a model for the occurrence of earthquakes (seismic ***source*** 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 seismic source and ground-motion models are combined, either probabilistically 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.

Site specific SHA were previously undertaken for the three sites by the Council for Geoscience (CGS), employing a methodology called the Parametric-Historic SHA. ***Using this methodology, median PGA values of 0.16 g, 0.23 g and 0.30 g were calculated for the Thyspunt, Bantamsklip and Duynefontein sites, respectively and these values constitute the current seismic hazard levels for the sites.***

These results were accepted by the National Nuclear Regulator (NNR). The NNR however, imposed the condition that current state of the art for SHA should be used in the evaluation of the sites when formal applications are made for a construction and operating licence. In order to meet this requirement, Eskom has decided to follow the regulations of the United States Nuclear Regulatory Commission (or US NRC), which is considered to be the most stringent, detailed, tried and tested set of regulations in the world, and therefore describes international best practice for the SHA and the proposed licensing process with the NNR. Additionally, the United States, like South Africa, is a member state of the International Atomic Energy Association (IAEA), and as such their national legislation is compatible with the IAEA regulations.

The present Chapter of the EIR describes the work carried out to date on the seismic hazard assessment of the three sites, and provides the current positions regarding their suitability for locating nuclear power plant installations.

ENVIRONMENTAL IMPACT ASSESSMENT FOR THE PROPOSED NUCLEAR POWER STATION ('NUCLEAR-1') AND ASSOCIATED INFRASTRUCTURE
SEISMIC HAZARD

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ABBREVIATIONS

AEC	Atomic Energy Corporation
CFR	Code of Federal Regulations
CGS	Council for Geoscience
EIA	Environmental Impact Assessment
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
NSIP	Nuclear Siting Investigation Programme
NUREG	*US NRC Regulation*
PGA	Peak Ground Acceleration
PNI&I	Palaeoseismic-Neotectonic Investigations and Integration
PSHA	Probabilistic Seismic Hazard Analysis
RG	*US NRC Regulatory Guide*
SHA	Seismic Hazard Analysis
SSE	Safe Shutdown Earthquake
SSHAC	Senior Seismic Hazard Analysis Committee
SSR	*Site Safety Report*
SRAFA	Safety Report And Final Assessment
SSEGM	Safe Shutdown Earthquake Ground Motion
USNRC	US Nuclear Regulatory Commission

GLOSSARY

Annual Frequency of Exceedance (AFE)	Rate at which a given level of ground motion is exceeded. This rate results from consideration of the seismic source 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, hypocentre location, magnitude, focal mechanism, moment tensor etc.
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, and the level of ground-motion uncertainty (ε) to consider.
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 hypocentre (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 (GMPE)	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 parameters 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 PGA. The time period of interest is often taken as a year, in which case the curve is called the annual frequency of exceedance.
Hypocenter	The hypocenter is the point within the earth where an 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 micrometers 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.
Magmatism	The formation of igneous rock from magma.
m_{max}	The maximum earthquake magnitude that can be generated by a seismogenic source.
Peak Ground Acceleration (PGA)	***The maximum acceleration amplitude measured (or expected) of an earthquake.***
Pluton	***A body of igneous rock that formed through crystallization from molten magma below the earth’s surface.***
Parametric-Historic Method	***PSHA method formerly used by CGS. This method is based predominantly on statistical inference from earthquake catalogues. Its use has been superseded by that of the standard Cornell-McGuire approach following the publication of RG 1.208 in 2007.***
Probabilistic Seismic Hazard	Combining available information on earthquake sources in a given region with theoretical and empirical relations among earthquake

Analysis (PSHA)	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 GMPEs. 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 EIA. It provides the evaluations of ground-motion ***vibratory hazard as well as of the hazard for deformation at or near the surface, in order to determine the suitability of the 3 sites as nuclear power sites, based on the work carried out to date. Further studies have been identified and are being performed, in order to permit adequate engineering solutions to geologic and seismic effects at the sites.***

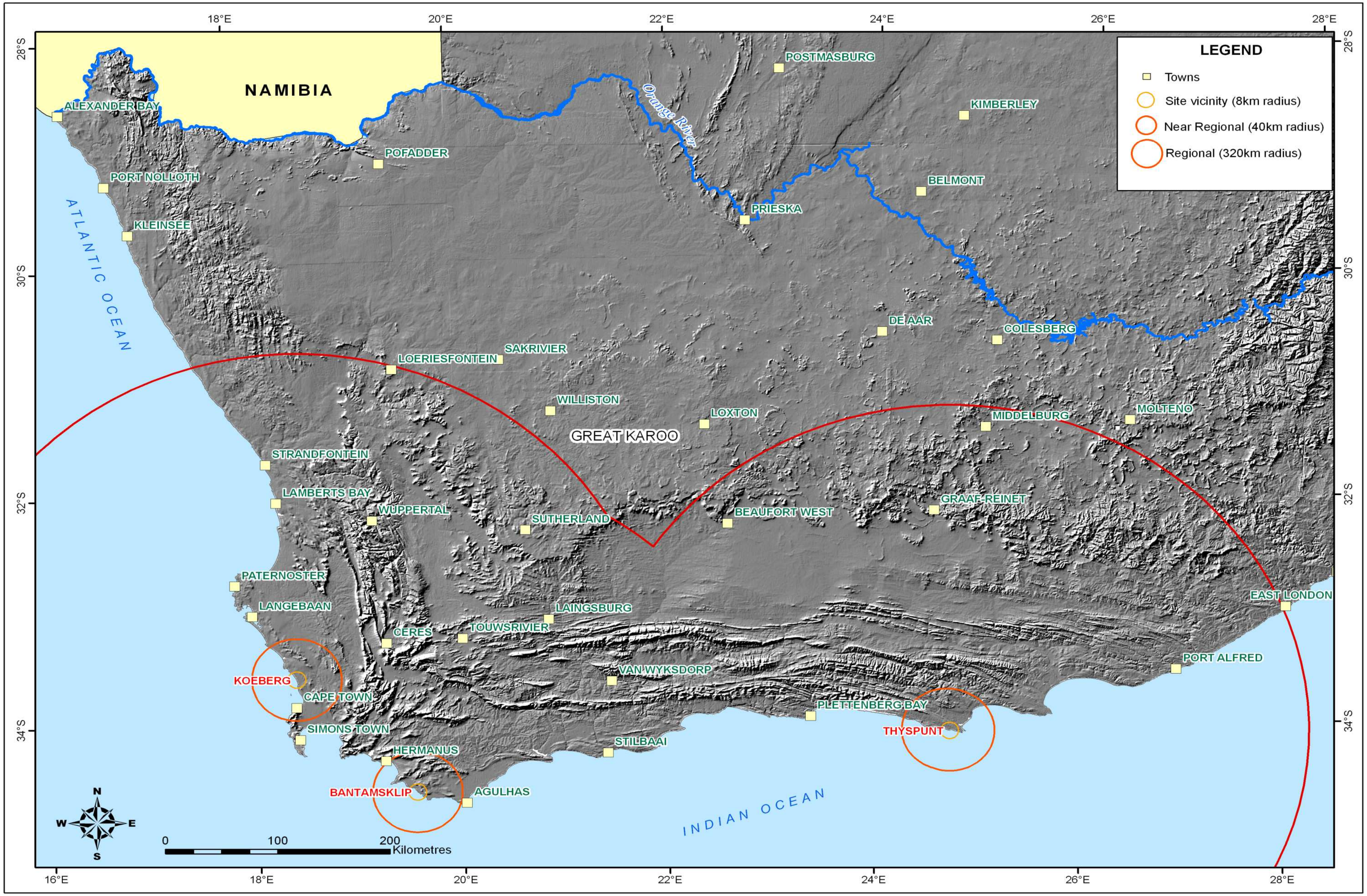
1.1.2 Site Location and Physiography

Following a thorough and detailed Nuclear Siting Investigation Programme (NSIP) and environmental scoping process, Eskom identified three localities along the South African south and west coast as preferred nuclear sites. They are: Duynefontein, which is located about 25 km N of Cape Town in the southwestern 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 southeast of Gansbaai along the southwestern 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-age 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).

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 Buffeljags, 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-age shoreline eroded into hills composed of calcarenite, and laterally against promontories of resistant rocks of the Table Mountain Group.

Figure 1.1: Location of the Proposed Nuclear Power Station Sites and regulatory radii that guide geological investigations



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-age marine and aeolian sediments, and buried by modern linear east – west dunes forming headland bypass dunefields. The landward extremity of the transgressive Miocene-age 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).

1.1.3 Terms of Reference

General Terms of Reference as supplied by Arcus GIBB (Pty) Ltd are detailed below:

- ***Describe the baseline conditions that exist in the study area and identify any sensitive areas that would need special consideration;***
- ***Ensure that all issues and concerns and potential environmental impacts relevant to the specific specialist study are addressed and recommend the inclusion of any additional issues required in the Terms of Reference, based on professional expertise and experience. Also consider comments on the previous specialist studies undertaken for the NSIP undertaken during the 1980s-1990s;***
- ***Provide a brief outline of the approach used in the study. Assumptions, sources of information and the difficulties with predictive models must also be clearly stated;***
- ***Indicate the reliability of information used in the assessment, as well as any constraints/limitations applicable to the report (e.g. any areas of insufficient information or uncertainty);***
- ***Identify the potential sources of risk to the affected environment during the construction, operational and decommissioning phases of the proposed project;***
- ***Identify and list relevant legislative and permit requirements applicable to the potential impacts of the proposed project;***
- ***Include an assessment of the "no go" alternative and identified feasible alternatives;***
- ***Assess and evaluate potential direct and indirect impacts during construction operational and decommissioning phases of the proposed project;***
- ***Identify and assess any cumulative effects arising from the proposed project;***
- ***Undertake field surveys, as appropriate to the requirements of the particular specialist study;***
- ***Identify areas where impacts could combine or interact with impacts likely to***

be covered by other specialists, resulting in aggravated or enhanced impacts and assess potential effects;

- ***Apply the precautionary principle in the assessment of impacts, in particular where there is major uncertainty, low levels of confidence in predictions and poor data or information;***
- ***Determine the significance of assessed impacts according to a Convention for Assigning Significance Ratings to Impacts;***
- ***Recommend practicable mitigation measures to minimise or eliminate negative impacts, enhance potential project benefits or to protect public and individual rights to compensation and indicate how these can be implemented in the final design, construction, operation and decommissioning of the proposed project;***
- ***Provide a revised significance rating of assessed impacts after the implementation of mitigation measures;***
- ***Identify ways to ensure that recommended mitigation measures would be implemented, as appropriate; and***
- ***Recommend an appropriate monitoring and review programme in order to track the effectiveness of proposed mitigation measures.***

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 EIA Regulations.

In addition to the EIA Regulations listed above, the National Nuclear Regulator Act, 1999 (No. 47 of 1999) regulates, amongst others, the seismic design criteria and safety assessments with respect to the construction and operating of nuclear power plants in South Africa. The geological and geophysical investigations ***performed*** for the siting of a new nuclear power plant Station are ***further*** 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 nuclear power plant sites, . but NNR requires that current state of the art and best engineering practice be applied in assessments which impact on safety.

The following US NRC codes have been consulted in determining the current seismic hazard levels for the sites:

- 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 Pants".
    - ***NUREG 0800 – Standard Review Plan (Revision 6 – March 2007). 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 nuclear power plants. "Standard Review Plans are not substitutes for regulatory guides or the U.S. NRC's (NRC) regulations and compliance with them are not required".***

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 SSEGM (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 Safe Shutdown Earthquake (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.***

Following the quantification of the seismic hazard for the 3 sites, the US NRC and IAEA published updated regulatory guides. These include:

- ***NUREG-1.208 A Performance-Based Approach to Define the Site-Specific Earthquake Ground Motion***
    - ***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 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.***
- ***IAEA SSG-9 Seismic Hazards in Site Evaluation for Nuclear Installations***
    - ***This site specific guide also provides guidance to the IAEA member states on the evaluation of seismic hazard at Nuclear facilities.***

Additionally, the American Standards Institute (ANSI) and the American Nuclear Society (ANS) have recently published standards including detailed technical requirements to follow for geo-scientific investigations and PSHA of nuclear facility sites:

- ***ANSI/ANS-2.27-2008 Criteria for Investigations of Nuclear Facility Sites for Seismic Hazard Assessments***
    - ***This standard provides detailed requirements and guidelines to follow in the geo-scientific investigations carried out to determine the inputs of a PSHA for nuclear installation sites.***

- ***ANSI/ANS-2.29-2008 Probabilistic Seismic Hazard Analysis***
  - ***This standard provides detailed requirements and guidelines to follow in the execution of a PSHA for nuclear installation sites.***

Work is currently in progress to ensure compliance to these nuclear regulatory requirements and will be completed for the nuclear licensing process through various submissions to the South African National Nuclear Regulator.

1.2.2 Prescribed Study Area

Since the US nuclear regulatory requirements for seismic hazard analysis are much more stringent and prescriptive than the IAEA requirements these were used to define the study areas as described below.

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

- **Acceptance criteria and compliance of Site Region (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 Site Vicinity (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 Site Area (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

The Seismic Hazard Impact Assessment Report represents a summary of work by geologists and seismologists over a period of several years. Geological and geophysical investigations were undertaken at all three sites under review during the 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 geological maps ***by the Council for Geoscience (CGS)*** form the basis of the existing geological database. The CGS has been involved in seismic monitoring for Eskom since 1994.

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). ***Seismic hazard values were established using the Parametric-Historic approach to SHA methodology. Once initial seismic hazard values had been established, additional palaeoseismic and neotectonic 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-age 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 results of this work were incorporated into several seismic hazard and sensitivity analyses which were used to confirm previously calculated PGA hazard values.***

Onshore and offshore geological and geophysical investigations continued at the Thyspunt, Bantamsklip and Duynefontein sites. The onshore geophysical investigations comprised of airborne magnetic surveys aided by ground follow-up methods, ***such as electromagnetic, 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 providing high resolution geophysical information.

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 extended 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 (interpretative) geophysical data to the current geological knowledge of the site (as defined in the PNI&I investigations), was unable to provide definitive solutions to problems ***such as*** 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 Site Vicinity and the Site Area, and where necessary further afield as dictated by the complexity of the geological situation (US NRC, 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 8 km Site Area and 40 km Site Vicinity areas of all three proposed sites. ***This work produced maps at 1:5,000 scale in the Site Area and 1:50,000 scale in the 40 km Site Vicinity.*** These investigations focused on geological features ***that might pose a threat to a Nuclear Power Station at any of these sites in terms of both possible sources of seismicity, not previously recognized, and surface or near-surface deformation.***

1.2.4 Seismic Hazard Analysis Methodology

In view of the severity of the potential consequences of a nuclear plant being exposed to high amplitudes of ground shaking, even though such an occurrence is expected to be very rare, consideration of seismic hazard impacts on the location, design and ***nuclear safety assessment of the plant.*** Therefore, substantial efforts have to be devoted to assessing this hazard by carrying out a SHA.

All seismic hazard analyses require the same fundamental input data; a model for the occurrence of earthquakes (seismic source 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 seismic source and ground-motion models are combined, either probabilistically 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 seismic source 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 during which instrumental recordings of earthquake occurences is extremely short compared to the typical recurrence time of the geological processes involved, it is 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 necessary 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 palaeoseismic information can also 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 seismic source 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 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 the SHA calculations carried out by CGS for the three sites, 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.

1.2.5 Assumptions and Limitations

The descriptions and facts given here stem from published data and work undertaken by the CGS ***during the period 1994 to 2002.*** In terms of the identification of faults and seismic risk the information represents the current knowledge and understanding based on a regional picture. ***As is often the case in SHA,*** new evidence of neotectonic movements may be discovered in ongoing investigations. The assumptions and limitations applicable are:

- ***To date it has not been possible*** to reliably associate specific seismic epicentres with specific geological structures. This applies to both the ***national*** seismic monitoring ***network and the Eskom NSIP micro-seismic monitoring project.*** Technically both projects have run long enough to satisfy standard regulatory requirements.
- 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 GMPEs to be used, notably due to the lack of strong motion data in South Africa. This is a very common problem in regions of low natural seismicity such as South Africa. In line with international best practice, research is ongoing to compare locally available information with the ground-motion levels predicted by the candidate equations.
- The EIA is based on the current state of knowledge ***obtained through extensive geo-scientific investigations and studies spanning several decades***.

2 DESCRIPTION OF AFFECTED ENVIRONMENT

The discussion in this section is not intended as an exhaustive treatise on the relevant seismic data, but rather to summarise the **currently** available data. 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 SHA, 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 ***(within 40 km)*** of the Thyspunt site. Further afield Goedhart (2006) established that the reactivation of a major Mesozoic-age 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. ***However***, 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 ***epochs, and hence, this fault was included in the PSHA.*** This is based upon the observation that the fault extend up to the sea floor, forming a significant fault scarp along two separate segments of the fault trace; at its western end and a ~60 km long segment showing a sea-floor scarp occurs along the fault trace southwest of Thyspunt, where it extends southeast into the northwest to southeast striking bend in the fault trace some 18 km 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-age 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. 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 north-northwest to south-southeast striking segment was last active at 116 Ma, 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, there is currently no indication that this fault is capable according to the definition of a capable fault in US regulatory Guide 10CFR 100, Appendix A definition.

2.1.2 Seismic Hazard

Maximum possible magnitude ***estimates were*** obtained for the seismicity ***associated*** with 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 were reassessed following a detailed palaeoseismic trench investigation, which suggested that fault reactivation was associated with a large earthquake (Goedhart, 2006). ***Based on this information and*** the Parametric-Historic method, a PGA ***on hard rock*** of 0.16 g has been calculated (SRAFA, 2004) for the Thyspunt site.

Ongoing investigations are being conducted to assign ranges of slip rates to these faults. The data in the instrumental and historical ***earthquake*** catalogues are ***being*** re-appraised, and these catalogues will subsequently be 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 GMPEs, using inversions of weak-motion data, stochastic simulations, and selection and ranking tools based on maximum-likelihood and information-theory approaches.

2.1.3 Impact of Climate Change

Climate change is not expected to have any impact on the seismic hazard at the proposed nuclear power station 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 on capable faults provided in section 2.1.1 is also applicable here. There is currently no evidence available of Quaternary-age activity and large (M>6) events on any of the faults ***observed at Bantamsklip.*** This statement should, however, be seen in the following context:

- The area is located on a Mesozoic rifted margin. Quaternary-age 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-age tectonic activity that could preserve surface is possibly several orders of magnitude ***lower*** than the rate of geomorphic evolution in the landscape. ***The chances for preservation of evidence for large seismic events would therefore be expected to be 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
- ***Although micro-seismic monitoring has been conducted over a 3 year period in the region around Bantamsklip, this network has been decommissioned.***

No observations of evidence for strong ground motion during the latest Pleistocene and Holocene ***epochs*** 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-age rocks and Cenozoic formations. ***For the current SHA*** it is inferred that they are all geologically old faults with no Pleistocene movement history.

A west-northwest striking fault with the characteristics of a pre-Cenozoic-age fault and a damage zone some 50 m wide and 80 degrees south-southwest dip, occurs at Celt Bay, some 3 km southeast 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 ***could*** be assocaietd with surface faulting. No evidence of Pleistocene activity along the Worcester fault has yet been found, ***although*** high regional erosion rates ***decrease the preservation potential of such 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-age volcanic activity on the offshore Alphards Bank some 50 km SE from the site, and ***there are records of only*** one M 2.2 event ***in this area which occurred*** 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-age aeolianites and limited exposures of marine calcarenites has 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 calcretisation 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.

West-northwest to east-southeast and east to west trending offshore faults on the northeastern margin of the Columbine-Agulhas arch, which bound the Bredasdorp Basin on its western side, may ***be of greater significance*** (although they do not seem to be currently seismically active) than northwest –southeast striking faults. The presence of Early Cenozoic-age mafic intrusive rocks on the Alphards Bank (Dingle et al., 1983) along the southeastward continuation of the west-northwest to east-southeast trending faults suggests that they may represent important lines of weakness in this area.

The presence of young mafic intrusive rocks southeast of Cape Agulhas introduce some uncertainty regarding seismic risk in the western Bredasdorp Basin, since the Early Cretaceous Koegelfontein Complex and associated Early Cenozoic-age 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 ***seismo-tectonic*** 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. ***Based on this information and the Parametric-Historic methodology, a PGA of 0.23 g has been calculated (SRAFA, 2004) for Bantamsklip on hard rock.***

Ongoing investigations are being conducted 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 GMPEs, using inversions of weak-motion data, stochastic simulations, and selection and ranking tools based on maximum-likelihood and information-theory approaches.

2.2.3 Impact of Climate Change

Climate change is not expected to have any impact on the seismic hazard at the proposed nuclear power station.

2.3 Duynefontein

The baseline description of the geology and tectonics (both regionally and locally) relating to the Duynefontein site has been discussed in greater detail in the 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. Evidence for a large earthquake with a ***maximum*** intensity of VIII, and M_L 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 to postulate the presence of a northwest 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 ***postulated*** fault could pass anywhere between 7 and 10 km offshore of Duynefontein (the inferred Melkbos Ridge Fault passes 7.5 km from the Koeberg Nuclear Power Station). No new research has been performed to confirm or refute the presence of the postulated 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 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

A PGA of 0.3 g was originally established for Duynefontein, based on the design value determined for Koeberg by Dames and Moore (1976). Based on the available geological information and using the Parametric-Historic methodology, a PGA of ***0.27 g,*** has been calculated for the Duynefontein site. ***Since the SHA for Duynefontein was regarded as reconfirmation work, the 0.3 g PGA was maintained as the design basis seismic event for the Koeberg Nuclear Power Station and hence, the Duynefontein site (SRAFA, 2004).***

Ongoing investigations are being conducted to assign ranges of slip rates to known faults. The data in the instrumental and historical catalogues is being reappraised, and these catalogues will subsequently be 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 GMPEs, using inversions of weak-motion data, stochastic simulations, and selection and ranking tools based on maximum-likelihood and information-theory approaches.

2.3.3 Impact of Climate Change

Climate change is not expected to have any impact on the seismic hazard at the proposed nuclear power station.

2.4 Summary of Seismic Data

The most important factor that has to be considered in the seismic design of a Nuclear Power Station and which ***needs to be incorporated into the design, is*** the level of ground motion (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 seismic ***source*** 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 are then combined through the PSHA calculations, and the design level of motion in terms of PGA and spectral accelerations at several response periods determined.

The SHA undertaken to date has determined the PGAs on hard rock of 0.16g, 0.23 g and 0.30g for the Thyspunt, Bantamsklip and Duynefontein sites, respectively.

As in the case of other nuclear power plants around the world, continued investigations into the seismo tectonic settings of the three sites is ongoing with the intent of reconfirming the hazard levels at regular intervals using the latest data and SHA methodologies.

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 many 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 impact if it would expose people, the environment or structures to potential substantial adverse effects, involving vibratory ground motion.

Note that the following discussion is limited to the consideration of vibratory ground motion that is strong enough to have the potential of causing damage to engineered structures.

3.1 Impact 1: Vibratory Ground Motion.

Stress release causes movement along known or new faults at surface or rock stress release at depth ***(blind faults)*** 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 impact of this hazard varies between the three sites and is discussed separately for each.

3.1.1 Thyspunt

Results of ***the SHA investigations to date indicate that the information available*** does not preclude Nuclear Power Station at the proposed Thyspunt site. The geological structure ***of greatest relevance to a SHA*** is the offshore Plettenberg Bay 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.

With the current state of knowledge ***stemming from the work done to date,*** there are no disqualifiers for this site..

3.1.2 Bantamsklip

The existing geo-scientific surveys served largely to 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 represents a Pliocene-age 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 ***midway between the*** Groenkloof and Elim Faults. No evidence could be found that indicates fault activity since the Late Cretaceous, ***but new information may be discovered if detailed investigations on*** the relationships ***between these faults and the*** Miocene-Quaternary sediments of this area should be undertaken.

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 will be confirmed by future on-land palaeoseismic investigations.

Based on ***the data*** available at this stage of the geo-scientific investigations, ***there are no disqualifiers for a Nuclear Power Station at the proposed Bantamsklip site.***

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 SHA. ***To date none of these structures could be demonstrated as being capable.***

Based on the current state of knowledge, there are no disqualifiers that preclude a Nuclear Power Station at the Duynefontein site.

3.2 Cumulative Impacts

Geological impacts related to the proposed development may involve hazards associated with site-specific soil conditions, erosion, fault rupture and ground shaking during earthquakes.

Since the effects of the site-specific geology on the level of ground-motion are explicitly included in the seismic hazard calculations to assess vibratory ground-motion levels used in the definition of the design parameters, no additional consideration of a cumulative impact is required, other than the consideration of secondary hazards such as fault rupture, liquefaction and slope stability which are discussed in other relevant sections of this report.

The distance between the sites is sufficient to ensure that when considering the three sites together, the impact on each site would be specific to that site and would not be combined with or contribute to 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. In addition, development on the site would be subject to stringent 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 of a geological hazard on individual facilities may occur, such a hazard will have a common impact on all facilities present at an affected locality.

Based on current knowledge, the three localities under review are considered suitable locations for Nuclear Power Stations following the extensive ***NSIP***. To date no geological evidence has been found that would halt the development of a Nuclear Power Station at any of these sites. However, a definitive statement regarding the hazard from surface fault rupture cannot be made until the foundations are excavated at the site.

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 a Nuclear Power Station . 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. 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

Tectonic movement along known or new faults at surface or rock stress release at depth result in earthquakes which may ***have a neutral to*** severely negative impact on a nuclear power station. ***Earthquakes*** are natural phenomena, with long ***mean recurrence intervals*** and can potentially occur at any time during construction, operation or decommissioning (**Table 4.1**).

Table 4.1:Impact Assessment: Thyspunt

Criteria	*Rating Scales*	*After Mitigation*
Nature	• ***Negative***	• ***Negative***
Extent (spatial limit of the impact)	• ***Medium***	• ***Medium***
Duration (the predicted lifetime of the impact)	• ***High***	• ***Low***
Intensity / Severity	• ***High***	• ***Low***
Impact on irreplaceable resources (is an irreplaceable resource impacted upon?)	• ***Medium***	• ***Low***
Consequence	• ***High***	• ***Low***
Probability (the likelihood of the impact occurring)	• ***Low***	• ***Low***
Significance	• ***Medium***	• ***Low***
Confidence level (the specialist's degree of confidence in the predictions and/or the information on which it is based)	• ***Medium***	• ***High***
Cumulative impacts	• ***Medium***	• ***Low***

(b)

(c) Extent

The vibratory earthquake ground motion will be felt over a large area, but the most severe direct negative impact will be restricted to the footprint area. However it may also have a negative impact on supporting infrastructure within the site area (i.e. within a 8 km radius). Hence a medium rating is given to this risk factor.

(d) Duration

The duration of any impact the vibratory ground motion resulting from tectonic fault movement, will vary depending on a host of secondary environmental impacts, which falls outside the scope of this study. In general the ground motion is a natural process from which the natural environment normally recovers through natural processes. However, if it is considered that vibratory ground motion has the potential to cause damage to the Nuclear Power Station facility, the impact duration should be considered to be high. However the impact and hence the duration of impact will be decreased significantly by the appropriate engineering mitigation.

(e) Intensity / Severity

The impact intensity of vibratory ground motion on the natural environment will vary, but in general it is expected to be low for the natural environment within the vicinity of the proposed Nuclear Power Station. However, vibratory ground motion can potentially cause damage to infrastructure and the severity of the impact on the environment is therefore considered to be high, although this will be reduced through the appropriate engineering mitigation.

(f) Impact of Irreplaceable Resources

Depending on a host of secondary impacts, the impact of vibratory ground motion on irreplaceable natural resources may vary. This falls outside the scope of this study. However surface deformation represents a natural process from which the environment normally recovers through natural processes, although some human intervention may also be required. Also note that other than facilitating such human intervention, the presence of a nuclear power station has no influence on the impact of vibratory ground motion on irreplaceable natural resources.

(g) Consequence

Based on the above information, and the impact assessment methodology employed, the consequence of surface deformation is high, but decreases to low after mitigation.

(h) Probability

Based on available information the probability of this impact occurring is very low.

(i) Significance

Based upon the above information, and the impact assessment methodology employed here, the significance of this impact is medium and decreases to low after mitigation.

(j) Degree of Confidence

The consultants have currently a medium level of confidence in the SHA. Ongoing investigations will increase this to high.

(k) 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 ***power plant unit*** is built and operated). ***Structures comprising a nuclear power plant are designed such that no interaction or pounding between adjacent structures can occur during the design basis event.***

Variation in the impact of a geological hazard on individual facilities may occur for a range of reasons (including engineering design). ***In some cases a fatal flaw caused by such an event to one particular facility may be sufficient to prohibit operation of an additional nuclear facility at the same locality that has not been affected to the same extent.***

(l) Mitigation Measures

- ***Additional geoscientific investigations to further reduce uncertainties in the seismic source and ground motion models.***
- ***Continued quantification of uncertainty and updating the SHA process to meet latest international regulatory requirements.***
- ***Application of the hazard results to ensure an appropriate Nuclear Power Station engineering design.***

(m) 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 NNR.

(n) No-Go Option

A decision not to proceed with a nuclear power station will have no impact on the seismic hazard at Thyspunt.

(o) Areas of High Sensitivity

From a seismic hazard point of view there are no sensitive areas that need to be avoided, except that the foundation of critical structures should not straddle the contact between the Goudini and Skurweberg formations.

4.1.2 Bantamsklip

(a) Nature of the impact

Tectonic movement along known or new faults at surface or rock stress release at depth result in earthquakes ***which may have a neutral to severely negative impact on a nuclear power station. Earthquakes*** are natural phenomena, with long ***mean recurrence intervals*** and can potentially occur at any time during construction, operation or decommissioning (**Table 4.2**).

(b) Extent

The vibratory earthquake ground motion will be felt over a large area, but the most severe direct negative impact will be restricted to the footprint area. However it may also have a negative impact on supporting infrastructure within the site area (i.e. within a 8 km radius). Hence a medium rating is given to this risk factor.

(c) Duration

The duration of any impact the vibratory ground motion resulting from tectonic fault movement, will vary depending on a host of secondary environmental impacts, which falls outside the scope of this study. In general the ground motion is a natural process from which the natural environment normally recovers through natural processes. However, if it is considered that vibratory ground motion has the potential to cause damage to the nuclear power station facility, the impact duration should be considered to be high. However the

impact and hence the duration of impact can be decreased significantly by the appropriate engineering mitigation.

(d) Intensity / Severity

The impact intensity of vibratory ground motion on the natural environment will vary, but in general it is expected to be low for the natural environment within the vicinity of the proposed Nuclear Power Station. However, vibratory ground motion may cause damage to infrastructure and the severity of the impact on the environment is therefore considered to be high, although this will be reduced through the appropriate engineering mitigation.

Table 4.2:Impact Assessment: Bantamsklip

Criteria	***Rating Scales***	***After Mitigation***
Nature	***• Negative***	***• Negative***
Extent (spatial limit of the impact)	***• Medium***	***• Medium***
Duration (the predicted lifetime of the impact)	***• High***	***• Low***
Intensity / Severity	***• High***	***• Low***
Impact on irreplaceable resources (is an irreplaceable resource impacted upon?)	***• High***	***• Low***
Consequence	***• High***	***• Low***
Probability (the likelihood of the impact occurring)	***• Low***	***• Low***
Significance	***• Medium***	***• Low***
Confidence level (the specialist's degree of confidence in the predictions and/or the information on which it is based)	***• Medium***	***• High***
Cumulative impacts	***• Medium***	***• Low***

(e) Impact of Irreplaceable Resources

Depending on a host of secondary impacts, the impact of vibratory ground motion on irreplaceable natural resources may vary. This falls outside the scope of this study. However surface deformation represents a natural process from which the environment normally recovers through natural processes, although some human intervention may also be required. Also note that other than facilitating such human intervention, the presence of a nuclear power station has no influence on the impact of vibratory ground motion on irreplaceable natural resources.

(f) Consequence

Based on the above information, and the impact assessment methodology employed, the consequence of surface deformation is high, but decreases to low after mitigation.

(g) Probability

Based on available information the probability of this impact occurring is very low.

(h) Significance

Based upon the above information, and the impact assessment methodology employed here, the significance of this impact is medium and decreases to low after mitigation.

(i) Degree of Confidence

The consultants have currently a medium level of confidence in the SHA. Ongoing investigations will increase this to high.

(j) 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). ***In some cases a fatal flaw caused by such an event to one particular facility may be sufficient to prohibit operation of an additional nuclear facility at the same locality that has not been affected to the same extent.***

(k) Mitigation Measures

- ***Additional geoscientific investigations to further reduce uncertainties in the seismic source and ground motion models.***
- ***Continued quantification of uncertainty and updating the SHA process to meet latest international regulatory requirements.***
- ***Application of the hazard results to ensure an appropriate Nuclear Power Station engineering design.***

(l) 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 NNR.

(m) No-Go Option

A decision not to proceed with a nuclear power station will have no impact on the seismic hazard at Bantamsklip.

(n) Areas of High Sensitivity

From a seismic hazard point of view there are no sensitive areas that need to be avoided at Bantamsklip.

4.1.3 Duynefontein

(a) Nature of the impact

Tectonic movement along known or new faults at surface or rock stress release at depth result in earthquakes ***which may have a neutral to severely negative impact on a nuclear power station. E***arthquakes are natural phenomena, with long mean recurrence intervals and can potentially occur at any time during construction, operation or decommissioning (Table 4.3).

(b) Extent

The vibratory earthquake ground motion will be felt over a large area, but the most severe direct negative impact will be restricted to the footprint area. However it may also have a negative impact on supporting infrastructure within the site area (i.e. within an 8 km radius). Hence a medium rating is given to this risk factor.

(c) Duration

The duration of any impact the vibratory ground motion resulting from tectonic fault movement, will vary depending on a host of secondary environmental impacts, which falls outside the scope of this study. In general the ground motion is a natural process from which the natural environment normally recovers through natural processes. However, if it is considered that vibratory ground motion has the potential to cause damage to the nuclear power station facility, the impact duration should be considered to be high. However the impact and hence the duration of impact will be decreased significantly by the appropriate engineering mitigation.

Table 4.3:Impact Assessment: Duynefontein

Criteria	*Rating Scales*	*After Mitigation*
Nature	• *Negative*	• *Negative*
Extent (spatial limit of the impact)	• *Medium*	• *Medium*
Duration (the predicted lifetime of the impact)	• *High*	• *Low*
Intensity / Severity	• *High*	• *Low*
Impact on irreplaceable resources (is an irreplaceable resource impacted upon?)	• *High*	• *Low*
Consequence	• *High*	• *Low*
Probability (the likelihood of the impact occurring)	• *Low*	• *Low*
Significance	• *Medium*	• *Low*
Confidence level (the specialist's degree of confidence in the predictions and/or the information on which it is based)	• *Medium*	• *High*
Cumulative impacts	• *Medium*	• *Low*

(d) Intensity / Severity

The impact intensity of vibratory ground motion on the natural environment will vary, but in general it is expected to be low for the natural environment within the vicinity of the proposed nuclear power station. However vibratory ground motion can potentially cause damage to infrastructure and the severity of the impact on the environment is therefore considered to be high, although this will be reduced through the appropriate engineering mitigation.

(e) Impact of Irreplaceable Resources

Depending on a host of secondary impacts, the impact of vibratory ground motion on irreplaceable natural resources may vary. This falls outside the scope of this study. However surface deformation represents a natural process from which the environment normally recovers through natural processes, although some human intervention may also be required. Also note that other than facilitating such human intervention, the presence of a nuclear power station has no influence on the impact of vibratory ground motion on irreplaceable natural resources.

(f) Consequence

Based on the above information, and the impact assessment methodology employed, the consequence of surface deformation is high, but decreases to low after mitigation.

(g) Probability

Based on available information the probability of this impact occurring is very low.

(h) Significance

Based upon the above information, and the impact assessment methodology employed here, the significance of this impact is medium and decreases to low after mitigation.

(i) Degree of Confidence

The consultants have currently a medium level of confidence in the SHA. Ongoing investigations will increase this to high.

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). In some cases a fatal flaw caused by such an event to one particular facility may be sufficient to prohibit operation of an additional nuclear facility at the same locality that has not been affected to the same extent.

(j) Mitigation Measures

- ***Additional geoscientific investigations to further reduce uncertainties in the seismic source and ground motion models.***
- ***A probabilistic Seismic Hazard Analysis following the SSHAC Level 3 methodology and meeting latest international regulatory requirements.***
- ***Use this information to ensure an appropriate nuclear power station engineering design.***

(k) 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 NNR.

(l) No-Go Option

A decision not to proceed with a nuclear power station will have no impact on the seismic hazard at Duynefontein.

(m) Areas of High Sensitivity

From a seismic hazard point of view there are no sensitive areas that need to be avoided at Duynefontein.

5 MITIGATION MEASURES

5.1 Impact 1. Vibratory Ground Motion

5.1.1 Thyspunt

Mitigation measures include (**Table 5.1**):

- The geotechnical and structural civil engineers shall **apply** the appropriate “seismic design criteria” for the design of nuclear safety & seismic classified utilities, and non classified utilities.
- ***Regularly update*** the expected ground motions and seismic design parameters derived from geological, seismotectonic and palaeoseismic ***information, as well as*** instrumentally recorded ***seismicity, including consideration of all aleatory and epistemic uncertainties associated with the data and models considered.***
- The ground motion parameters ***thus determined*** are to be used as design input for determining the SSEGM while the site is ***operational*** as well as ***during*** 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 ongoing fault characterization, followed by the compilation of ***updated*** source models. This information will then be utilized in ***regular updates of the*** PSHA that will follow current internationally accepted practice.
- Continued seismic monitoring. In terms of 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 ***earlier information being derived predominantly*** based on macro seismic observations.

  The US Code of Federal Regulations recommends the installation of micro-seismic monitoring networks at a Nuclear Power Station. 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 Nuclear Power Station, and even after decommissioning when re-use of the site is considered. ***Seismic monitoring of the sites using permanent and temporary seismograph stations has been undertaken since 1998. The Buffelsbos station near Thyspunt has been incorporated in the South African National Seismic Network in late 2008 and been in continuous operation since this date.***

  It is recommended that strong-motion accelerographs be installed on rock outcrops at the site.

5.1.2 Bantamsklip

Mitigation measures include (**Table 5.2**):

- The geotechnical and structural civil engineers shall **apply** the appropriate “seismic design criteria” for the design of ***nuclear safety and seismic classified*** utilities, and non classified utilities.
- ***Regularly update*** the expected ground motions and seismic design parameters derived from geologic, seismotectonic, palaeoseismic and instrumentally recorded events.
- The ground motion parameters thus determined are to be used as design input for determining the SSEGM while the site is ***operational*** as well as *during* 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 ***ongoing*** fault characterization, followed by the compilation of ***updated*** source models. This information will then be utilized in ***regular updates of the*** PSHA that will follow current internationally accepted practice.
- Continued seismic monitoring. ***In terms of*** 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 ***earlier information being derived predominantly*** based on macro seismic observations.

  The US Code of Federal Regulations recommends the installation of micro-seismic monitoring networks at a Nuclear Power Station. 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 Nuclear Power Station, and even after decommissioning when re-use of the site is considered.

  Seismic monitoring of the sites using permanent and temporary seismograph stations has been undertaken since 1998. The Elim seismograph station, ***which forms part of the South African National Seismograph Network operated by CGS,*** 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 (**Table 5.3**):

- The geotechnical and structural civil engineers shall apply the appropriate “seismic design criteria” for the design of ***nuclear safety and seismic classified*** utilities, ***and non classified utilities.***
- ***Regularly update*** the expected ground motions and seismic design parameters derived from geologic, seismotectonic, palaeoseismic and instrumentally recorded events.
- The ground motion parameters ***thus determined*** are to be used as design input for

determining the SSEGM while the site is ***operational*** 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 ***ongoing*** fault characterization, followed by the compilation of ***updated*** source models. This information will then be utilized in ***regular updates of the*** PSHA that will follow current internationally accepted practice.
- Continued microseismic monitoring. ***In terms of*** 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 ***earlier information being derived predominantly*** based on macro seismic observations.

  The US Code of Federal Regulations recommends the installation of micro-seismic monitoring networks at Nuclear Power Stations. 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 Nuclear Power Station, and even after decommissioning when re-use of the site is considered.

  Seismic monitoring of the sites using permanent and temporary seismograph stations has been undertaken since 1998. CGS will continue to monitor seismic activity in the vicinity of the Duynefontein using the existing seismograph network.

Table 5.1: Impact and Mitigation Assessment: Thyspunt

Impact	*Nature*	*Intensity*	*Extent*	*Duration*	*Impact on irreplaceable resources*	*Consequence*	*Probability*	*SIGNIFICANCE*
Impact 1: Vibratory Ground Motion.	*Negative*	*High*	*Medium*	*High*	*Medium*	*High*	*Low*	*Medium*
With Mitigation	*Negative*	*Low*	*Medium*	*Low*	*Low*	*Low*	*Low*	*Low*

Table 5.2: Impact and Mitigation Assessment: Bantamsklip

Impact	*Nature*	*Intensity*	*Extent*	*Duration*	*Impact on irreplaceable resources*	*Consequence*	*Probability*	*SIGNIFICANCE*
Impact 1: Vibratory Ground Motion.	*Negative*	*High*	*Medium*	*High*	*Medium*	*High*	*Low*	*Medium*
With Mitigation	*Negative*	*Low*	*Medium*	*Low*	*Low*	*Low*	*Low*	*Low*

Table 5.3: Impact and Mitigation Assessment: Duynefontein

Impact	*Nature*	*Intensity*	*Extent*	*Duration*	*Impact on irreplaceable resources*	*Consequence*	*Probability*	*SIGNIFICANCE*
Impact 1: Vibratory Ground Motion.	*Negative*	*High*	*Medium*	*High*	*Medium*	*High*	*Low*	*Medium*
With Mitigation	*Negative*	*Low*	*Medium*	*Low*	*Low*	*Low*	*Low*	*Low*

6 CONCLUSION AND RECOMMENDATIONS

The report describes ***the*** published seismic data and investigations **for the three sites** and outlines the uncertainties related to available data. ***The ongoing investigations that are being undertaken for these different sites along the South African coastline aim to reduce these uncertainties, and ensure agreement with the latest international regulatory requirements.***

6.1 Thyspunt

At Thyspunt the onshore regional pre-Quaternary-age geology and tectonics are well understood. Several 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. Based on the current state of knowledge there are no disqualifiers for this site.

6.2 Bantamsklip

At Bantamsklip the onshore regional pre-Quaternary-age geology and tectonics are well understood. The airborne, ground, and marine geophysical surveys conducted by the CGS and Fugro within the Site Area (8 km radius) and part of the Site Vicinity area (40 km radius) to a large extent complemented the known onshore and offshore geology at Bantamsklip. The results of the surveys confirmed 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-age 50 m palaeo-shoreline.

Many faults have been identified in the region surrounding Bantamsklip, but ***are*** located in an area of very subdued seismicity and no evidence of prehistoric strong ground motion **exists**. Surface deposits ***render the*** characterisation of fault capability of the numerous faults located in close proximity to the proposed site location exceedingly difficult. There is consequently significant uncertainty regarding the seismotectonic model for Bantamsklip. Nevertheless, based on the current state of knowledge there are no disqualifiers for this site.

6.3 Duynefontein

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

6.4 Conclusions

The ground shaking hazard from earthquakes represents the most serious geological hazard impacting on the design of a new Nuclear Power Station site. Mitigation for this hazard entails ***use of a very low probability of exceedance when determining the ground motions for establishing the design basis of the power plant.***

As in the case of other nuclear power plants around the world, investigations, studies and seismic monitoring will be conducted to ensure regular updates to the seismic hazard. The methodologies used to perform PSHA are continually evolving and the most up to date, accepted methodology (according to US NRC and IAEA) will be used in each of the PSHA updates.

The SHA undertaken to date has determined the PGAs on hard rock of 0.16g, 0.23 g and 0.30g for the Thyspunt, Bantamsklip and Duynefontein sites, respectively.

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Company name	Council for Geoscience
Specialist signature	Johann Neveling (Pr. Sci. Nat.) Erna Hattingh (Pr. Sci. Nat.)
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