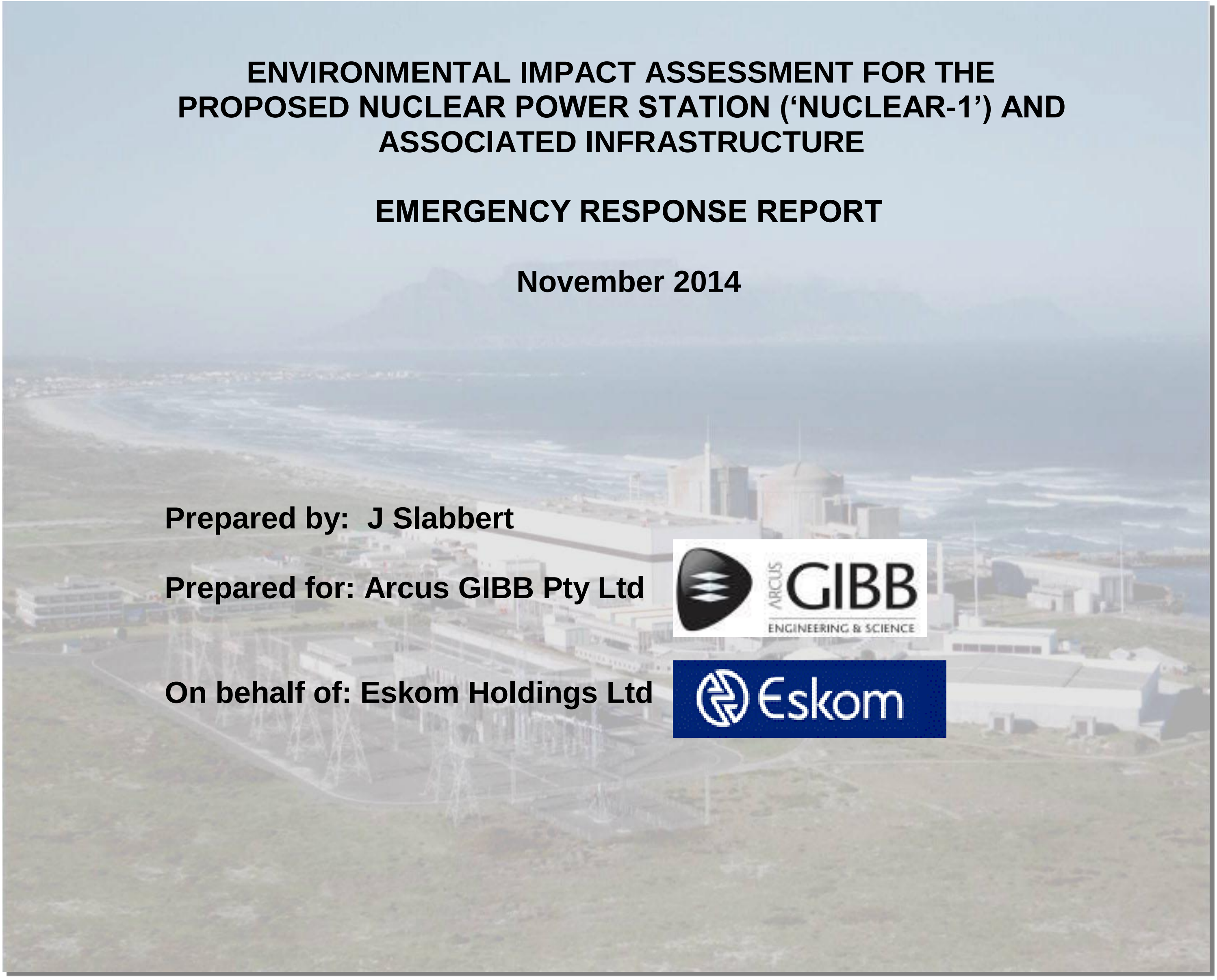

# ENVIRONMENTAL IMPACT ASSESSMENT FOR THE PROPOSED NUCLEAR POWER STATION (‘NUCLEAR-1’) AND ASSOCIATED INFRASTRUCTURE

## EMERGENCY RESPONSE REPORT

**November 2014**

**Prepared by: J Slabbert**

**Prepared for: Arcus GIBB Pty Ltd**

**On behalf of: Eskom Holdings Ltd**

## DECLARATION OF INDEPENDENCE

I, Johan Slabbert, an independent consultant, hereby confirm my independence as a specialist and declare that I do not 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 worked performed, specifically in connection with the Environmental Impact Assessment for the proposed conventional nuclear power station ('Nuclear-1'). I further declare that I am confident in the results of the studies undertaken with information made available by Eskom and conclusions drawn as a result of it – as is described in my attached report.

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## EXECUTIVE SUMMARY

Three sites, of which one is located in the Eastern Cape and two in the Western Cape are being investigated for a nuclear installation consisting of a nuclear power plant and associated infrastructure. This report forms part of the Environmental Impact Report (EIR) that covers the impacts and mitigation measures associated with the construction and operation of a nuclear installation.

The fundamental safety objective in the development of a nuclear installation is to protect people and the environment from the harmful effects of ionising radiation. One of the safety principles that form the basis of this objective is an Emergency Plan (EP), a plan to ensure sufficient arrangements and emergency preparedness for effective and adequate response in the case of a nuclear accident [1]. This report provides information on the feasibility of developing an EP for each site.

In demonstrating the feasibility of a nuclear emergency plan, many site related factors are taken into account. The factors are:

- Population density and distribution;
- Special geographical features, such as mountainous terrains, rivers, capabilities of local transport and communication network;
- Agricultural activities that are sensitive to possible discharges of radionuclides; and
- Disastrous external events or foreseeable natural phenomena.

The scope and extent of arrangements for emergency preparedness and response have to reflect:

- The frequencies of occurrence which are postulated for nuclear accidents and the possible consequences of such accidents;
- The characteristics of the radiation risks associated with these accidents; and
- The nature and location of the nuclear installation.

The importance of these site related factors are dependent on the nuclear hazard posed by a nuclear power station (NPS). Safety objectives of the new generation NPS envisaged for Eskom entail enhanced safety design features when compared to most existing operating nuclear reactors in the world today. Design features are included in these reactors to practically eliminate severe accidents, such as those caused by natural external events that caused the Fukushima nuclear installation accident.

The aim is to simplify emergency planning and off-site countermeasures in the following manner:

- Minimal emergency protection action beyond 800 m from the reactor should the accident result in early releases of radioactivity to the atmosphere from the reactor containment;
- No delayed action such as temporary transfer of people at any time beyond approximately 3 km from the reactor;
- No long-term action involving permanent (longer than 1 year) resettlement of the public at any distance beyond 800 m from the reactor;
- Restriction on the consumption of foodstuff and crops should be limited in terms of timescale and ground area in order to limit the economic impact.

The key findings and recommendations of this Emergency Response study can be summarised as follows:

Eskom committed to building nuclear installations with enhanced safety design features compared to the majority of reactors operating currently in the world. A radiological consequence assessment of postulated reference accidents show that the need for *off-site* short-term emergency interventions like sheltering, evacuation or iodine prophylaxis is unlikely. Protective actions related to food may be required for a limited period of time, up to distances of 40 km. The EP will therefore include protective measures such as the following:

- An immediate ban on the consumption of locally grown food in an area affected by the accident;
- The protection of local food and water supplies by, for example, covering open wells and sheltering animals and animal feed; and
- Long-term sampling and control of locally grown food and feed. Control of milk production and distributors is generally considered particularly important because it is a significant part of children's diets.

An effective emergency plan for each of the new sites, Bantamsklip and Thyspunt, is feasible subject to a degree of infrastructure upgrade. An important aspect of infrastructure upgrade will involve improvement of the off-site access roads that will service the sites, especially during the construction phase. Flooding hazards in the region will be an important design consideration for these new roads. This will ensure successful emergency actions in the unlikely event that they are required, such as emergency support access to the site. The final layout of the site and design of access routes have to take into consideration adverse environmental conditions that could exist at the time of a nuclear emergency.

The existing EP at Duynefontein for the Koeberg NPS will incorporate a new nuclear installation since the existing EPZs are larger than those required for Nuclear-1.

The final and detailed emergency plan for each site has to be approved by the National Nuclear Regulator. This approval will be based on detailed safety assessments that have to provide final justification for the technical basis of a site's emergency plan.

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

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## GLOSSARY

| | |
|---|---|
| Accident | Any unintended event, including operating error, equipment failure or other mishap, the consequences of potential consequences of which are not negligible from the point of view of protection and safety. |
| Cloud shine | Gamma radiation from radioactive materials in an airborne plume |
| Deterministic effect | A radiation induced health effect that is certain to occur – with the severity that increases with increasing dose – in an individual exposed to a radiation dose greater than some threshold dose. The level of the threshold dose is characteristic of the particular health effect but may also depend, to a limited extent, on the exposed individual. Examples of deterministic effects include erythema and radiation sickness. |
| Emergency | Any natural or man caused situation that results in or may result in substantial injury or harm to people, property or the environment, and which prompt action is needed to protect people, property or the environment. |
| Emergency plan | A document describing the organizational structure, roles and responsibilities, concept of operation, means and principles of intervention during an emergency. |
| Emergency planning zone | Zone within which plans are developed to take protective actions in case of a nuclear accident |
| Evacuation | The rapid, temporary removal of people from the area to avoid or reduce short term radiation exposure in the event of an emergency. |
| Exposure pathway | A route by which radiation or radioactive material can reach or irradiate humans |
| Iodine prophylaxis | The ingestion of a compound of stable iodine (usually potassium iodine) to prevent or reduce uptake or radioactive isotopes of iodine by the thyroid in the event of an accident involving radioactive iodine. The term thyroid blocking is used in the literature as a synonym. |
| Longer term protective action zone (LPZ) | Zone within which plans are developed to control agricultural products. |
| Plume (atmospheric) | The airborne “cloud” of material released to the environment, which may contain radioactive materials and may or may not be invisible. |
| Precautionary action zone (PAZ) | Zone that should be automatically evacuated or sheltered in the event of an imminent release to prevent deterministic effects in the population |
| Relocation | The removal of members of the public from their homes for an extended period of time, as a protective action in a chronic exposure situation. |

| | |
|---|---|
| Ground shine | Gamma radiation from radioactive materials deposited on the ground |
| Sheltering | A protective action whereby members of the public are advised to stay indoors with windows and doors closed, intended to reduce their exposure in an emergency exposure situation. |
| Stochastic effect | A health effect, the probability of occurrence of which is greater for a higher radiation dose and the severity of which (if it occurs) is independent of dose. Stochastic effects may be somatic effects or hereditary effects, and generally occur without a threshold level of dose. Examples include cancer and leukaemia. |
| Urgent protective action | Protective action that is taken within the first few days after the accident and includes sheltering, stable iodine, evacuation and immediate ban on locally grown food. |
| Urgent protective action zone | Zone within which plans are developed to take protective actions if the environmental surveys and plant parameters indicate the need to do so. |

# 1 INTRODUCTION

## 1.1 Description of Proposed Project and Emergency Planning Objectives

The Environmental Impact Assessment concerns the construction and operation of a nuclear installation for generating at sites identified in the Eastern and Western Cape areas. A nuclear emergency plan (EP) will be an important element of the nuclear installation safety. The feasibility of an EP has to be assessed for each site. The feasibility assessment is a component of a comprehensive safety assessment that grows in detail during multiple nuclear licensing stages. It culminates in the testing of the final emergency plan accepted by the National Nuclear Regulator (NNR) and based on the detailed design and completed construction of the nuclear power station (NPS), prior to initial operation.

The EP includes arrangements based on criteria set in advance to determine when to take different protective actions and what capability is required to protect and inform personnel at the scene and the public. These arrangements are based on emergency planning zones (EPZs), which represent the areas in which planning for specific protective actions are based on estimated health risks posed by those accidents that could, under severe conditions, release radioactivity to the environment. Protective actions include measures to limit the exposure of the public to radioactive contamination through external radiation exposure, inhalation of airborne radioactivity and ingestion of contaminated foodstuff. The objectives of these actions are to prevent early acute radiation effects, referred to as deterministic effects, and to reduce the likelihood of late radiation effects referred to as stochastic effects, principally cancer.

For nuclear emergencies, two sets of requirements have to be fulfilled.

- Functional (response) requirements; and
- Infrastructure (preparedness) requirements.

Functional response requirements refer to the “capability” to perform an activity. The “capability” includes having in place the necessary authority and responsibility, organisation, personnel, procedures, facilities, equipment and training to effectively perform the task or function when needed during an emergency.

The “capability” includes having in place the necessary infrastructure needed during an emergency. Infrastructure means transport and communications networks, industrial activities and, in general, anything that may influence the rapid and free movement of people and vehicles in the region of the site.

## 1.2 Project Terms of Reference in Respect of Emergency Planning

The general terms of reference for the EIA project of which this study forms part are to provide:

- Discussion of relevant policies and frameworks;
- The affected environments (baseline information) as well as inferred changes to the baseline environment considering the effects of climate change;

- Identification of information gaps, limitations and additional information required;
- Description of the anticipated impacts using the impact assessment criteria as defined for the project;
- Development of relevant mitigation measures that include an emergency plan for nuclear events;
- Determination of the effects of climate change on the proposed development and vice versa in terms of their fields of expertise;
- Utilisation of information from the existing Koeberg Nuclear Power Station (KNPS) in order to determine the cumulative impacts at the Duynefontein site;
- Assessment of the impacts associated with a desalination plant; and
- Derivation of monitoring and auditing programmes, where necessary.

The Terms of Reference specific to Emergency Response are the qualitative assessment of the feasibility of a nuclear emergency plan for the sites. Preliminary quantitative aspects have been included based on reference nuclear reactors representing the designs considered for the sites.

# 2 LEGISLATIVE FRAMEWORK

The legislative framework for nuclear emergency planning is mainly determined by two acts:

- National Environmental Management Act, 1998 (Act No. 107 of 1998)
- National Nuclear Regulator Act, 1999 (Act No. 47 of 1999)

Section 30(1)(a) of the National Environmental Management Act, 1998 (Act No. 107 of 1998) provides for control of emergency incidents including a major emission, fire or explosion leading to serious danger to the public or potentially serious pollution of detriment to the environment, whether immediate or delayed.

In terms of section 38(2) of the National Nuclear Regulator Act the NNR must ensure that an emergency plan is established. It is established in terms of section 38(1) by agreement between the holder of a nuclear authorisation and the relevant municipalities and provincial authorities. Such an emergency plan must be effective for the protection of persons and the environment.

At the outset of this EIA, the Department of Environmental Affairs (DEA) (previously the Department of Environmental Affairs and Tourism) as the lead authority on environmental matters, and the National Nuclear Regulator (NNR) agreed to work in close collaboration regarding the common issues of the EIA process and the NNR licensing process. A cooperative governance agreement was entered into between the DEA and the NNR. [2].This agreement provides for a working relationship to minimize duplication and is of specific relevance to a nuclear EP. Lead responsibility rests with the NNR for the following:

- Investigation of accidents, incidents and other occurrences which impact on the public;
- Conduction of regulatory research and development on nuclear safety matters; and
- Development of legislation, safety standards and regulatory practices including conditions of authorisation (where applicable) and guidelines.

The agreement states specifically that NNR Regulation No. R388 [3] on safety standards and regulatory practice contained in Regulation No R388 shall be applicable to all relevant provisions for the regulation, monitoring and control of radiation hazards falling within the respective responsibilities of the parties.

The NNR Siting regulations, R. 927 of 2011 [4] define the specific requirements to demonstrate that it is feasible to develop an EP for a site. It states that the identification and determination of emergency planning zones use the characteristics of the site, accident source term analysis, design information, radiological impact analysis as well as risk insights provided by safety analysis of the nuclear installation. The emergency planning zones include the following:

- An exclusion zone (EZ) with a radius determined for the purposes of evacuating persons in the event of a nuclear accident. Within the boundaries of that zone or within any erven intersecting with that zone there must be no members of the public resident, no uncontrolled recreational activities, no commercial activities or institutions that are not directly linked to the operation of nuclear installations or other uses for which an authorisation has been not been granted;
- An overall Emergency Planning Zone (EPZ) of such size that emergency or remedial measures must be considered where the potential exists that any members of the public may receive more than an annual effective dose of 1mSv due to the source term (i.e. the release of radioactivity during an accident);
- A Long-Term Protective Action Planning Zone (LPZ), where preparations for effective implementation of protective actions to reduce the risk of stochastic health effect from long term exposure to deposition and ingestion must be developed in advance.

Other international conventions and national acts for which compliance has to be demonstrated in terms of the nuclear authorisation process are the following:

- The Convention on Nuclear Safety that requires emergency plans to be prepared and tested for any new nuclear installation before the facility commences operation above a low power level and to be agreed by the regulatory body [5].
- The Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management, which also requires each contracting party to ensure that before and during operation of a spent fuel or radioactive waste management facility there are appropriate on-site and, if necessary, off-site emergency plans. Such emergency plans should also be tested at an appropriate frequency [6].
- The Convention on Early Notification of a Nuclear Accident [7], which requires that in the event of an accident South Africa shall (i) notify, directly or through the International Atomic Energy Agency (IAEA), those states that are or may be physically affected and the IAEA of the nuclear accident, its nature, the time of its occurrence and its exact location where appropriate; and (ii) promptly provide the states referred to above (i) directly or through the IAEA, and (ii) the IAEA with such available information relevant to minimising the radiological consequences in those states.
- The Convention on Assistance in the Case of a Nuclear or Radiological Accident [8], which requires the contracting parties to cooperate with other contracting parties and with the IAEA in accordance with the provisions of this convention to facilitate prompt assistance in the event of a nuclear accident or radiological emergency to minimise its consequences and to protect life,

property and the environment from the effects of radioactive releases. This includes the preparation of emergency plans.
- The Disaster Management Act (2002), which requires the Minister to prescribe a national disaster management framework. The framework must reflect a proportionate emphasis on disasters of different kinds, severity and magnitude that occur or may occur in South Africa [9].

In addition, it is required [10] that the relevant provincial and/or municipal authorities must:
- Develop and implement processes, including associated acceptance criteria, for the conduct of periodic assessment of current and planned population distribution, disaster management infrastructure and new development, to ensure that the emergency plan, as contemplated in Section 38 of the National Nuclear Regulator Act (1999), can be implemented effectively at all times;
- Document the processes contemplated in subsection 4(a) in procedures acceptable to the Regulator; and
- Report to the NNR on the implementation and the results of the monitoring processes at intervals acceptable to the Regulator.

Further to the national statutes (acts and regulations) a number of provincial and local authority regulations/ordinances must be satisfied, particularly those related to land-use planning, economics and service provision. The suite of applicable national and provincial legislation and policies are discussed in Chapter 6 of the Environmental Impact Report.

# 3 THE CONCEPT OF FEASIBILITY OF AN EMERGENCY PLAN

Demonstration of the feasibility of an EP is a standard requirement in the early stages of nuclear installation safety assessment. The extent to which feasibility has to be demonstrated is a function of the potential off-site impact resulting from the severe accident that serves as reference accident for the EP. The requirements are extensive for reactor types where the reference accident can result in significant radiological impacts requiring precautionary and urgent emergency action to typical distances of 16 km, as is the case for the KNPS. This means that there should be no adverse site conditions that could hinder the sheltering or evacuation of the population in the region or the ingress or egress of external services needed to deal with an emergency. The feasibility of an emergency plan for an NPS is demonstrated on the basis of site-specific natural and infrastructural conditions in the region, e.g.:

- Transport and communications networks;
- Industrial activities and, in general; and
- Anything that may influence the rapid and free movement of people and vehicles in the region of the site.

Many site related factors are taken into account in demonstrating the feasibility of an emergency plan. The most important ones are [11]:
- Population density and distribution in the region;
- Distance of the site from population centres;
- Special groups of the population who are difficult to evacuate or shelter, such as people in hospitals or prisons, or nomadic groups;
- Particular geographical features such as islands, mountains and rivers;
- Characteristics of local transport and communications networks;

- Industrial facilities which may entail potentially hazardous activities;
- Agricultural activities that are sensitive to possible discharges of radionuclides; and
- Possible concurrent external events.

It is shown in the next section that the improved safety features of the latest generation of NPS that Eskom proposes make them less sensitive to the factors that are considered to determine feasibility of an emergency plan. Response to a nuclear emergency includes safety systems that will make it unlikely that any radioactive releases will result that may require off-site protective actions.

# 4 TECHNICAL BASIS OF A NUCLEAR EMERGENCY PLAN AND EMERGENCY PLANNING ZONES

## 4.1 The technical basis

The specific objectives for emergency planning of the proposed nuclear power station (in line with the proposed emergency planning guidelines of the European Utility Requirements) are:

- Minimal emergency protection action beyond 800 m from the reactor during early releases from the reactor containment;
- No delayed action such as temporary transfer of people at any time beyond approximately 3 km from the reactor;
- No long-term action involving permanent (longer than 1 year) resettlement of the public at any distance beyond 800 m from the reactor; and
- Restriction on the consumption of foodstuff and crops should be limited in terms of timescale and ground area in order to limit the economic impact.

The underlined terms above are defined as follows:

Emergency protection action: actions involving public evacuation, based on projected doses up to seven days, which may be implemented during the emergency phase of an accident, e.g. during the period in which significant releases may occur.

Delayed action: actions involving temporary public relocation, based on projected doses up to 30 days caused by groundshine and aerosol re-suspension, which may be implemented after the practical end of the release phase of an accident.

Long-term action: actions involving public resettlement, based on projected doses up to 50 years caused by groundshine and aerosol re-suspension. Doses due to ingestion are not considered in this definition.

An emergency plan consists of measures for preventing deterministic effects and to mitigate stochastic effects of a nuclear accident. Emergency preparedness has to be maintained throughout the life of an NPS: from the moment nuclear fuel arrives on site and also after it has been shut down at the end of its life and radioactive material is still on site.

In designing a nuclear installation a safety analysis is carried out to identify all events, whether occurring offsite or on the site, that could initiate accident sequences at an NPS. A comprehensive safety analysis report provides detail on the consequences of these accident sequences. The results must demonstrate that strict health risk criteria are met should there be a release of radioactivity during an accident.

Various layers of defence are included in the design of an NPS to prevent accidents. The design concept is referred to as defence in depth. Only when the most extreme accident conditions occur resulting in the breach of multiple layers of defence, could there be a release of radioactivity to the outside environment. The last layer of defence to protect people is the emergency plan.

The emergency plan takes information from the assessment of postulated severe accidents as well as lessons learnt from real accidents that have occurred in the world. The Fukushima nuclear accident is an example. Nuclear power stations all over the world are performing tests, referred to as “stress tests”, to identify areas for improvement. The effectiveness of emergency plans is also reviewed during these “stress tests”.

The emergency plan for off-site actions is based on emergency planning zones within which specific actions are planned for the protection of people. The planning zones are based on calculation methodologies to determine potential radiation doses as a result of different exposure pathways that may exist as a result of the accident. The methodologies typically take into consideration the following steps:

- Estimation of source terms (the quantity, composition time and duration of the radioactivity release) for each of the accidents considered to be relevant for off-site emergency planning for the site.
- Calculation of the projected contamination in the environment and the dose to the local population (should no emergency action be taken) arising from the accident. Calculations to determine avertable dose when countermeasures are taken in the different emergency planning zones.
- Arrangements are made for taking urgent protective action that emergency planning zones and include:
    - A precautionary action zone (PAZ), for which arrangements are made with the goal of taking precautionary urgent protective action, such as evacuation, before a release of radioactive material occurs or shortly after a release of radioactive material begins, on the basis of conditions at the NPS in order to substantially reduce the risk of severe deterministic health effects.
    - An urgent protective action planning zone (UPZ), for which arrangements shall be made for urgent protective action to be taken promptly, for example sheltering, in order to avert doses off the site in accordance with international standards.
    - The Food Restriction Planning Radius is the area where preparations for effective implementation of protective actions to reduce the risk of stochastic health effects from the ingestion of locally grown food should be developed in advance. In general, protective actions such as relocation, food restrictions and agricultural countermeasures are based on environmental monitoring and food sampling following the accident.

The distances or radii from the NPS of the different emergency planning zones are calculated by using the radioactive source term from a postulated severe accident, and are referred to as the reference accident. This reference accident is determined by evaluating accidents that can occur at a very low probability. This probability is typically less than once in a million years, also expressed as an occurrence frequency of less than$10^{-6}$/y.

## 4.2 Emergency Planning Zones

Studies using a nuclear accident computer code, PC COSYMA, have been performed to determine radiation dose from accidents for the type of advanced reactors considered by Eskom as reference technologies; i.e. the AP1000 of Westinghouse and the EPR of AREVA [12]. The accident source terms used in these are discussed and listed in Appendix 1 (see also Radiological Impact Assessment Impact Report).

The results of the studies were measured against the following objectives to simplify emergency planning and off-site countermeasures:

- Minimal emergency protection action beyond 800 m from the reactor should the accident result in early releases of radioactivity to the atmosphere from the reactor containment building;
- No delayed action such as temporary transfer of people at any time beyond approximately 3 km from the reactor;
- No long-term action involving permanent (longer than 1 year) resettlement of the public at any distance beyond 800 m from the reactor; and
- Restriction on the consumption of foodstuff and crops should be limited in terms of timescale and ground area in order to limit the economic impact.

The results obtained using nuclear accident consequence analysis codes [13] are listed in

Table **4-1**. These are based on initial conservative screening studies and refined analysis will be carried out when detailed design becomes available.

## Table 4-1: Dose Estimates for Severe Accidents and a Comparison to UPZ and LPZ Intervention Level Requirements

| Protective Action | Generic Intervention Level | Exposure duration | Objective for EPZ distance, km | Projected Dose Estimates for the AP1000 and EPR Reactor Technologies | | |
|---|---|---|---|---|---|---|
| | | | | Reactor Technology | Projected Total Dose estimated; mSv | EPZ objective of Eskom met? |
| Sheltering | 10 mSv | 2 days | 0.8 | EPR | 2.4 | Yes |
| | | | | AP1000 | 22.8 | No<br><br>The requirement is met at 2 km where the projected dose is<10 mSv (6.7 mSv) The Exclusion Zone can be extended to this distance. |
| Evacuation | 50 mSv | 7 days | 0.8 | EPR | 2.6 | Yes |
| | | | | AP1000 | 25.0 | Yes |
| Iodine prophylaxis | 100 mGy | — | 0.8 | EPR | 5.8 (Committed absorbed dose) | Yes |
| | | | | AP1000 | 45.7 (Committed absorbed dose) | Yes |
| Temporary relocation | 30 mSv during initial 30 days and 10 mSv in subsequent 30 days | | 3 | EPR | 0.10 (first 30 days) and 0.01 (subsequent 30 days) | Yes |
| | | | | AP1000 | 1.2 (first 30 days) and 0.2 (subsequent 30 days) | Yes |
| Permanent resettlement | 1000 mSv | Lifetime | 0.8 | EPR | 2.0 | Yes |
| | | | | AP1000 | 24.0 | Yes |
| Food banning/replacement | | | 40 | EPR | Projected dose decreases to approximately 1 mSv at 40km in first year following an accident; no food banning or replacement considered. Food banning and replacement will be required | |
| | | | | AP1000 | | |

| Protective Action | Generic Intervention Level | Exposure duration | Objective for EPZ distance, km | Projected Dose Estimates for the AP1000 and EPR Reactor Technologies | | |
|---|---|---|---|---|---|---|
| | | | | Reactor Technology | Projected Total Dose estimated; mSv | EPZ objective of Eskom met? |
| | | | | | for distances < 40km. | |

**Note**: Effective dose: cloudshine, groundshine, resuspension and deposition on skin and clothing as applicable to intervention scenario; Committed Effective Dose - Inhalation (50y)

The results show that emergency actions for the two reference reactor technologies would be limited. The AP1000 is not necessarily disqualified by not meeting the specific objective of 0.8 km. The dose results are based on initial conservative screening studies. Refined analysis when the detail design becomes available should allow less conservatism in the calculations and the objective of 0.8 km may yet be met for the AP1000. If it cannot be met, exclusion zones equal to 2 km should be achievable at the sites since it a distance typical of the owner controlled boundaries at the sites. No off-site short-term emergency interventions would be required beyond the owner controlled boundary of the NPS. However, the final emergency plan will be based on EPZs agreed to by the NNR.

The feasibility of an emergency plan that can be extended even beyond the calculated EPZ depends on acceptable site aspects such that there must be no adverse conditions to hinder the ingress or egress of external services that may be needed to deal with an emergency. These aspects of the three sites are discussed in the next section.

# 5 AN OVERVIEW OF THE SITE ASPECTS IMPORTANT TO EMERGENCY PLANNING

## 5.1 Introduction

The sites included in the EIA were identified based on previous site investigations undertaken since the 1980s and work carried out during this EIA. They include Thyspunt in the Eastern Cape; Bantamsklip in the Western Cape and Duynefontein, which includes the existing KNPS site in the Western Cape.

The Thyspunt and Bantamsklip sites have low population densities, unlike Duynefontein. However, Duynefontein has the advantage of the existing KNPS EP that makes provision for urgent action up to 16 km and longer term emergency planning up to 80 km. All the sites have agricultural areas that could be affected by a release from the reference accidents investigated. Infrastructure such as roads will have to be upgraded for the construction phase at each site. This will improve the accessibility of the site during an emergency. This is of specific importance for Thyspunt where flooding events have caused damage to the R330, the main access road to St. Francis.

Communications and emergency notification will entail a notification scheme that includes the capability of local and national agencies to provide information promptly over radio and TV at the time of activation of emergency actions. Initial notifications to the public, for example, might request them to listen to radio and TV for further instructions. It will also rely on existing communication infrastructure such as telephone exchanges and cell phone communication. Further site specific information is provided in the next sections.

## 5.2 Land Use

### 5.2.1 Bantamsklip

Numerous agricultural land units are located in the area and cattle, milk and sheep production are the dominant agricultural practices. This production is concentrated within the NW to NE sectors.

Agricultural production within the 7.5 km radius from the proposed Bantamsklip site is limited. The rural settlement of Buffeljags is situated within this sector, NW of the proposed Bantamsklip site.

The 7.5 to 10 km distance annulus reflects more intensive agricultural use between the NW and the NE sectors. Land uses include cattle farming, dairy production, fynbos harvesting and sheep farming. The bulk of agricultural production is concentrated in the 10 to 16 km radius. As a whole the NNW to NE sectors are the most productive, producing 84% of the area's milk.

Meat production (cattle) takes place from the NW to the SE sectors with the NNW and the N sectors being the most productive. These two sectors account for 74% of total production within a 16 km radius for this activity.

Trout are farmed within the NE sector, in the 10 to 16 km radius. A total of 40 tonnes of trout are produced annually. Fynbos is also harvested within the area. Harvesting is erratic and total production numbers could not be ascertained. About 2 000 kg of honey is produced within the area. This production is concentrated in the ENE sector within a 16 km radius from the proposed Bantamsklip site.

Permanent residential activities are focussed in the two coastal resort towns of Franskraal and Pearly Beach, and the two rural villages of Baardskeerdersbos and Wolwegat. Pearly Beach is located 6 km away to the NW. A small coastal resort (Die Dam), which is run by Cape Nature, is located 14 km from Bantamsklip to the SE.

### 5.2.2 Thyspunt

The Thyspunt site is situated on the coastal plain W of Cape St. Francis and some 4 km ESE of Oyster Bay. The land-use pattern within a 20 km radius of the site can be classified in the following categories in order of importance: significant extensive agricultural activity, with the closest being dairy pastures within 3 km and centre-pivot irrigated crops (grazing) at a distance of 4 km; tall shrubland (dune strandveld and dune fynbos) within a 5 km radius from Thyspunt; commercial dryland agriculture between the NW and NE sectors and EW trending sand dunes across the strandveld. Some fynbos spreads into dryland crops between the N and NNE sectors from the N. Centre-pivot irrigated crop is found inside commercial dryland agriculture between the NNW and N sectors. Oyster Bay is also situated in this zone and is the closest residential area to Thyspunt (i.e. about 5 km).

### 5.2.3 Duynefontein

Located on the coast approximately 30 km N of Cape Town, Duynefontein contains the existing KNPS. The land-use pattern within a 20 km radius of the site can be classified in the following categories in order of importance: cultivated (commercial dryland); fallow land (areas disturbed by agriculture); tall shrubland (strandveld); mixture of cultivated (commercial irrigated) and agricultural industry; low shrubland (fynbos and renosterveld); urban/built-up (residential); bare soil (sand dunes); urban/built-up (light industrial); wetlands; water bodies; urban/built-up (heavy industrial); mines and quarries (surface-based mining); and urban/built-up (informal squatter settlements).

The land within the 5 km radius is predominantly covered by tall shrubland (strandveld), low shrubland (fynbos), sand dunes and the existing KNPS directly S of the site. Urban development is limited to the northern extension of Melkbosstrand (Duynefontein and Van Riebeeckstrand) further south. Duynefontein is the closest residential area, located 3 km SSE of the site. Fallow land borders the sector on the NE. Parts of the area, especially E of the West Coast Road (R27), are heavily infested with alien vegetation. Poorly vegetated sands occur in the dune areas N of the site and further inland to the N, corresponding with the southern part of the Witzand mobile dune system.

The 5-10 km radius reflects the first intensive agricultural use between the ENE and ESE sectors. Cultivated land, a large portion of which now lies fallow, is dominant in this area with wheat, fodder crops and dairy farming being the main agricultural products. Chicken farming is present in the ENE sector, 9 km from the site, and beyond into the Klein Dassenberg smallholdings SE of Atlantis. Also present in this zone is the Atlantis industrial area in the NE and Melkbosstrand residential area on the coast to the south. Strandveld vegetation covers the northern portion of the zone and the extreme southern part (S of Melkbosstrand). The most fertile land is found in the 10-20 km band NE of the site. Known as the Klein Dassenberg smallholdings, this area shows more specialised farming activities that include bee-keeping, vegetables, poultry and egg production, stud-farming and dairy farming. Atlantis is the largest urban node in the northern half of the study area. In addition, well-established wheat farms and accompanying high production of fodder crops characterise the E and ESE sectors. Some of the farmers here also have a well-established dairy component. The nature of the farming is typical of the Swartland. Extensive areas, transformed by agriculture but no longer cultivated, are found between the NNW and NE sectors and between the SE and SSE sectors. As a result of urban development and proximity to the sea, there is a decrease in agriculture towards the south. Most of the land N of Table View is developed or destined for future urban development.

## 5.3 Population distribution

### 5.3.1 Bantamsklip

A relatively small population resides within 16 km of the NPS site (approximately 2 560 people in 2008) with Pearly Beach to the NW containing the highest population density in this distance radius.

### 5.3.2 Thyspunt

A relatively small population resides within the vicinity of site Oyster Bay/ Umzamowethu the nearest and with Sea Vista to the ENE containing the highest population density.

### 5.3.3 Duynefontein

There is a maximum cumulative population of approximately 3.9 million people within 80 km of the site (estimated 2008). The Cape Town region, South Peninsula region, Blaauwberg region, Tygerberg region, Oostenberg region, and Helderberg region are densely populated, as is the area NNE of Duynefontein corresponding with Atlantis. The EP of the KNPS is maintained with the latest relevant information for effective emergency actions, e.g. population data and traffic models as required for evacuation.

## 5.4 Infrastructure (transport & communication)

### 5.4.1 Bantamsklip

The major road in the network with the highest traffic volumes is the MR00028 between Ratelrivier and Gansbaai with a traffic volume of approximately 8000 vehicles per day (vpd). TR02802 (R43) serves as a link to Hermanus and to the N2 via the MR00267 (R326) and carries a volume of approximately 5000 vpd. The MR00267, which serves as the main link on the eastern side of the Bantamsklip site to the N2, carries a vehicle volume of 1 668 vpd. MR00262 runs between Vogelvlei and Bredasdorp and carries a low vehicle volume of approximately 450 vpd. MR00261 connects Agulhas to Bredasdorp and further extends to Goudini and Caledon and carries an approximate vehicle volume of approximately 3000 vpd.

The telephone exchanges falling within a 25 km radius of the Bantamsklip site are listed in

**Table 5-1**.

**Table 5-1:Telephone Exchanges: Bantamsklip**

• R a d i o a n

| Exchange | Distance (km) | Sector |
|---|---|---|
| T1 - Pearly Beach | 7.37 | NW |
| T2 - Franskraalstrand | 18.95 | NW |
| T3 - Gansbaai | 23.09 | NW |
| T4 - Haasvlakte | 22.83 | ENE |

Sentech (Pty) Ltd controls the radio and television transmitters in the region. There are no radio or television transmitters within a 25 km radius of the site. The nearest transmitter to Bantamsklip is located at Napier (34° 31’ 45” S, 19° 53’ 33” E) and transmits KFM, RSG, SAFM as well as SABC1 and SABC2. This transmitter is approximately 37 km from the Bantamsklip site.

### 5.4.2 Thyspunt

Current traffic volumes on the N2 in the vicinity of Humansdorp are in the order of 3 768 vpd in both directions, with the percentage of trucks being 18.38%. Information on accident hotspots and accident statistics are not available. However, road signs warn motorists that the 5 km section to the E of the N2/R330 interchange is an “accident hotspot”.

The telephone exchanges falling within a 25 km radius of the Thyspunt site are listed in Table 5-2.

**Table 5-2: Telephone Exchanges: Thyspunt**

| Exchange | Distance (km) | Direction |
|---|---|---|
| T1 - Oyster Bay | 5.04 | WNW |
| T3 – St. Francis Bay | 11.58 | ENE |
| T4 - Aston Bay | 22.12 | ENE |
| T5 - Jeffreys Bay | 24.75 | NE |
| T6 - Wavecrest | 26.87 | NE |
| T7 - Humansdorp | 18.80 | NNE |

Sentech (Pty) Ltd controls the radio and television transmitters in the region. The nearest transmitter to Thyspunt is located at Port Elizabeth (33° 56’ 10” S, 25° 26’ 29” E) and transmits RSG, SAFM, R2000, LOBO, 5FM, METRO FM, LOTUS FM and ALGOA Radio as well as SABC1, 2, 3, eTV and MNET. This transmitter is approximately 90 km from the Thyspunt site.

### 5.4.3 Duynefontein

The R27 and the N7 serve primarily as north-south national and regional distributors, with the additional function of providing local rural access. The R27 links the Cape Town metropolitan area with the north western coastal areas, traversing the farm Duynefontein at approximately 2.3 km from KNPS. This road provides the major access to the Duynefontein site and is a dual carriageway from Table Bay Boulevard to Table View.

The telephone exchanges falling within a 25 km radius of the Duynefontein site are listed in Table **5-3**.

**Table 5-3: Telephone Exchanges: Duynefontein**

| Exchange | Distance (km) | Direction | Total |
|---|---|---|---|
| Altria | 9.19 | NNE | 1 700 |
| Atlantis | 13.25 | NNE | 8 250 |
| Bloubergstrand | 14.84 | SSE | 5 124 |
| Bothasig | 24.75 | SSE | 15 216 |
| Darling | 32.43 | N | 1 878 |
| Durbanville | 27.70 | SE | 21 946 |
| Kalbaskraal | 23.08 | ENE | 544 |
| Klipheuwel | 25.89 | E | 512 |
| Maitland | 28.60 | S | 16 768 |
| Mamre | 17.73 | NNE | 1 048 |
| Melkbosstrand | 6.70 | SSE | 3 828 |
| Milnerton | 24.27 | SSE | 2 648 |
| Philadelphia | 14.05 | E | 400 |
| Robben Island | 16.25 | SSW | 208 |
| Table View | 19.65 | SSE | 18 928 |

Sentech (Pty) Ltd controls all radio and television transmitters in the region. There are no radio or television installations within a 25 km radius of the Duynefontein site. However, the Sentech Tygerberg Transmitter station is the closest. It is located on Tierkop, approximately 27.6 km SE of the site. The regional operations centre of Sentech, situated approximately 23 km S of the Duynefontein site, handles all transmissions of radio and television programmes.

## 5.5 Atmospheric dispersion potential

An important characteristic of a site is the atmospheric dispersion potential. Poor dispersion at the time of an accident can result in higher radiological exposure. The meteorology and dispersion characteristics of the sites are discussed in detail in the specialist study for the sites air quality impact and climatology [14]. A site's atmospheric dispersion potential during an accident is measured by a dispersion coefficient, χ/Q. It is the ratio of the radioactivity concentration per $m^3$ of air and the amount of radioactivity released per second. One of the criteria for the atmospheric dispersion potential at a site's boundary is that χ/Q should be equal to or less than $10^{-3}$ sec/$m^3$ (≤ $10^{-3}$ sec/$m^3$) for a 2 hour period during accident release [15]. Values smaller than this indicate that a site's atmospheric dispersion potential is better than what is required.  Additional dispersion modelling was carried out for the Bantamsklip and Thyspunt sites. Atmospheric dispersion coefficients for gaseous releases were determined using hourly meteorological data collected for a full year on each site. The results are shown in **Figure 5-1** and **Figure 5-2** and indicate that the sites have good dispersion potentials. χ/Q is much smaller and less than $10^{-6}$ sec/$m^3$ for areas that will fall inside the site boundaries.

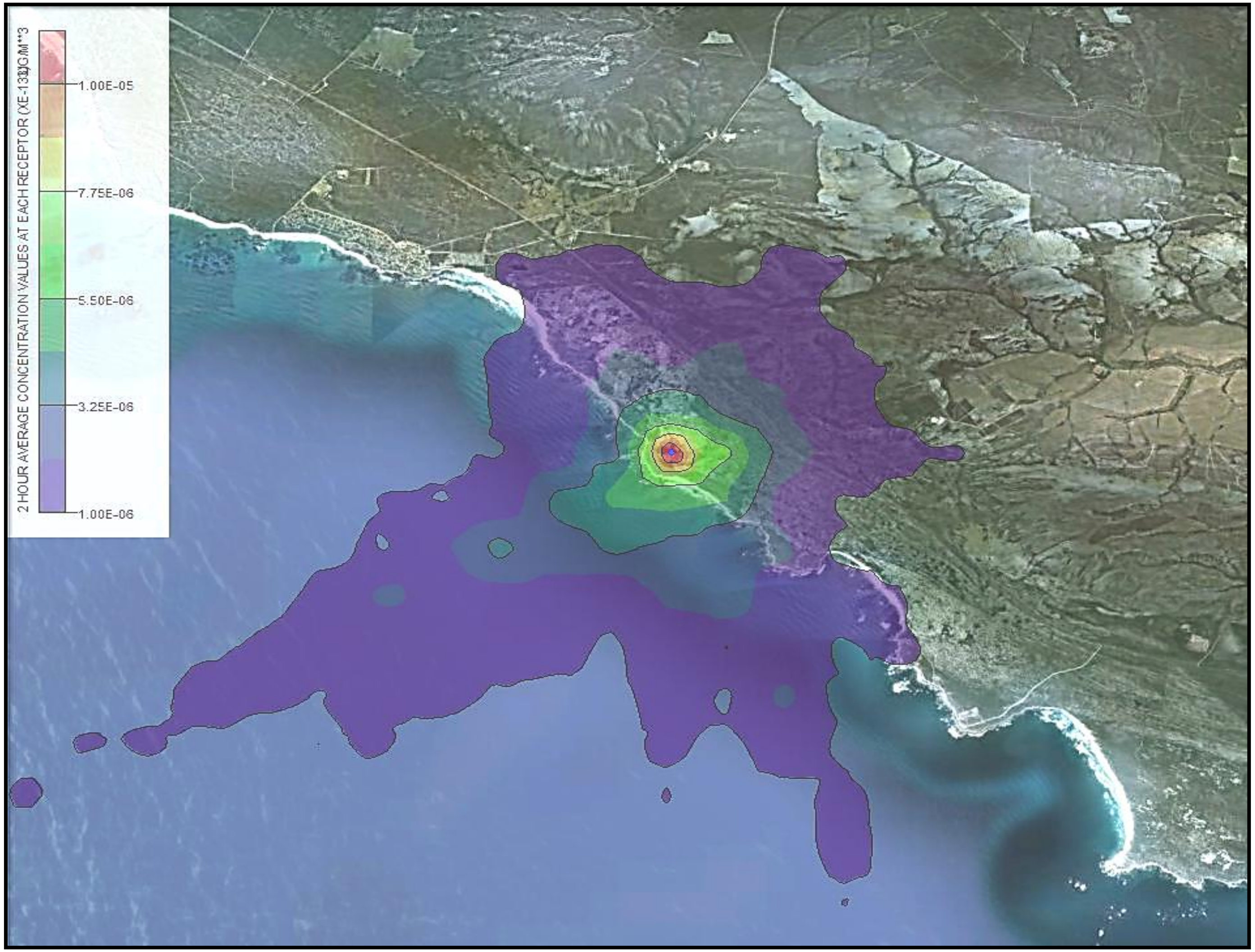


**Figure 5-1: Bantamsklip Atmospheric Dispersion Coefficient (2 hr max)**

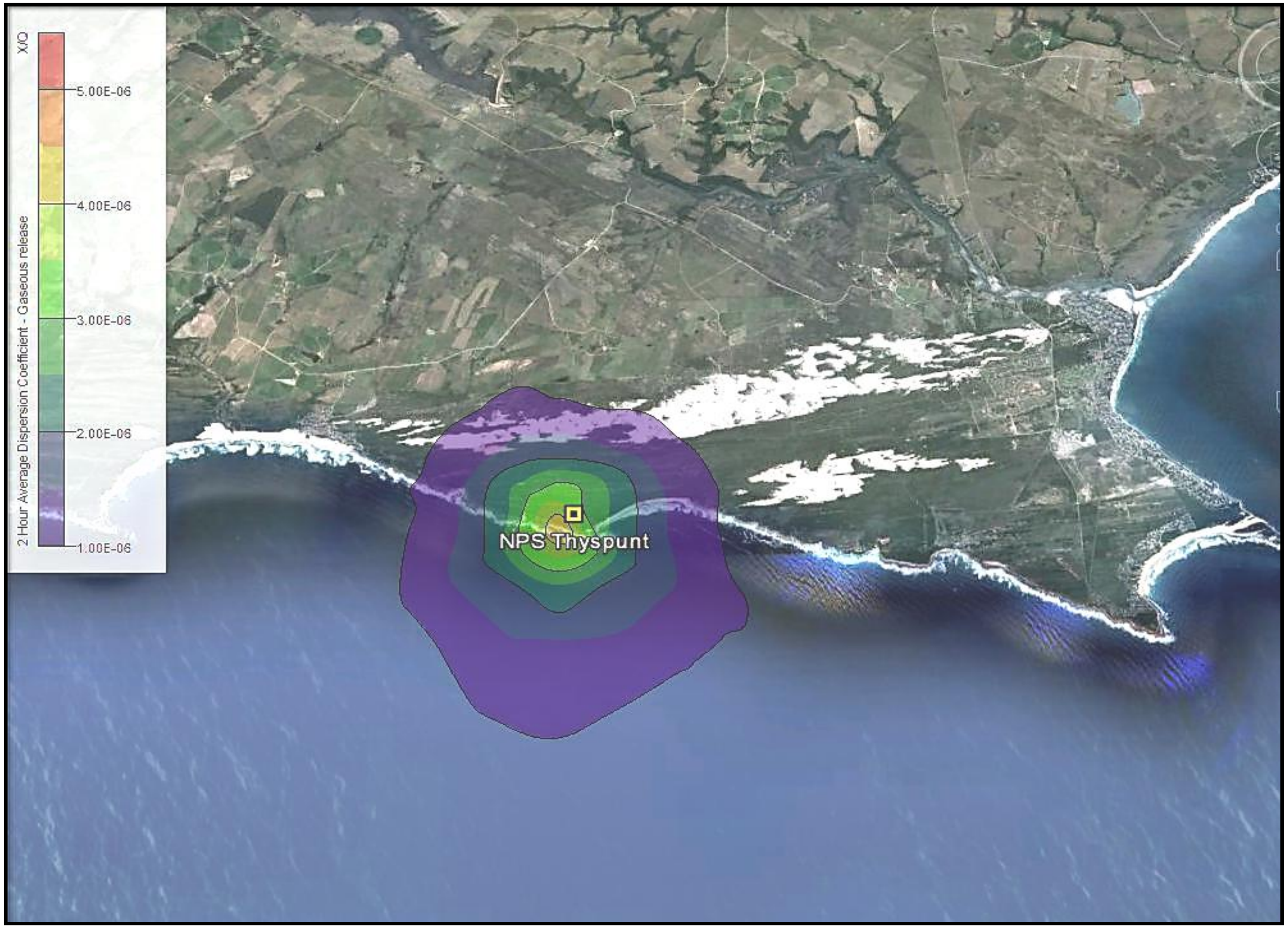


**Figure 5-2: Thyspunt Atmospheric Dispersion Coefficient (2 hr max)**

In the case of Duynefontein where an EP already exists for the KNPS it was demonstrated that the current EPZs (5km, 16 km and 80 km for the PAZ, UPZ and LPZ, respectively) envelope the new nuclear installation EPZ objectives listed in

**Table 4-1**. This is illustrated in **Figure 5-3**.

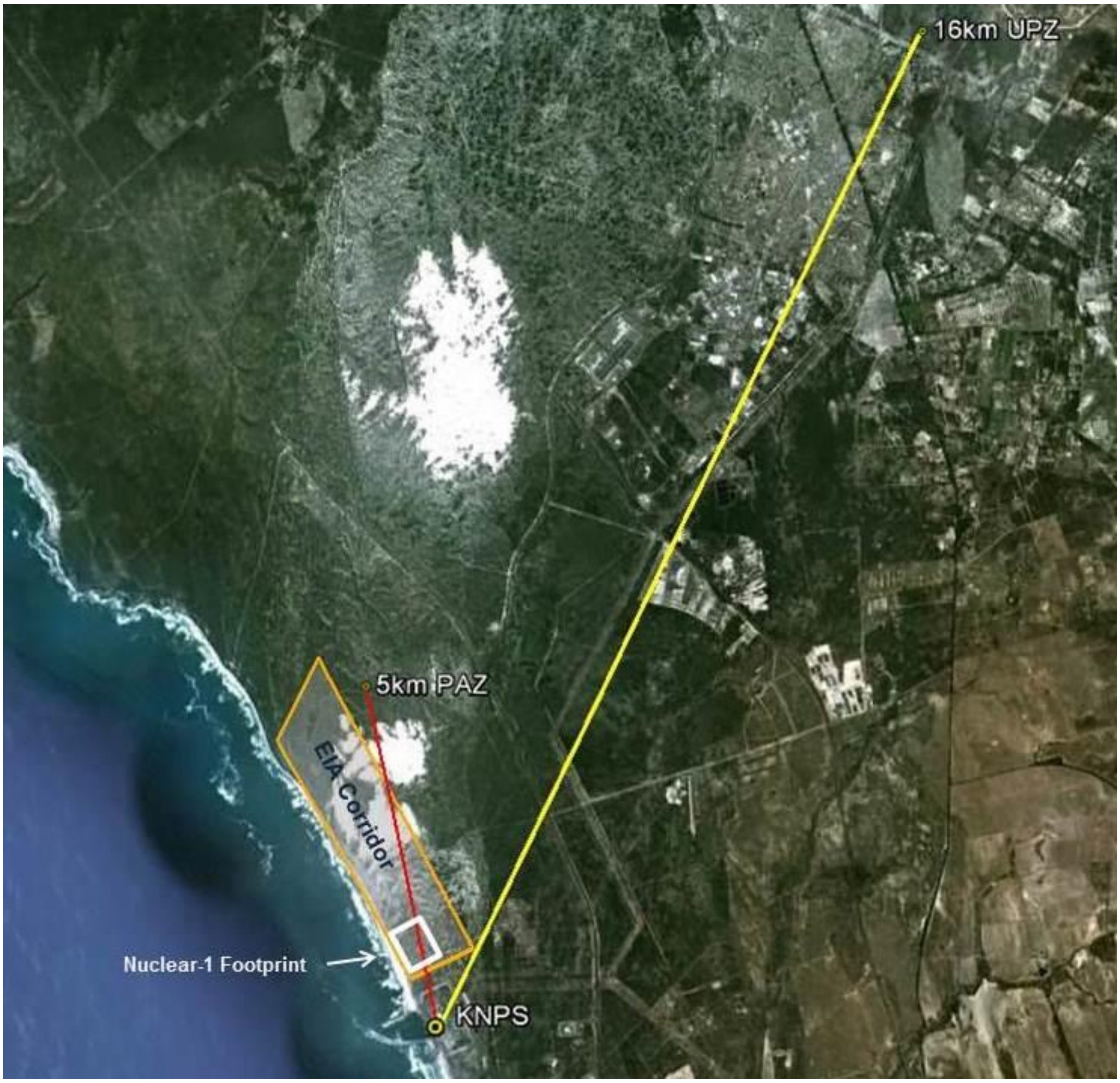


**Figure 5-3: Illustration of the Nuclear Installation Footprint in Relation to the Existing EPZ of the KNPS**

# 6 ORGANISATIONAL STRUCTURE FOR AN EMERGENCY PLAN

There are progressive stages of response to a nuclear emergency plan, depending on the seriousness of the potential consequences of an accident. These are [16]:

1. *Unusual Event*– An abnormal occurrence that indicates an unplanned deviation from normal operations, the actual or potential consequences of which require notification of the Emergency Controller and activation of the appropriate components of the Nuclear Emergency Plan.

2. *Alert*– A situation exists that could develop into a site or general emergency and therefore requires notification of all emergency personnel in order to obtain a state of readiness to respond.
3. *Site Emergency*– An emergency condition exists that poses a serious radiological hazard on site but poses no serious radiological hazard beyond the public exclusion boundary.
4. *General Emergency*– An emergency condition exists that poses, or potentially poses, a serious radiological hazard beyond the public exclusion boundary.

The design aims of the new generation of nuclear reactors are to avoid the last stage, i.e. a General Emergency requiring off-site urgent actions.

A flow diagram illustrating the Eskom Nuclear Emergency Organisation is shown in **Figure 6-1** and facilitates communication and decision-making. The functions of the main role players are briefly described as follows:

1. A nuclear installation's operating personnel on shift perform emergency response functions.
2. There is an Emergency Control Centre for the nuclear installation from where control is exercised for emergencies. Additional communication facilities enable an Emergency Controller to keep all reactor units on the site abreast of developments during an emergency. The Emergency Controller is assisted by a dual function Technical Support Centre (TSC) that is equipped to deal with any severe accident.
3. Eskom Nuclear Installation Specialists and the nuclear installation supplier company will render the technical support to the nuclear installation Emergency Control Centre in the case of an emergency.
4. A Regional Emergency Control Centre will be equipped with information data and systems that clearly report nuclear installation specific conditions during an emergency.
5. The NNR will adapt their response plans to include the nuclear installation specific information.
6. The Megawatt Park National Emergency Centre will adapt their response plans to include new nuclear installation-specific information.

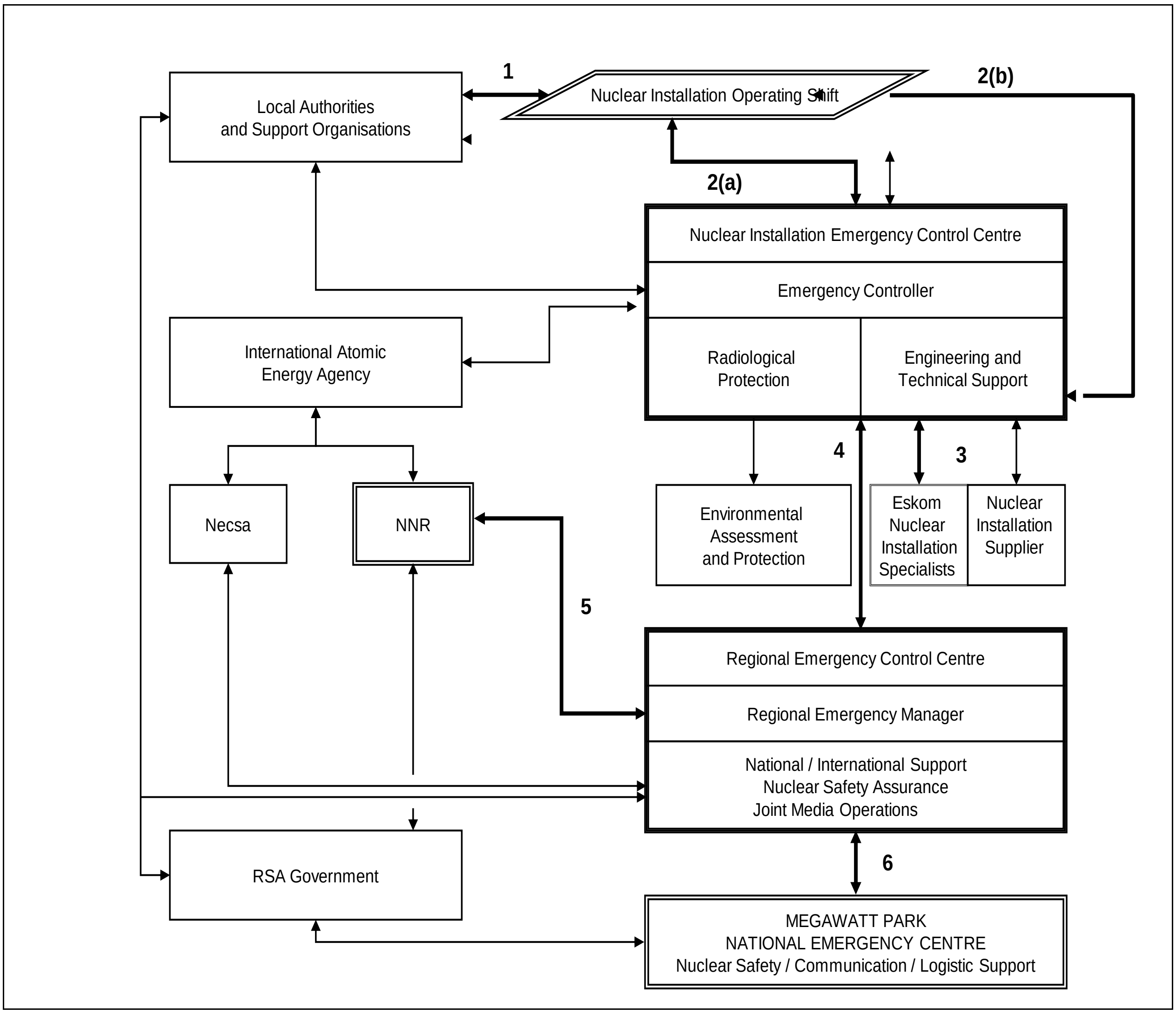


**Figure 6-1: Nuclear Emergency Organisation**

# 7 THE FUKUSHIMA NUCLEAR EMERGENCY

The safety of nuclear energy is being questioned following the Fukushima accident. It is therefore important to include a brief discussion to provide some perspective and how it impacts on emergency planning for the proposed Nuclear-1 power station.

On 11 March 2011, at 14.46 local time, a 9.0-magnitude earthquake created a destructive tsunami. The tsunami flooded over 500 km$^2$ of land and more than 20 000 lives were lost. The tsunami caused the loss of important safety systems at the Fukushima Daiichi nuclear power station. This resulted in the nuclear accident starkly demonstrated the external events such as earthquakes and their likelihood of occurrence are important (if not the most important) considerations in the selection of a site for a nuclear power station. Earthquakes are discussed in the Seismic Risk Assessment of the EIR.

Lessons learnt from the accident and the latest safety system designs provide confidence that the new generation of nuclear installation proposed for Nuclear-1 will be able to deal with a Fukushima type event. Furthermore, South Africa and the location of the three sites are vastly different to Japan when comparing the occurrence of natural disasters such as earthquakes that could challenge the safety of a nuclear installation. A simple illustration is the comparison of different regions of the world where major earthquakes occur. **Figure 7-1** illustrates information available from the United States Geological Survey's Earthquake Hazard Program [17]. The white circles show earthquakes larger than magnitude 6 since 1970 to present. The comparison between Japan and South Africa, where no circle is indicated in the region of the three sites, speaks for itself.

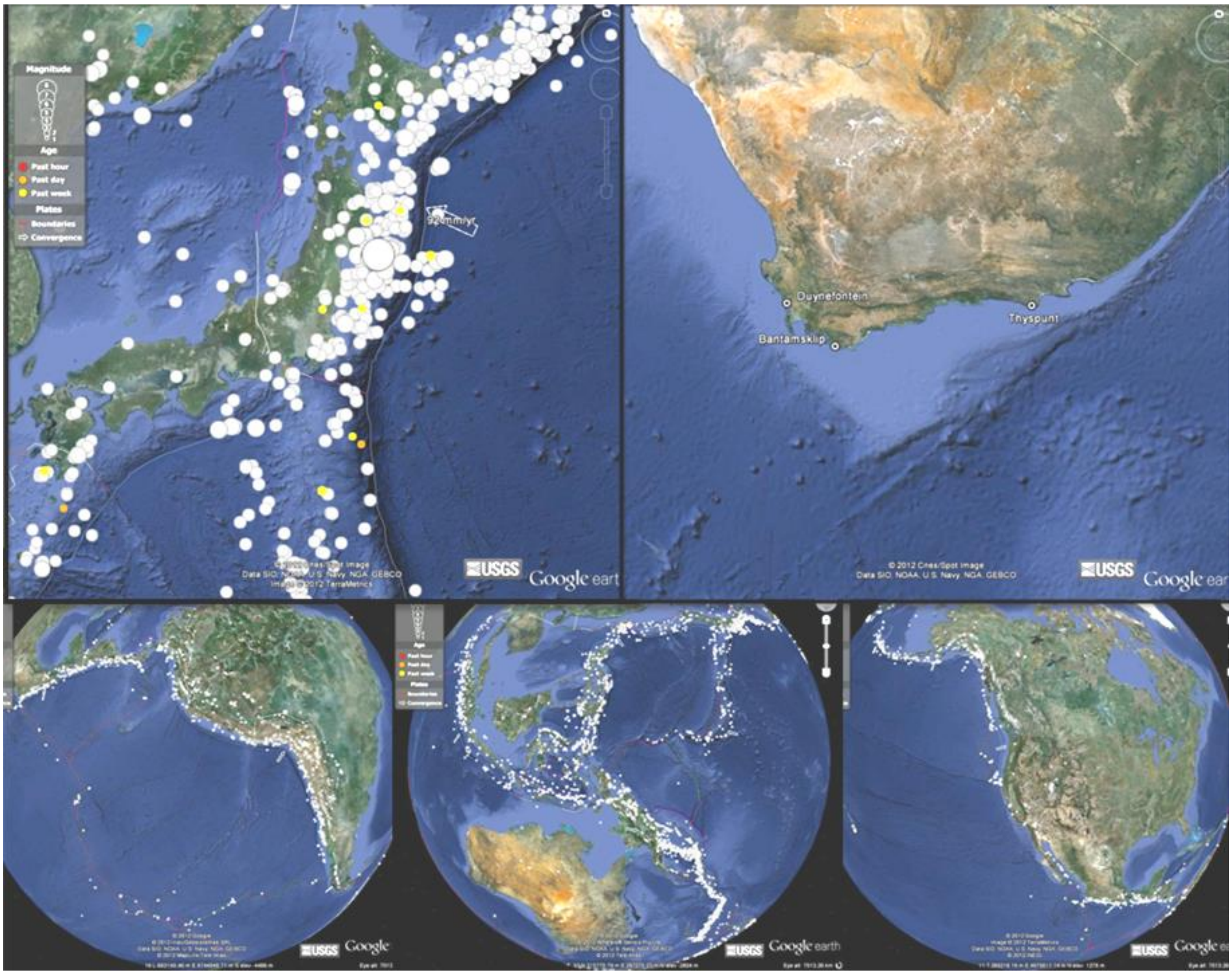


**Figure 7-1: A History of Earthquakes Since 1970 (white dots indicating earthquakes)**

Emergency plans, and the possible impact of external events to effectively implement an EP, are being reviewed for improving safety even further. Lessons learnt from the Fukushima nuclear disaster are incorporated in EPs, irrespective of a region's lower likelihood for the type of natural disasters that occurred at Fukushima. The NNR, in line with other regulators internationally, has requested the KNPS to review safety features and incorporate lessons learnt from the disaster in their safety programmes. The reviews include the KNPS EP.

It is more than three years since the accident and a recent report by the United Nations Special Commission on the Effects of Atomic Radiation (UNSCEAR) provides the most comprehensive international scientific analysis of the levels and effects of exposure to radiation following the accident [18]. More than 80 experts from eighteen United Nations Member States carried out the analytical work for the study.

Earlier dose assessments indicated, using conservative assumptions, that total effective doses in the two most affected areas of the Fukushima prefecture are from 10 to 50 mSv. In the rest of the prefecture, the total effective dose is estimated to be from 1 to 10 mSv. The results can be compared to UNSCEAR's latest estimate of the average global dose from natural radiation, which is 2.4 milliSieverts per year (mSv/y). It ranges between about 1 and 13 mSv, while sizeable population groups receive 10 to 20 mSv annually. The Japanese people receive an effective dose of radiation from naturally occurring sources of about 2.1 mSv/y. Health studies that show there have been no measurable adverse health effects for exposures (total effective dose) below 100 mSv. The main findings in the UNSCEAR report can be summarised as follows:

- For the population affected by the accident, cancer rates are expected to remain stable. UNSCEAR does not expect significant changes in future cancer statistics that could be attributed to radiation exposure from the accident.
- Cancer rates to remain stable;
- Theoretical increased risk of thyroid cancer among most exposed children;
- No impact on birth defects/hereditary effects No discernible increase in cancer rates for workers;
- Temporary impact on wildlife.

A further perspective on radiation levels is provided by comparing the Fukushima accident radiation dose of members of the public with radiation levels in high natural background radiation areas in South Africa. Some areas in the Karoo are examples. where natural mineralized outcrops can be described as radiation "hotspots". It is normally identifiable as patches of black mineralized "koffieklip" and is illustrated in **Figure 7-2**. At some of these hotspot areas radiation levels as high as 0.150 mSv/h (on contact) can be measured. This equates to 1315 mSv/y. Typical background external radiation levels at the three Eskom sites are less than 1 mSv/y [19].

**Figure 7-2: Occurrence of High Natural Radiation Levels in the Karoo**

# 8 CONCLUSIONS

Eskom is committed to building nuclear installations with enhanced safety design features compared to the majority of reactors currently operating in the world. A radiological consequence assessment of postulated reference accidents show that the need for *off-site* short-term emergency interventions like sheltering, evacuation or iodine prophylaxis is unlikely. Protective actions related to food may be required for a limited period of time following an accident. The EP will therefore include protective measures such as the following:

- An immediate ban on the consumption of locally grown food in an area affected by the accident;
- The protection of local food and water supplies by, for example, covering open wells and sheltering animals and animal feed; and
- Long-term sampling and control of locally grown food and feed. Control of milk production and distributors is generally considered particularly important because it is a significant part of children’s diets.

It is concluded that effective emergency plans for each of the new sites, (Bantamsklip and Thyspunt) are feasible, subject to a degree of infrastructure upgrade. An important aspect of infrastructure upgrade will involve improvement of the óff-site access roads that will service the site. Flooding hazards in the region will be an important design consideration of these new roads. This will ensure successful emergency actions in the event that they are required, such as emergency support access to the site. The final layout of the site and design of access routes therefore have to take into consideration adverse environmental conditions that could exist at the time of a nuclear emergency.

The existing EP for the KNPS will incorporate a new nuclear installation and feasibility at the Duynefontein site. The EPZs already in place for the KNPS envelope those required for Nuclear-1.

The final and detailed emergency plan for each site has to be approved by the NNR. This includes the revised EP for Duynefontein that will include new nuclear installations. This approval will be based on detailed safety assessments that have to provide final justification for the technical basis of a site's emergency plan. Off-site short-term emergency actions may only be applicable to the Duynefontein Site, because of the existing KNPS.

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## Appendix 1 Reference Accidents for EPZ Assessment

The choice of a reference accident to determine EPZ for a site is based on postulated severe accidents described in Safety Analysis Reports for the EPR and AP1000 reference technologies.

Severe accidents occur when safety systems are impaired and are unable to prevent significant reactor core damage. The source terms for these severe accidents and their estimated frequencies of occurrence are derived by performing a Probabilistic Safety Assessment (PSA) which, amongst other things, deals with the performance of a reactor containment under severe accident conditions [20]. These source terms released to the atmosphere, along with calculations of the off-site radiation dose as a function of distance, are used as inputs into the development of off-site emergency planning.

The part of PSAs dealing with NPS containment systems is referred to as a Level 2 PSA. It is an essential parts of a safety analysis report that is required for nuclear authorisation of advanced light water reactors such as the AP1000 and EPR. Its purpose is to demonstrate the NPS capability to address severe accident containment challenges. This capability is based on design features and characteristics to achieve an extremely low probability for core damage accident sequences which could result in bypass containment, i.e. a source term to the atmosphere.

The occurrence frequency objective for large off-site releases requiring urgent off-site response is $1x10^{-5}$ per reactor-year for an existing NPS. The numerical value for a large off-site radioactive release for new generation plants is required to be significantly lower and the aim is practical elimination of accident sequences that could lead to large early radioactive releases to the atmosphere. The PSAs for the EPR and AP1000 demonstrate significantly lower frequencies than $1x10^{-5}$/y and provide information on source terms and release categories to the environment.

The AP1000 has a severe accident mitigation goal which is to ensure the functioning of the containment in the event of an accident resulting in a significant structural degradation of the reactor core. Specific design features have been incorporated for the retention and stabilisation of the molten core inside the containment as well as for the mitigation of environmental effects that can compromise its fission product retention capability. These design features provide redundant and diverse mitigation of challenging phenomena in the unlikely event of a severe accident. These features include the reactor coolant automatic depressurisation system, the ability to flood the reactor vessel cavity, hydrogen igniters in the large dry containment and the passive containment cooling system. These design features act to maintain reactor coolant system (RCS) integrity, prevent containment overpressurisation from hydrogen detonation or deflagration and to remove heat from the containment. These mitigation features maintain the potential for fission-product release from the AP1000 containment very low.

The EP requirements in respect of the AP1000 are based on the reference accident listed in Table A-1and the associated source term listed in Table A-2. [20; 21].

The EPR has a severe accident mitigation goal similar to the AP1000. Design features to address severe accident challenges include:

- Provision of dedicated valves for rapid depressurisation of the RCS.

- Multiple Passive Autocatalytic Hydrogen Recombiners to minimise the risk of hydrogen detonation.
- The containment is designed to promote atmospheric mixing with the ability to withstand the loads produced by hydrogen deflagration.
- A dedicated compartment to spread and cool molten core debris for long-term stabilisation.
- A severe accident heat removal system with two trains allowing one train to be serviced or repaired in the long term if necessary.
- Electrical and instrumentation and control systems dedicated and qualified to support severe accident mitigation features.
- The reactor building consisting of an inner containment building and an outer shield building with a sub-atmospheric annulus.

The EP requirements in respect of the EPR are based on the reference accident listed in Table A-1and the associated source term listed in Table A- 3.

**Table A-1: Reference Accident Occurrence Frequencies**

| Release Category | | Release Frequency (per yr) |
|---|---|---|
| No containment failure | RC8 | $3.58 \times 10^{-7}$ |
| Intact containment leakage | IC | $2.21 \times 10^{-7}$ |

**Table A-2: AP1000 Core Inventory and Intact Containment Release Fraction to the Environment**

| Group No | Group Description | Radionuclide | Bq | Release Fraction | Activity Released |
|---|---|---|---|---|---|
| 1 | Noble Gases | Kr-85m | 9.73E+17 | 2.60E-03 | 2.53E+15 |
| | | Kr-85 | 3.92E+16 | 2.60E-03 | 1.02E+14 |
| | | Kr-87 | 1.88E+18 | 2.60E-03 | 4.88E+15 |
| | | Kr-88 | 2.64E+18 | 2.60E-03 | 6.87E+15 |
| | | Xe-131m | 3.92E+16 | 2.60E-03 | 1.02E+14 |
| | | Xe-133m | 2.16E+17 | 2.60E-03 | 5.62E+14 |
| | | Xe-133 | 7.03E+18 | 2.60E-03 | 1.83E+16 |
| | | Xe-135m | 1.43E+18 | 2.60E-03 | 3.72E+15 |
| | | Xe-135 | 1.79E+18 | 2.60E-03 | 4.66E+15 |
| | | Xe-138 | 6.11E+18 | 2.60E-03 | 1.59E+16 |
| 2 | CsI | I-130 | 1.35E+17 | 1.20E-05 | 1.63E+12 |
| | | I-131 | 3.56E+18 | 1.20E-05 | 4.28E+13 |

| Group No | Group Description | Radionuclide | Bq | Release Fraction | Activity Released |
|---|---|---|---|---|---|
| | | I-132 | 5.18E+18 | 1.20E-05 | 6.22E+13 |
| | | I-133 | 7.36E+18 | 1.20E-05 | 8.84E+13 |
| | | I-134 | 8.07E+18 | 1.20E-05 | 9.68E+13 |
| | | I-135 | 6.88E+18 | 1.20E-05 | 8.26E+13 |
| 3 | $TeO_2$ | Te-127m | 4.88E+16 | 9.50E-06 | 4.64E+11 |
| | | Te-127 | 3.77E+17 | 9.50E-06 | 3.59E+12 |
| | | Te-129m | 1.67E+17 | 9.50E-06 | 1.58E+12 |
| | | Te-129 | 1.12E+18 | 9.50E-06 | 1.07E+13 |
| | | Te-131m | 5.18E+17 | 9.50E-06 | 4.92E+12 |
| | | Te-132 | 5.11E+18 | 9.50E-06 | 4.85E+13 |
| 4 | SrO | Sr-89 | 3.57E+18 | 1.10E-05 | 3.93E+13 |
| | | Sr-90 | 3.07E+17 | 1.10E-05 | 3.38E+12 |
| | | Sr-91 | 4.44E+18 | 1.10E-05 | 4.88E+13 |
| | | Sr-92 | 4.77E+18 | 1.10E-05 | 5.25E+13 |
| 5 | $MoO_2$ | Ru-103 | 5.37E+18 | 1.30E-05 | 6.97E+13 |
| | | Ru-105 | 3.64E+18 | 1.30E-05 | 4.73E+13 |
| | | Ru-106 | 1.76E+18 | 1.30E-05 | 2.29E+13 |
| | | Rh-105 | 3.33E+18 | 1.30E-05 | 4.33E+13 |
| | | Mo-99 | 6.81E+18 | 1.30E-05 | 8.85E+13 |
| | | Tc-99m | 5.96E+18 | 1.30E-05 | 7.74E+13 |
| 6 | CsOH | Cs-134 | 7.18E+17 | 1.10E-05 | 7.90E+12 |
| | | Cs-136 | 2.05E+17 | 1.10E-05 | 2.25E+12 |
| | | Cs-137 | 4.18E+17 | 1.10E-05 | 4.60E+12 |
| | | Cs-138 | 6.73E+18 | 1.10E-05 | 7.41E+13 |
| | | Rb-86 | 8.47E+15 | 1.10E-05 | 9.32E+10 |
| 7 | BaO | Ba-139 | 6.59E+18 | 1.20E-05 | 7.90E+13 |
| | | Ba-140 | 6.33E+18 | 1.20E-05 | 7.59E+13 |

| Group No | Group Description | Radionuclide | Bq | Release Fraction | Activity Released |
|---|---|---|---|---|---|
| 8 | $La_2O_3$ | Y-90 | 3.20E+17 | 1.40E-06 | 4.49E+11 |
| | | Y-91 | 4.96E+18 | 1.40E-06 | 6.94E+12 |
| | | Y-92 | 4.81E+18 | 1.40E-06 | 6.73E+12 |
| | | Y-93 | 5.51E+18 | 1.40E-06 | 7.72E+12 |
| | | Nb-95 | 6.18E+18 | 1.40E-06 | 8.65E+12 |
| | | Zr-95 | 6.14E+18 | 1.40E-06 | 8.60E+12 |
| | | Zr-97 | 6.07E+18 | 1.40E-06 | 8.50E+12 |
| | | La-140 | 6.73E+18 | 1.40E-06 | 9.43E+12 |
| | | La-141 | 5.99E+18 | 1.40E-06 | 8.39E+12 |
| | | La-142 | 5.81E+18 | 1.40E-06 | 8.13E+12 |
| | | Pr-143 | 5.40E+18 | 1.40E-06 | 7.56E+12 |
| | | Nd-147 | 2.40E+18 | 1.40E-06 | 3.36E+12 |
| 9 | $CeO_2$ | Ce-141 | 6.03E+18 | 1.50E-06 | 9.05E+12 |
| | | Ce-143 | 5.62E+18 | 1.50E-06 | 8.44E+12 |
| | | Ce-144 | 4.55E+18 | 1.50E-06 | 6.83E+12 |
| 10 | Sb | Sb-127 | 3.81E+17 | 1.30E-05 | 4.95E+12 |
| | | Sb-129 | 1.15E+18 | 1.30E-05 | 1.49E+13 |
| 11 | $UO_2$ | Np-239 | 7.14E+19 | 0.00E+00 | 0.00E+00 |
| | | Pu-238 | 1.42E+16 | 0.00E+00 | 0.00E+00 |
| | | Pu-239 | 1.25E+15 | 0.00E+00 | 0.00E+00 |
| | | Pu-240 | 1.83E+15 | 0.00E+00 | 0.00E+00 |
| | | Pu-241 | 4.11E+17 | 0.00E+00 | 0.00E+00 |
| | | Am-241 | 4.63E+14 | 0.00E+00 | 0.00E+00 |
| | | Cm-242 | 1.09E+17 | 0.00E+00 | 0.00E+00 |
| | | Cm-244 | 1.34E+16 | 0.00E+00 | 0.00E+00 |

**Table A- 3: EPR Core Inventory and Intact Containment Release Fraction to the Environment**

| Group No | Radionuclide | Bq | Release Fraction | Activity Released |
|---|---|---|---|---|
| 1 | Kr-83m | 6.00E+17 | 4.50E-04 | 2.70E+14 |
| | Kr-85m | 1.30E+18 | 4.50E-04 | 5.85E+14 |
| | Kr-87 | 2.50E+18 | 4.50E-04 | 1.13E+15 |
| | Kr-88 | 3.50E+18 | 4.50E-04 | 1.58E+15 |
| | | | | |
| | Xe-133m | 3.10E+17 | 4.50E-04 | 1.40E+14 |
| | Xe-133 | 9.70E+18 | 4.50E-04 | 4.37E+15 |
| | Xe-135m | 2.10E+18 | 4.50E-04 | 9.45E+14 |
| | Xe-135 | 3.00E+18 | 4.50E-04 | 1.35E+15 |
| | Xe-138 | 8.60E+18 | 4.50E-04 | 3.87E+15 |
| 2 | | | | |
| | 1-131 | 4.80E+18 | 1.20E-06 | 5.76E+12 |
| | 1-132 | 7.00E+18 | 1.20E-06 | 8.40E+12 |
| | 1-133 | 1.00E+19 | 1.20E-06 | 1.20E+13 |
| | 1-134 | 1.10E+19 | 1.20E-06 | 1.32E+13 |
| | 1-135 | 9.50E+18 | 1.20E-06 | 1.14E+13 |
| 3 | Te-127 | 3.90E+17 | 0.00E+00 | 0.00E+00 |
| | Te-129 | 1.40E+18 | 0.00E+00 | 0.00E+00 |
| | Te-129m | 2.90E+17 | 0.00E+00 | 0.00E+00 |
| | Te-131 | 4.10E+18 | 0.00E+00 | 0.00E+00 |
| | Te-131m | 9.20E+17 | 0.00E+00 | 0.00E+00 |
| | Te-132 | 6.90E+18 | 0.00E+00 | 0.00E+00 |
| | Te-133 | 5.40E+18 | 0.00E+00 | 0.00E+00 |
| | Te-133m | 4.50E+18 | 0.00E+00 | 0.00E+00 |
| | Te-134 | 8.90E+18 | 0.00E+00 | 0.00E+00 |
| 4 | Sr-89 | 4.90E+18 | 2.20E-07 | 1.08E+12 |

| Group No | Radionuclide | Bq | Release Fraction | Activity Released |
|---|---|---|---|---|
| | Sr-90 | 4.70E+17 | 2.20E-07 | 1.03E+11 |
| | Sr-91 | 6.10E+18 | 2.20E-07 | 1.34E+12 |
| | Sr-92 | 6.40E+18 | 2.20E-07 | 1.41E+12 |
| 5 | Mo-99 | 9.10E+18 | 6.40E-07 | 5.82E+12 |
| | Tc-99m | 8.10E+18 | 6.40E-07 | 5.18E+12 |
| | Ru-103 | 7.40E+18 | 6.40E-07 | 4.74E+12 |
| | Ru-105 | 5.00E+18 | 6.40E-07 | 3.20E+12 |
| | Ru-106 | 2.60E+18 | 6.40E-07 | 1.66E+12 |
| | Rh-103m | 7.40E+18 | 6.40E-07 | 4.74E+12 |
| | Rh-105 | 4.60E+18 | 6.40E-07 | 2.94E+12 |
| 6 | Cs-134 | 9.30E+17 | 7.30E-07 | 6.79E+11 |
| | Cs-137 | 6.40E+17 | 7.30E-07 | 4.67E+11 |
| | Cs-138 | 9.30E+18 | 7.30E-07 | 6.79E+12 |
| | Rb-88 | 3.60E+18 | 7.30E-07 | 2.63E+12 |
| | Rb-89 | 4.70E+18 | 7.30E-07 | 3.43E+12 |
| 7 | Ba-140 | 8.90E+18 | 5.10E-07 | 4.54E+12 |
| 8 | Y-90 | 4.90E+17 | 1.00E-08 | 4.90E+09 |
| | Y-91 | 6.30E+18 | 1.00E-08 | 6.30E+10 |
| | Y-92 | 6.50E+18 | 1.00E-08 | 6.50E+10 |
| | Y 95 | 4.40E+18 | 1.00E-08 | 4.40E+10 |
| | Zr-95 | 8.30E+18 | 1.00E-08 | 8.30E+10 |
| | Zr-97 | 7.90E+18 | 1.00E-08 | 7.90E+10 |
| | Nb-95 | 8.30E+18 | 1.00E-08 | 8.30E+10 |
| | La-140 | 9.40E+18 | 1.00E-08 | 9.40E+10 |
| | Pr-143 | 7.40E+18 | 1.00E-08 | 7.40E+10 |
| | Nd-147 | 3.30E+18 | 1.00E-08 | 3.30E+10 |
| 9 | Ce-141 | 8.10E+18 | 4.20E-08 | 3.40E+11 |

| Group No | Radionuclide | Bq | Release Fraction | Activity Released |
|---|---|---|---|---|
| | Ce-143 | 7.60E+18 | 4.20E-08 | 3.19E+11 |
| | Ce-144 | 6.10E+18 | 4.20E-08 | 2.56E+11 |
| 10 | Sb-127 | 4.00E+17 | 1.30E-06 | 5.20E+11 |
| | Sb-129 | 1.50E+18 | 1.30E-06 | 1.95E+12 |
| | Sb-131 | 3.80E+18 | 1.30E-06 | 4.94E+12 |
| 12 | Np-239 | 9.20E+19 | 0.00E+00 | 0.00E+00 |
| | Pu-238 | 9.00E+15 | 0.00E+00 | 0.00E+00 |
| | Pu-241 | 7.60E+17 | 0.00E+00 | 0.00E+00 |
| | Cm-242 | 2.40E+17 | 0.00E+00 | 0.00E+00 |
| | Cm-244 | 1.70E+16 | 0.00E+00 | 0.00E+00 |