

CHAPTER 3: SITE SELECTION AND JUSTIFICATION

3.1 Introduction

The selection of a site for an away-from-reactor spent fuel storage facility shares a lot of features common to many other types of nuclear facilities. Any potential site will require an adequately controlled single-use land area to accommodate storage facilities and various infrastructures and to ensure that radiation doses due to resulting activities from all pathways are within acceptable limits as defined by the regulator [15].

Site selection for storage of spent fuel at the proposed CISF departs from the consensus that the facility will be established on the Vaalputs national radioactive waste disposal facility site. A big challenge, however, would be to identify three or more potential/candidate areas on the site and choose a suitable one from them in order to achieve the storage purpose with a minimum of damage and detriment to human health and the environment.

The prospects for achieving the purpose of establishing the CISF on the Vaalputs site are dependent on the properties of the area or site to be selected. The fundamental requirement on the site that is chosen is therefore that there is an area at the site that can satisfy the safety requirements for long-term storage of spent fuel. In order for the site to be available and the project to be feasible, there must also be acceptance in the concerned municipality and among nearby residents. These basic requirements should guide NRWDI's siting work.

To find the most suitable site, NRWDI has to conduct general siting studies (general and regional compilations and analyses), feasibility studies (comprehensive compilations and analyses of siting prospects at the municipal level) and site investigations (comprehensive investigations of geosphere and biosphere on selected sites). Applications with the National Nuclear Regulator (NNR) for a licence to build the CISF on the Vaalputs site would need to contain this information and material that shows that site-specific feasibility studies have been conducted at the candidate sites (areas) and that site investigations have been conducted at the preferred site (area).

In terms of the NNR Act No.47 of 1999 (NNRA), nuclear authorisations are required for the siting of nuclear installations. The regulation on the siting of new nuclear installations requires the applicant for a nuclear site licence for the siting of a nuclear facility to submit, in support of the application, a Site Safety Report (SSR) to the NNR comprising the following [16]:

- Motivation for the choice of the site;
- Statement as to the proposed use of the site (maximum thermal power, general design characteristics, etc.);
- Source term analysis;
- Characteristics of the site, in terms of external events;
- Probabilistic Risk Assessment (including cumulative impact of nuclear installations);
- Analysis of the impact on the public, due to normal operations;
- Analysis to demonstrate the viability of an emergency plan; and
- Identification and determination of the emergency planning zones.

The SSR is required to address the following topics: description of site and environs, population growth and distribution, land use, adjacent sea usage (if applicable), nearby transportation, civil and industrial facilities, meteorology, oceanography and cooling water

supply, impact of natural hazards, impact of external man-made hazards, hydrology, geology and seismology, fresh water supply, site control, emergency services, radioactive effluents, and ecology.

The following regulatory documents directly relevant to the siting of new nuclear installations have been issued by the NNR:

- RD-0024: Requirements on Risk Assessment and Compliance with Principal Safety Criteria for Nuclear Installations;
- RG-0011: Interim Guidance for the Siting of Nuclear Facilities;
- PP-0014: Consideration of External Events for Nuclear Installations; and
- PP-0015: Emergency Plan Technical Basis for New Nuclear Installations.

It must be said here that the siting requirements and consequent site investigation programme for a storage facility for spent fuel are less onerous than those for a deep geological repository (DGR) as they largely concern the properties of the surface environment, and the same requirements would, in any case, apply also to the surface facilities of the DGR (e.g., waste receipt and handling facilities and the encapsulation plant). Consequently, the work required to characterise and qualify the CISF site would be a sub-set of the type of site characterisation work needed for the DGR.

3.2 Laws and Regulations

Requirements governing the siting of nuclear installations are laid down in the National Nuclear Regulator Act No.47 of 1999 and the National Environmental Management Act No.107 of 1998. This section summarises these Requirements.

3.2.1 National Nuclear Regulator Act, No 47 of 1999

All nuclear installations fall under the regulatory authority of the NNR in terms of the National Nuclear Regulator Act No.47 of 1999. The regulator's responsibilities include the siting, design, construction, operation, manufacture of component parts, and decontamination, decommissioning and closure of nuclear installations. The NNR is obliged to establish cooperative governance agreements with other relevant regulators, notably the then-Department of Environmental Affairs (DEA), which is now the Department of Forestry, Fisheries and the Environment (DFFE), regarding the environmental impact assessment (EIA) process where cooperative governance is important.

The Regulations on Licensing of Sites for New Nuclear Installations has been published in the Government Gazette (11 November 2011) under this Act. The most relevant issues in these regulations pertaining to the site selection of a CISF is summarised as follows:

3.2.1.1 Purpose and scope of regulations (No.2)

The purpose of these Regulations is to establish requirements for applications for nuclear installation site licenses for siting.

3.2.1.2 Lodging of applications (No.3)

- (1) Any person wishing to site a nuclear installation in terms of section 21(1) of the NNR Act must lodge an application for a nuclear installation site license with the Chief Executive Officer of NNR.

- (2) An application must: (a) be supported by a Site Safety Report containing such information as listed in regulation 5, and (b) be accompanied by the prescribed application fee, if any.

3.2.1.3 Factors to be considered when evaluating sites for nuclear installation (No.4)

Factors to be considered in evaluating an application for a nuclear installation site license will include, but not be limited, to:

- (1) Factors relating to all nuclear installations in the vicinity.
- (2) The proposed nuclear installation design(s), and the characteristics specific to the site. New nuclear installation(s) must reflect through their design, construction and operation an acceptably low probability of postulated events that could result in release of quantities of radioactive material.
- (3) The site location and the engineered safety features of all nuclear installations, included as safety measures against the hazardous consequences of postulated events, must ensure an acceptably low risk of public exposure.
- (4) The site must be such that radiological doses and risks from normal operation and postulated events associated with all nuclear installations in the vicinity will be acceptably low.
- (5) Natural phenomena and potential man-made hazards must be appropriately accounted for in the design of the new nuclear installation(s), and that adequate emergency plans and nuclear security measures can be developed.
- (6) The cumulative radiological impact of all nuclear Installations and actions, in the vicinity, for which authorisations have already been granted by the Regulator, including the potential impact of nuclear installation(s) referred to in the scope of the nuclear installation site license to be granted by the Regulator.

3.2.1.4 Requirements for a Site Safety Report (No.5)

A Site Safety Report referred to in Regulation 3(2)(a) must contain the following:

- (1) A motivation for the choice of the site to ensure a low risk of public exposure from the operation of the nuclear installation(s).
- (2) A statement as to the proposed use of the site in terms of the range of technologies and plant designs being considered for the nuclear installation(s) and use of the site, including where appropriate the maximum thermal power, general design characteristics such as the engineered safety features of the nuclear installation(s) included as safety measures against the hazardous consequences of postulated events, and the layout on the site.
- (3) The characteristics of the site relevant to the design assessment, risk and dose calculations, including inter alia:
 - (a) External events;
 - (b) Meteorological data;
 - (c) Land use;
 - (d) Population demographics;
 - (e) Regional development
 - (f) Projections of the above data commensurate with the design life of the nuclear installation(s).

3.2.2 National Environmental Management Act No.107 of 1998

The National Environmental Management Act No.107 of 1998 (NEMA), as amended, together with the EIA Regulations, 2014, does not contain any specific provisions regulating the siting of a nuclear installation such as the storage facility for spent nuclear fuel. However, it refers

to the need for public participation in environmental matters (such as siting of facilities) by stating that "... the law should establish procedures and institutions to facilitate and promote public participation in environmental governance". Compliance with this Act is controlled by the DEA, which is responsible for administering the EIAs to be submitted by implementing agencies. The EIA requires public participation (scoping) as part of the overall siting process.

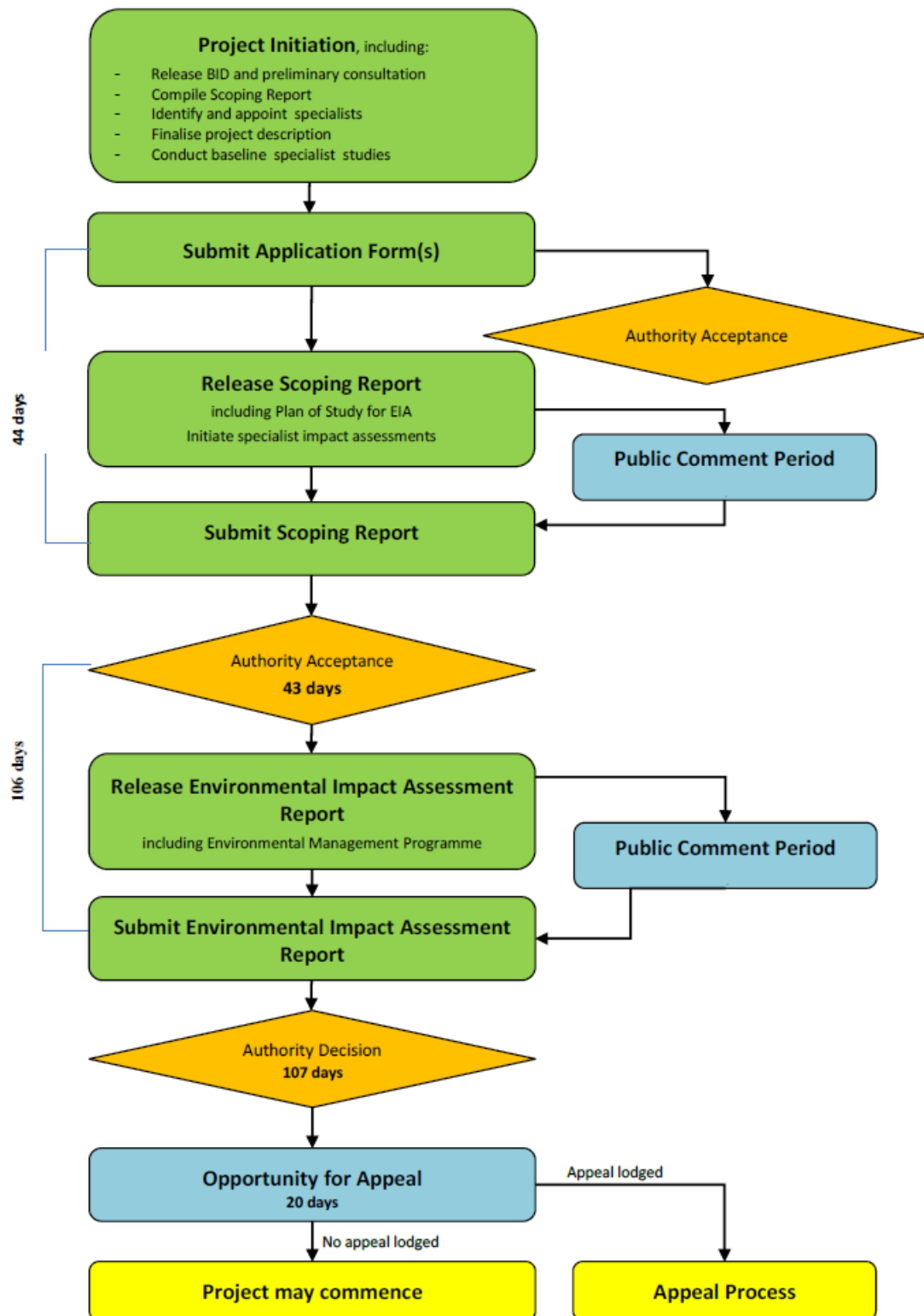
The scope of an EIA process within the framework of the NEMA EIA regulations depends on the extent of the proposed activity and whether the activity is listed in either GN R.544 or GN R.546, which would only require a Basic Assessment Process, or GN R.545, which would require a full EIA process respectively (whereby GN R stands for Government Notice or Regulation).

Before commencing with the CISF siting project, NRWDI is thus required to undertake a Scoping and Environmental Impact Reporting (S&EIR) process, also referred to as EIA process, required in terms of NEMA, as amended, and the EIA Regulations, 2014, and to obtain authorisation in terms of NEMA from the DFFE. The aims of the S&EIR process are to:

- Notify stakeholders of the proposed development (and EIA process);
- Provide stakeholders with the opportunity to participate effectively in the process and identify relevant issues and concerns;
- Ensure that stakeholders' issues and concerns are addressed in the assessment and are accurately recorded and reflected in the Scoping and EIA Reports;
- Assess the potential positive and negative environmental impacts associated with the proposed activity; and
- Make recommendations as to how the potential negative impacts can be effectively mitigated and the benefits enhanced.

An overview of the S&EIR process proposed for the project is shown in Figure 3.1.

Consultation with the public and authorities forms a critical part of the S&EIR process and is intended to provide all stakeholders with opportunities to raise issues and concerns that should be addressed in the S&EIR process and to comment on the documentation submitted to DFFE.



Source: [17]

Figure 3.1: Scoping and Environmental Impacting Report Process

3.3 Site Alternatives in Site Selection

3.3.1 General Consideration for Alternatives

Consideration of potential alternatives in the EIA process is one of the most critical elements of the scoping phase [18]. The role of alternatives is to find the most effective way of meeting the need and purpose of the proposal, either through enhancing the environmental benefits of the proposed activity, and or through reducing or avoiding potentially significant negative impacts. Site layout alternatives, for example, permit consideration of different spatial configurations of an activity on a particular site. Multiple sites allow choices and increase the chances of having at least one success, thus giving flexibility to the programme and prevent unexpected results at any site necessarily leading to a major realignment of effort.

Due consideration of alternatives ensures that the EIA is not reduced to defence of a single project proposal that is the desire of the proponent. Rather, it provides the opportunity for an unbiased, proactive consideration of options, to determine the most optimal course of action.

Recognition of the valuable role of alternatives implies a desire for transparency in the EIA process and a willingness to explore all feasible options in an objective manner, with a view to facilitating balanced decision-making in order to achieve sustainable development. Stakeholder confidence is established when alternatives are considered in an open and transparent manner and there is public acceptance of the alternatives to be considered. The entire EIA process often proceeds more smoothly as a result.

However, exploration of sites is an expensive undertaking, accordingly there is much judgement needed in deciding the number of sites which should be included throughout the siting process [19].

3.3.2 General Site Selection Criteria

General site selection criteria are provided by two of the most authoritative international guidelines for the storage of spent fuel from the United States Nuclear Regulatory Commission (US-NRC) and the International Atomic Energy Agency (IAEA).

In Subpart E of Title 10, Code of Federal Regulations Energy Part 72, of the US-NRC [20] the need to establish site characteristics that may directly affect the safety or environmental impact of a spent fuel storage facility is described, which include natural phenomena such as earthquakes. Although these guidelines were clearly designed to suit the situation in the US, the following points are of importance:

- (a) Sites other than bedrock sites must be evaluated for soil stability, particularly due to vibratory ground motion.
- (b) Site-specific investigations must prove that soil conditions are adequate for the proposed foundation loading.
- (c) The design earthquake shall have a minimum value of 0.10 g for the horizontal ground motion.

The IAEA [21] also emphasises confinement or containment of the fuel as a major selection criterion which refers to the protection against earthquakes, storms, tornadoes etc. Determination of the site characteristics shall include geological and seismological investigations.

The NNR is not prescriptive concerning the site selection exercises for spent fuel storage but adopts a policy of collaboration and consultation during the whole process.

3.3.3 Site Alternatives Considered

For the purpose of this project, the site selection study was confined to three existing sites and a new or “greenfield” site. These are:

- Koeberg site, an existing site;
- Pelindaba site, an existing site;
- Vaalputs site, an existing site;
- Greenfield site, a new non-existing site that is yet to be searched for.

By virtue of the fact that they have been previously shown to be favourable sites for hosting the respective licensed nuclear installations currently operating on them, the three existing sites present attractive opportunities for license. In addition to enjoying acceptance by the local population, these sites also possess a wealth of site data that will support both the EIA process and the licensing process. In contrast, a greenfield site has no benefit of existing infrastructure and resources that the existing sites would leverage upon for the CISF establishment.

Figure 3.2 shows the location of the Koeberg, Pelindaba and Vaalputs in the country. The figure does not show the greenfield site because it could be anywhere in the country.



Source: [22].

Figure 3.2: Locations of Vaalputs, Koeberg and Pelindaba Sites

Based on the available data of the three sites, the selection of the preferred site was made. Table 3.1 summarises the evaluation of the sites. The assessment of the considered sites indicates that the Vaalputs site carries more advantages and less challenges than any other proposed site. The following section therefore focuses on the characterisation and justification of Vaalputs as the preferred site for the establishment of the proposed CISF.

Table 3.1: Siting Implications for Identified Sites

| Site | Site Location/Description | Siting Implications | |
|------|---------------------------|--------------------------------|-------------|
| | | Attractiveness as a host site: | Challenges: |

| Koeberg (existing) | <ul style="list-style-type: none"> • Hosts the Koeberg nuclear power plant (KNPP). • Located on a sandy coastline of the West Coast, approximately 27 km north of the Cape Town and 1.5 km north of the residential area of Duynfontein. • The topography of the area is relatively flat with an active dune field extending north of KNPP. • The vegetation of the area consists of low coastal shrub (Cape Dune Strandveld and Atlantis Fynbos) up to 1.5 m high, typical of much of the West Coast. | <ul style="list-style-type: none"> • only on-site transfer and transport of spent fuel. • wealth of site data that will support both EIA and licensing processes is available. • 10 years for implementation (6 years for approvals; 4 years for construction). | <ul style="list-style-type: none"> • possible public opposition. • possible refusal of license by regulator |
|---------------------------|---|---|--|
| Pelindaba (existing) | <ul style="list-style-type: none"> • Situated south of the Hartebeespoort Dam and about 27 km west of Pretoria. • Stretches over 2 362 hectares in area. • Houses multiple chemical and nuclear facilities including the material test reactor, SAFARI-1. • Sits in the foothills of the Magaliesberg, one of the oldest ranges in Southern Africa (rocks are of Achaean age, more than 2600 Ma). • The region around the site is mostly rural and agricultural land. | <ul style="list-style-type: none"> • wealth of site data that will support both EIA and licensing processes is available. • 10 years for implementation (6 years for approvals; 4 years for construction). | <ul style="list-style-type: none"> • possible resistance from government. • possible public opposition. • distance between site and KNPP for transport of spent fuel. |
| Vaalputs (existing) | <ul style="list-style-type: none"> • Located in the Northern Cape Province, 90 km south-east of Springbok and 200 km from the Namibian border. • Situated in the District of Namaqualand on adjoining portions of the farm Vaalputs (portion 1, Geelpan and portion 2, Garing) and Bokseputs (portion 1, Stofkloof) and is about 10 000 ha in extent. • Hosts the national radioactive waste disposal facility. • Forms part of the area of about 2 500 km² which is topographically elevated above the surrounding plateau. | <ul style="list-style-type: none"> • opportunity for speedy and successful licensing of facility exists. • acceptance by the local population is possible and almost certain. • wealth of site data that will support both EIA and licensing processes is available. • co-location of CISF and DGR is possible. • 10 years for implementation (6 years for approvals; 4 years for construction). | <ul style="list-style-type: none"> • distance between site and KNPP for transport. |
| Greenfield (non-existing) | <ul style="list-style-type: none"> • A new site yet to be searched for. • Can be located anywhere in the country. | <ul style="list-style-type: none"> • co-location of CISF and DGR is possible. • 14 years for implementation (10 years for siting & approvals; 4 years for construction). | <ul style="list-style-type: none"> • requirement for new infrastructure and resources. • possible public opposition. • distance between site and KNPP for transport. |

3.4 Vaalputs Site Characterisation and Justification

3.4.1 Site Location and Infrastructure

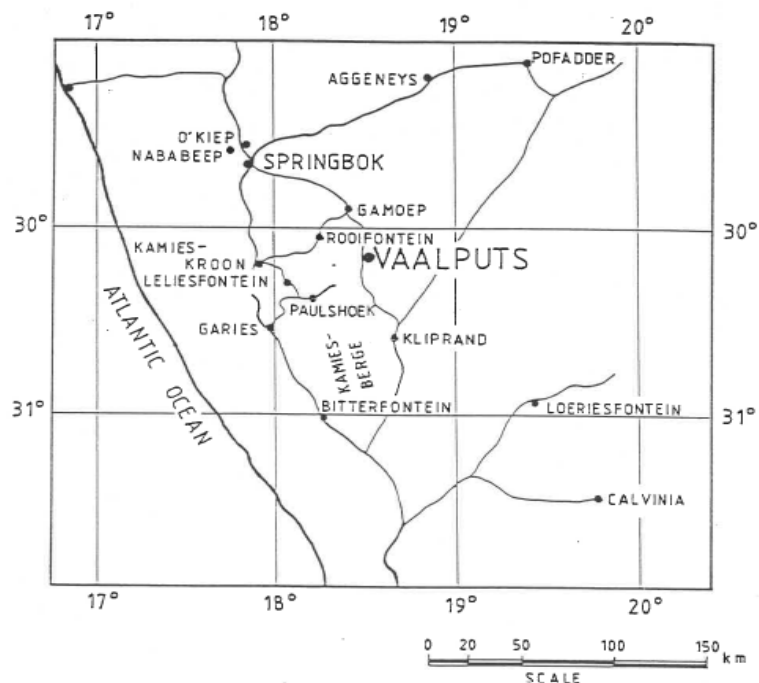
The Vaalputs site is located in the Northern Cape Province, 90 km south-east of Springbok and 200 km from the Namibian border. The site is situated in the District of Namaqualand on adjoining portions of the farm Vaalputs (portion 1, Geelpan and portion 2, Garing) and Bokseputs (portion 1, Stofkloof) and is approximately 10 000 ha in extent. The distances from neighbouring towns and settlements are given in Table 3.2. The locality of Vaalputs in relation

to these neighbouring towns and settlements is shown in Figure 3.3, while its locality in Relation to neighbouring farms is shown in Figure 3.4.

Table 3.2: Distances to Vaalputs Neighbouring Points

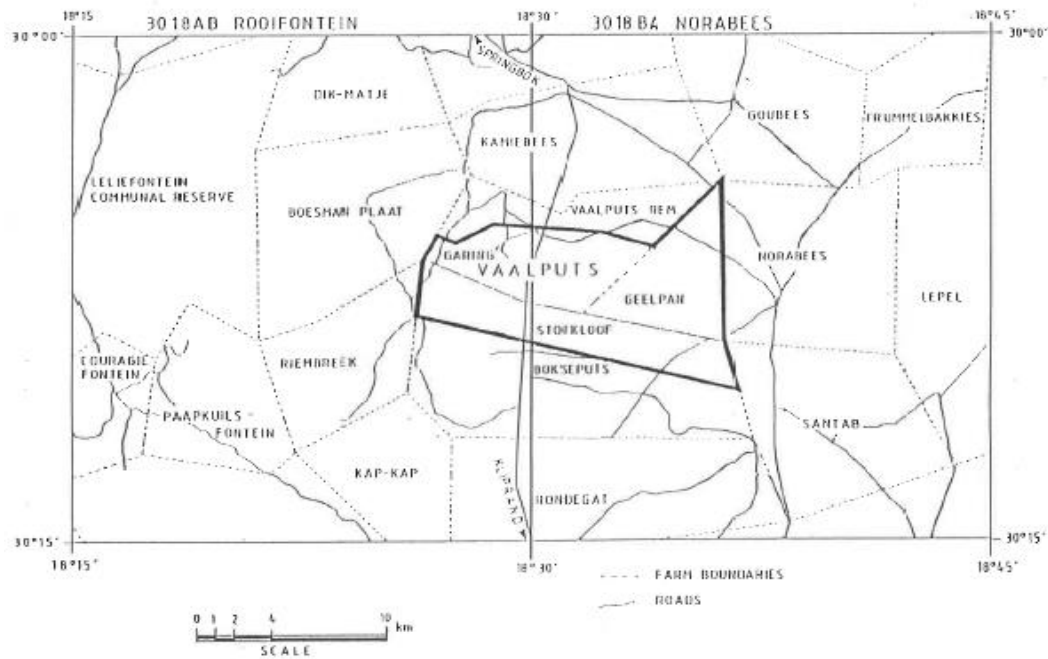
| Town | km |
|----------------|-----|
| Okiep | 95 |
| Springbok | 90 |
| Nabapeep | 100 |
| Kamieskroon | 60 |
| Garies | 73 |
| Rooifontein | 25 |
| Liliefontein | 45 |
| Paulshoek | 35 |
| Kliprand | 55 |
| Bitterfontein | 105 |
| Loeriesfontein | 130 |

Source: [23]



Source: [23]

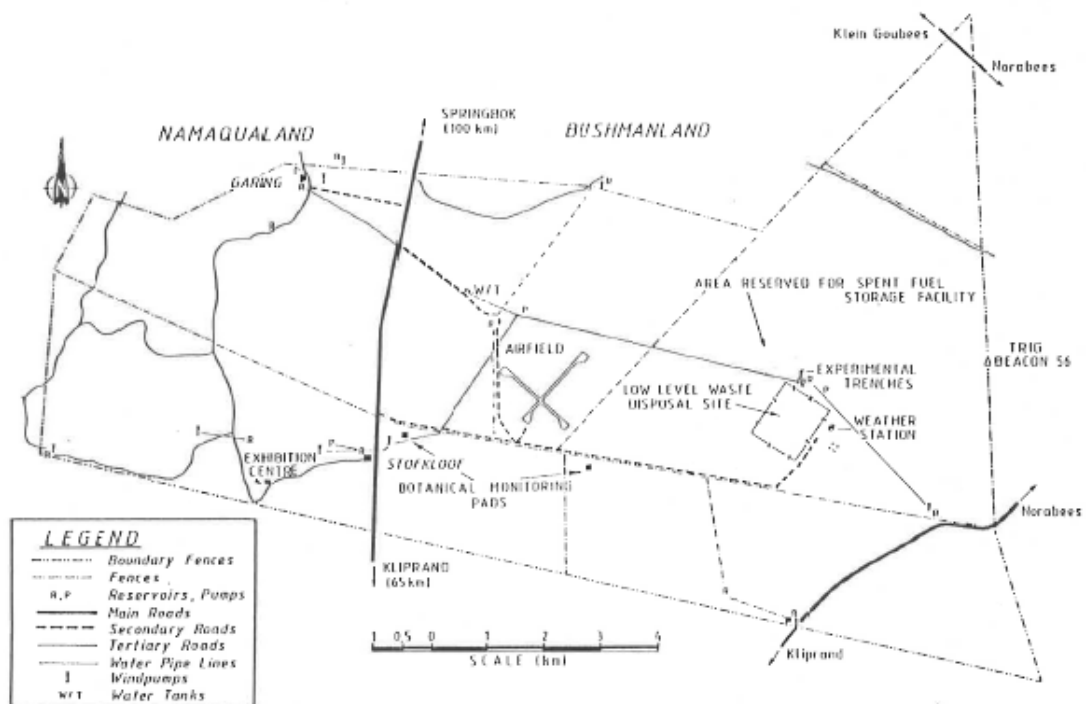
Figure 3.3: Locality of Vaalputs in Relation to Neighbouring Towns and Settlements



Source: [23]

Figure 3.4: Locality of Vaalputs in Relation to Neighbouring Farms

The infrastructure of Vaalputs is given in Figure 3.5.



Source: [23]

Figure 3.5: Infrastructure of Vaalputs

3.4.2 Site Description

Physiographically, Vaalputs is divided into two portions separated by a major north-south watershed:

1. The eastern section is situated at an elevation of about 1 000 metres above mean sea level on the featureless Bushmanland Plateau on which the radioactive waste disposal facility is located.
2. The western section lies on the eastern edge of the Great Escarpment which constitutes the major watershed of the environment separating the Buffels drainage basin from the Koa and Olifants drainage basins.

One of the parameters favouring the selection of Vaalputs was that it formed part of the area of about 2 500 km² which is topographically elevated above the surrounding plateau. This means that there is no water catchment area in the Kamiesberge and the little Namaqua highland, that could potentially create a flood situation. Therefore, all rainfall falling onto this area will drain away into one of the above-mentioned drainage basins along low-gradient water courses or simply percolate into the sand finally dissipating by evaporation.

The topography of the plateau area is only slightly undulating with the eastern portion characterised by low-amplitude fossil dunes which strike in a north-easterly directions. The drainage courses are largely inactive and frequently end in depressions or pans. The interdunes troughs may, however, constitute local ephemeral drainages having a gradient of approximately 1:500 along which minor ponding has been noted. The surface topography of Geelpan (including the disposal site) has been contoured to 1 m intervals from accurately elevated and co-ordinated points by land surveying.

3.4.3 Population Distribution

The rural area surrounding Vaalputs is sparsely populated. Details on the activities and habits of the surrounding population were originally collected by means of a questionnaire distributed to the owners of all farms within a 20 km radius of the planned facility. The survey, completed in 1985, indicated that a population of 102 lived in the 20 km radius with about 35% of this community being migratory. The farmers who have other farms move to the wetter areas during the winter rainfall season and return to Bushmanland for the summer months. A survey conducted by scientists of the Earth and Environmental Technology Department of the Atomic Energy Corporation (AEC) (now Necsa) in 1990, found a population of 99 in the same area. The AEC people who lived there permanently accounted for 3 in the west of the area. The farming community is fairly evenly spaced over the 20 km zone [23].

The distribution of the population is such that 15% of the people live in the north-east quadrant of the 20 km zone, which is the predicted direction of groundwater flow. The majority of the population is concentrated in the southerly and westerly sectors of the 20 km zone. In the event of wind-blown effluent, the predominant wind direction is from SSW towards NNW where only 10% of the people live. However, the strongest winds vary from northerly to westerly towards the south and east, which support 25% of the local population.

Apart from the development at Vaalputs, there is no knowledge of other growth areas in the region which could result in an increase of population. Due to the aridity of the area and the low agricultural potential, the permanent population in a 20 km radius around Vaalputs is not expected to increase significantly over the next 100 years.

3.4.4 Uses of Adjacent Lands and Waters

The major agricultural activity in a 20 km radius around Vaalputs is sheep farming with 66% of the area supporting sheep [23]. A few farmers have goats, cows and chickens mainly for their own use. Although the water is brackish, certain farmers have managed to irrigate crops

for their own use. The farms rearing sheep are located to the north, west and south-west of Vaalputs. Sheep are raised for mutton as well as for karakul pelts. Sheep generally graze off the natural vegetation which is supplemented with imported fodder. During the dry season. Farmers move sheep to wetter areas if they have such land available. Some time ago, the dry weather resulted in some farmers deserting their Bushmanland farms altogether.

The main source of fresh drinking water for the surrounding population is rain water which is often in short supply. Fresh water is transported from surrounding areas in certain instances. In many cases, the farmer has to make do with the freshest of his water boreholes and 61% of the population within the 20 km radius use borehole water for drinking. Borehole water is otherwise used for watering the livestock and irrigating crops on a small scale.

Generally, the type of agricultural activity practised in this region is not expected to change under more favourable climatic conditions. Any increase in average rainfall, as experienced in 1985 and 1986, will occur in episodic events with the area remaining essentially semi-arid. It is expected that sheep farming will remain the major activity. Cultivation of crops will continue to be hampered by the availability of fresh water.

3.4.5 Regional Meteorology

Vaalputs is situated in the region described as desert and poor steppe by the Weather Bureau – Region W. This region is large, covering the entire Northern Cape Province. The rainfall is unreliable with a maximum annual precipitation which may be 200% of the norm [24]. Generally, precipitation decreases from the interior of the subcontinent towards the west coast. Rainfall data, which was obtained at Vaalputs weather station between December 1985 and February 1992, average 73.2 mm p.a. over six years 1986 to 1991 [25]. Furthermore, Vaalputs is situated in a transition area between convectional showers in the interior in summer and autumn and sparse winter rainfall along the west coast. The bulk of the precipitation can be accounted for in single, rare, heavy showers, and hail is seldom recorded in this area [24].

3.5 Vaalputs Geology

3.5.1 Stratigraphy and Lithology

During the initial phase of site selection, a suitable site for the disposal of low-level radioactive waste was chosen as being geologically, geohydrologically and geomorphologically favourable in terms of preliminary screening criteria in the area south of Gamoep on the Bushmanland Plateau [26].

The geomorphological history of the area is exceedingly complex, and a record of aggradational and degradational cycles and of a progressive climatic change from humid to arid through the last 25 Ma, remains preserved in the region [27].

The main rock type in the vicinity of Vaalputs is granitic gneisses and metasediments which constitute part of the Namaqualand Metamorphic Complex, approximately 1100 Ma old. Much of Vaalputs is covered by surficial deposits, in particular, that portion in which the radioactive waste disposal site is situated. In order to evaluate the nature and structure of the basement rocks, in addition to detecting potential base metal mineralisation and diamondiferous kimberlite pipes, both airborne and ground geophysical surveys were conducted. No economic mineralisation of any type was discovered at less than 600 m from surface by subsequent follow-up geophysical investigations.

The Vaalputs Formation, in the vicinity of the disposal site, overlies the Norabees granite suite. Lithologically from the base upwards the surficial deposits consist of 10 to 15 m of in situ developed kaolinitic/montmorillonitic clay derived from the underlying basement; 15 to 20 m fluvial red/brown to greyish clayey grit; 1 to 5 m of calcrete with some silcrete nodules; and 0.5 to 1 m of loose and partially ferruginised aeolian sand.

The main stratigraphic relationships of Vaalputs and environment are summarised in Table 3.3.

Table 3.3: Stratigraphic Relationships of Vaalputs and Environment

| Rock Type | Formations | Approximate Age (Ma) |
|---|---------------------------------|----------------------|
| Wind-blown sand | - | 0.005 |
| Surficial deposits (gritty clay and calcrete) | Vaalputs and Dasdap | 25 |
| Kimberlitic and related intrusions | - | 70-35 |
| Tillite/shale | Dwyka | 250 |
| Granite gneiss/metasediments | Namaqualand Complex Metamorphic | 1 100 |

Source: [23]

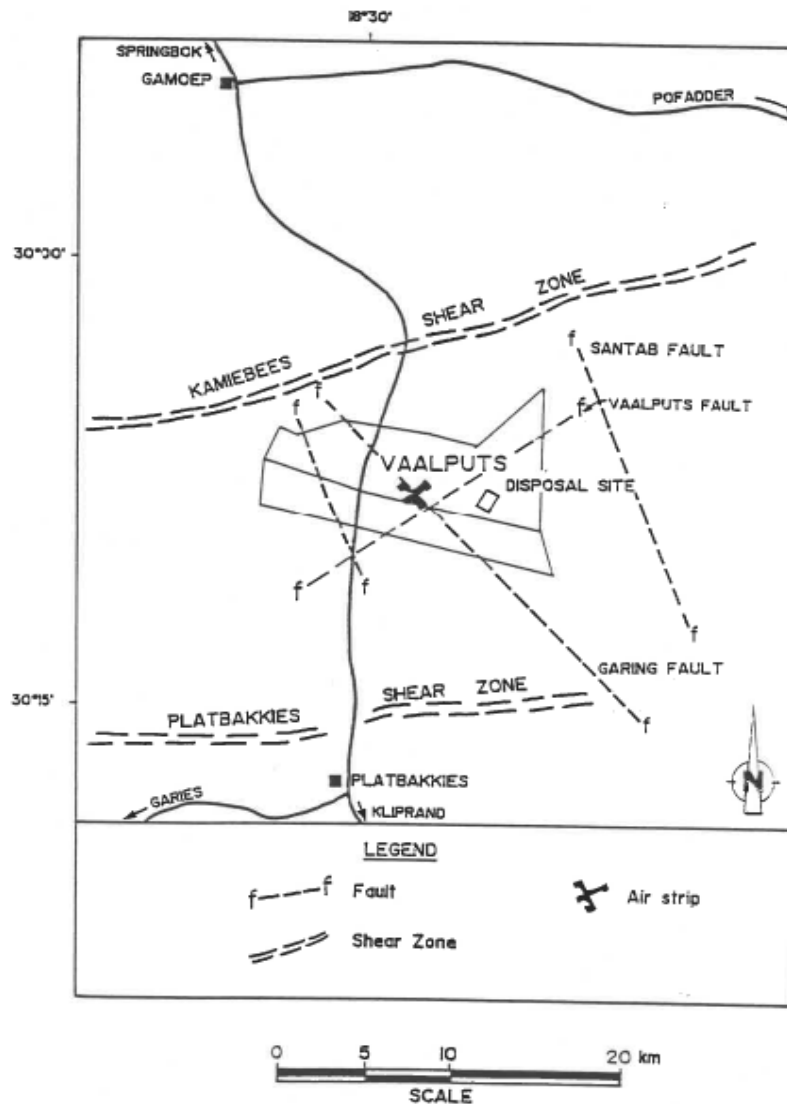
3.5.2 Structural Geology

As illustrated in Figure 3.6, the major shear zones occur to the north and south of Vaalputs which are associated with the development of the Namaqualand Metamorphic Complex and subsequent faulting relating to rifting during the Mesozoic (230-65 Ma). The Garing and Vaalputs faults are the closest structural features to the disposal area and both originated in the Precambrian.

The Garing fault is situated about 3 km south-west of the reception building. This fault had its major movement prior to the end of the Mesozoic but with indications of some minor movement during the Tertiary and even post-Tertiary [28]. However, micro-seismic monitoring at Vaalputs since 1989 detected no seismic activity on any of these structures.

3.5.3 Neotectonics

In the Vaalputs area, structures of neotectonic origin, namely fractures and faults with slickensides, are extensively preserved in Late Cretaceous residual silcretes, in early Cenozoic alluvial deposits of the Dasdap Formation, and in the more recent siltstones of the Vaalputs Form [29]. Activity of the faults outlasted however the deposition of the sediments as calcified, wind-blown Kalahari sand dunes appear truncated by NNW-trending faults in satellite images of the area. South of Vaalputs, fractures of Cenozoic age were recorded in the Vanrhynsdorp area. To the north, in Namibia, the NW-SE trending Kuiseb-Hebron fault downfaults by up to 65 m Cenozoic to Quaternary deposits [23].



Source: [23]

Figure 3.6: Major Faults and Shears in the Vaalputs Vicinity

East of Vaalputs the pre-Cenozoic basement was deformed, probably during the Pliocene by rare ENE-trending faults, and by two NE-oriented axes of upwarp. The more prominent axis is defined by an upwarp of ca. 50 m and trends ENE-WSW. Such structure represents the extension of the Griqualand-Transvaal uplift axis whose western extension probably runs through the Leliefontein-Garies area [30]. This region is deeply dissected, but includes a number of elevated peaks, four of which are between 1 500 m and 1 700 m high. Cenozoic tectonism in the northwest Cape is possibly also reflected by the differential uplift of ca. 30 m experienced by the region around the mouth of the Orange River relative to the Saldanha Bay area [31].

3.5.4 Engineering Geology

As part of an investigation for the establishment of a spent fuel storage demonstration store, a site next to the decontamination building was evaluated [32]. Although, at the time, this site was not considered for a full-scale storage facility, the geotechnical features of the clay basement there are typical of the homogenous clay of the whole of the Vaalputs basin. The results of this 1993 investigation can, therefore, be treated as an analogue for any potential

full-scale storage site in the area. Drilling was undertaken to obtain information on the following:

- (a) The geotechnical conditions of the founding material in the vicinity of the proposed facility;
- (b) In situ Penetration Test (SPT) values of the founding material;
- (c) Determination of the ground profile of the surficial clay deposits;
- (d) The depth of the granitic basement rocks below the sandy clay.

Three potential sites were investigated and six boreholes were drilled to obtain the necessary information. The drill cores were delivered to Van Wyk and Louw Inc. Consulting Engineers who had been contracted to investigate the geotechnical parameters of the founding material [33]. The SPT tests that were conducted during the drilling programme indicated a stiff and competent ground profile in all the boreholes. The high SPT values were attributed to calcretisation and cementation of the clay and sand. The basement granite in the area is about 15 m.

Although the clay of Vaalputs is known to have expansion capabilities, the high incidence of calcrete and sand limits the potential for the expansion of clay having any significant effect on an overlying structure. The depth to the granitic basement is important in order to aid with the calculation of the seismic site effects (as discussed in the following section). The depth varies from 10 m to 25 m in the current disposal area.

3.6 Vaalputs Seismicity

3.6.1 Seismic History and Relationship to Geological Structure

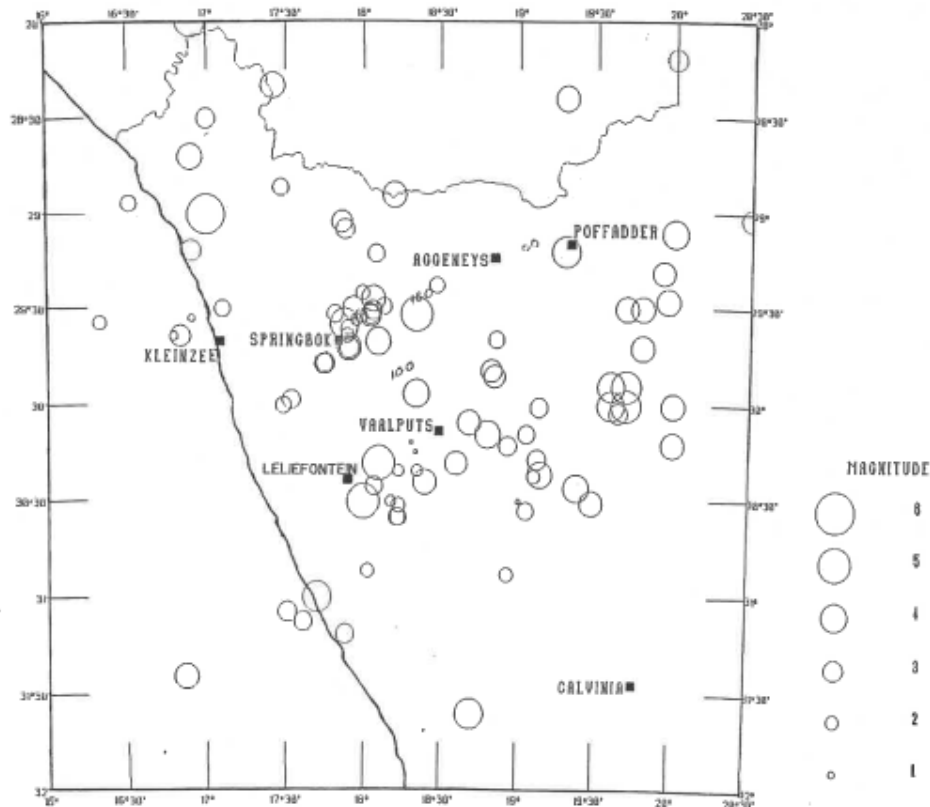
Seismic monitoring started at Vaalputs in mid and late 1989 when seismic recording systems were installed at Vaalputs and Kleinzee respectively. Up to June 1993, the two stations had recorded a total of 55 seismic events [34]. Although the earthquake activity did not appear rather diffused or scattered at that point, three distinct phenomena could be observed:

- A cluster of epicentres in the Okiep/Nababeep vicinity;
- A cluster of earthquake epicentres south-west of Vaalputs in the Leliefontein area; and
- A possible alignment of earthquake epicentres along a south-west, north-east striking belt running through Garies, Leliefontein and Vaalputs (the Platbakkies seismic trend).

Figure 3.7 indicates epicentral locations of all seismic events recorded in the North-western Cape.

The cluster of seismic events around Okiep was most probably related to the mining activities in the area. The event of 27 November 1989 (Richter magnitude +/- 3.7) was felt in Nababeep and had an epicentre close to the Concordia mine. As this mine was closed, it was not possible to associate the event with possible rock bursts or underground collapses.

The cluster of micro-seismic events near Leliefontein, ca. 80 m south of Springbok, are of natural geological origin because there is no mining activity in the area.



Source: [23]

Figure 3.7: Epicentral Locations of All Seismic Events Recorded in the North-Western Cape.

3.6.2 Site Seismic Effects

Probably the most important step in any seismic analysis is the determination of the probable and possible earthquake ground motions to be expected at a site where construction is to take place. These motions are essentially a function of:

- The regional seismicity;
- The nature of the source mechanism;
- The travel path geology; and
- Local site conditions.

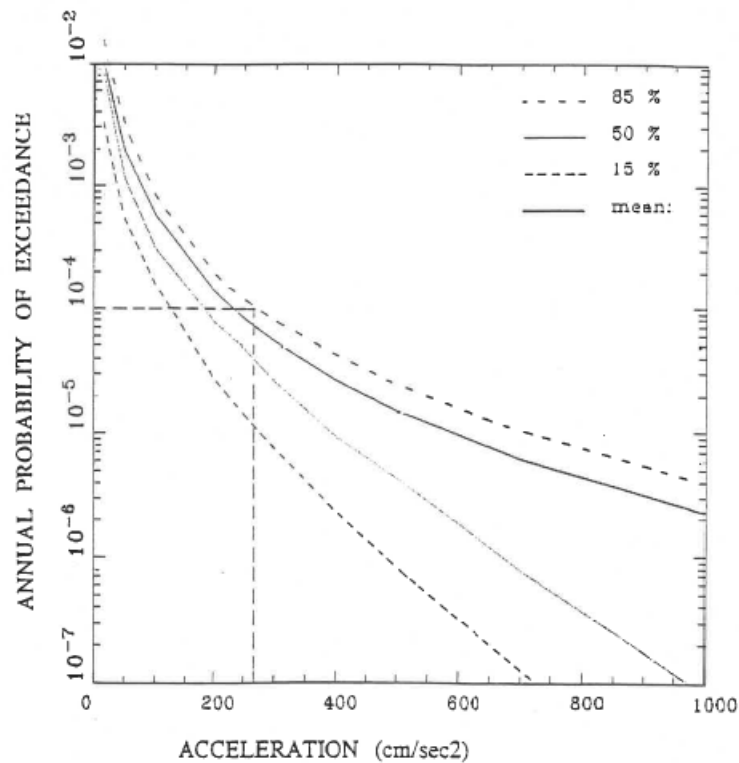
The regional seismicity and its many associated uncertainties are described in Section 3.4.1 above. The study of earthquake source mechanisms has only been done in a very few selective sites in South Africa [35], [36]. Very little is known about any earthquake source mechanism in the north-western Cape area.

To investigate the travel path geology and local site conditions, analysis was made of some 15 seismic events that were recorded on the granitic basement at Vaalputs. The results were extrapolated to the softer soil conditions where the demonstration facility would have been built.

3.6.3 Influence of Ground Accelerations on Spent Fuel Storage Casks

Ground motion models for the Vaalputs terrain have been calculated for the evaluation of seismic hazard at the Vaalputs site, uncertainty of the seismic hazard and the major contributors to that uncertainty. The results are shown in Figure 3.8 for annual probabilities of

exceedance between 10^{-2} and 10^{-7} from which an appropriate and realistic design level should be selected. A general consensus in the nuclear literature indicates that design levels at 10^{-4} annual probabilities of exceedance are both realistic in terms of current design capabilities and appropriate regarding the required safety [37].



Source: [23]

Figure 3.8: Annual Probability of Exceedance for Peak Ground Accelerations at Vaalputs

A 10^{-4} annual exceedance probability will result in a corresponding peak ground acceleration (pga) of 0.27 g at Vaalputs at an 85% confidence level. So, if a 0.27 g horizontal pga is accepted as the seismic design conditions for Vaalputs, then the corresponding vertical acceleration would be about two thirds of that, which is 0.18 g.

To demonstrate the possible effects of these accelerations on the stability of a spent fuel storage cask, a horizontally placed cask has been taken as an example. Thomas [38] describes the tip over potential of a fully loaded CASTOR X/28F cask in an upright position during a seismic event with a horizontal acceleration assumed to be 0.3 g and vertical acceleration of 0.2 g (design accelerations agreed to for Koeberg by the Licensing Branch of the Atomic Energy Board, which later became AEC and then Necsa). The upright, vertically standing cask has its centre of gravity at 2.462 m above ground level and it was demonstrated by Thomas [38] that the abovementioned ground accelerations could not tip over the cask. Horizontally placed casks will have a lower centre of gravity than those in the upright position (about 1.4 m above ground level for the horizontal position) and will have the added advantages of the storage cradles keeping it in position.

It is therefore concluded that for the lower design accelerations at Vaalputs (compared to Koeberg) the casks in horizontal position or in upright position will remain intact during the expected maximum pga. Even in the highly unlikely event of the casks being toppled over or being lifted from its storage cradles they could only drop vertically for a distance of 0.7 m. Drop tests done on similar casks than the CASTOR X/28F have in any event indicated that

the CASTOR X/28F cask could withstand a vertical drop of about 9 m without losing its containment or shielding integrity [39].

3.7 Vaalputs Geohydrology

3.7.1 Surface Water

The Vaalputs disposal facility is located at the triple-junction of three river basins, namely, the Koa basin to the north and north-east, the Buffels basin to the west and the Olifants basin to the south and south-east. Based on topographical and the piezometric level data, the actual disposal site is located within the Koa River drainage system. The Buffels and Olifants Rivers are active drainages, while the Koa River is generally inactive. In the Koa River, the mean annual runoff (MAR) is restricted to the quaternary sub-catchments in the lower part of the valley where steeper slopes facilitate runoff. The upper part of the valley, in which the disposal site is located, constitute ineffective drainage areas or enclosed basins. Runoff from these areas does not reach the major river system or the ocean, but may cause local streamflow or contribute to local pans, marshes or vleis and (ultimately) groundwater. The disposal site is located in an extensive dune field dominated by low, longitudinal dunes orientated in a north-easterly direction. Small pans occur in the interdune areas and, in some cases, depressions on the dunes.

In modelling the rainfall runoff processes in the trench area at Vaalputs, computer simulation on the catchment south of the trench area indicated no surface runoff for the frequent, short-duration, intense storms experienced in the area because the precipitation tends to penetrate the sandy surface [40]. To make the results conservative, a 1 in 100 years storm event was used in the simulation. Surface runoff occurs once the sandy aquifer reaches saturation over its complete depth, after which no more infiltration takes place and groundwater on the perched water table will rapidly commence flowing in the general direction of the trenches. This is common for long-duration storms (24 hour). It was predicted that, for a 48-hour storm of 125 mm, 110 000 m³ of rainwater will run into pans and will eventually infiltrate the aquifer.

3.7.2 Unsaturated Zone

The unsaturated zone is defined as the strata between the land surface and the water table. At Vaalputs, the unsaturated zone below the trench area is between 50 and 55 m thick consisting of surficial material mainly clay with varying degrees of sand percentage of between 15 and 30 m in thickness, while the Norabees granite and associated rocks constitute the remaining strata down to the water table.

Various parameters were determined in the unsaturated zone for input into the hydrological model. Redding and Hutson [41] noted that, generally, percolation as a result of rainfall will be extremely low in Bushmanland and is likely to be negligible except after rare periods of continuous high rainfall.

Surface sealing during rain storms can lead to increased runoff further reducing percolation. During packer testing, a slight decrease in the permeability of the unsaturated zone was noticed in instances where the same section was tested in one day. This can be ascribed to the swelling of clay minerals after injection of water during the first test. This could indicate that small cracks within the weathered granite may close whilst infiltration is taking place thereby reducing the amount of recharge via infiltration. The infiltration and evaporation calculations of stormwater has been confirmed by the neutron probe measurements during the high rainfall incident of December 1985.

Natural isotope investigations have provided a qualitative understanding of the soil moisture movement in the unsaturated zone. These have also confirmed the low percolation rate except where fractures cracks or other permeable zones permit moisture movement to lower levels and where lateral spread along discontinuities, such as calcrete and silcrete bands could take place. Any important lateral or even vertical movement is probably confined to the weathered sections.

A solute transport model of a simulated trench filled with drums of radioactive waste illustrated that even under high rainfall conditions the downward movement of Cs-137 is extremely slow and the upward movement negligible. Over a 100-year period, with distribution coefficient (K_d) values about ten times lower than the measured value, and all the activity assumed to be in the soil, available for transport, the movement of Cs-137 in the trench was found to be insignificant [42].

Percolation measurements taken with a neutron probe after the 1-in-a-100-year rainfall event of December 1985 at Vaalputs and natural isotope profiling, showed that rainwater only penetrated to 3.5 m below surface and seven months the moisture content of the soil was back to levels experienced before the event.

Soil chemistry data indicate that the soils at the disposal site are of the sodic type with high ESPs which inhibit the downward movement of soil moisture. Sodic soils are defined as soils with exchangeable sodium percentage (ESP) values greater than 15% and they are unique in their hydraulic properties because of their potential to retard the downward movement of water when irrigated with pure water, e.g., rain [43]. The distribution coefficient (K_d) is a measure of the interaction between a particular dissolved ion or molecule, the porous medium and the fluid.

Table 3.4 gives the K_d values for the radionuclides Cs-137, Co-60, Sr-90 and U-238 in the different layers of the sedimentary profile which were determined by Meyer and Loots [44] using the general expression:

$$K_d = \frac{\text{grams element/grams soil}}{\text{grams element/grams water}}$$

Distribution coefficients are high for Cs and Co. Values for U-238 and Sr-90 seem to be low but the presence of stable secondary yellow uranium minerals in the environment is evidence of the immobility of uranium due to factors other than K_d (e.g., complexing phenomena).

Table 3.4: Average Distribution Coefficients (K_d) for Various Lithologies

| Lithology | K_d Value | | | |
|-------------------------|-------------|-----|------|-----|
| | Element | | | |
| | U | Cs | Co | Sr |
| Loose red sand | 2.5 | 485 | 1528 | 9.1 |
| Calcretised sand | 2.5 | 589 | 2295 | 8.4 |
| Brown sandy gritty clay | 6.8 | 341 | 1076 | 7.1 |
| White clay | 1.4 | 220 | 1524 | 8.3 |

| | | | | |
|-------------------|-----|-----|-----|-----|
| Weathered granite | 3.0 | 261 | 578 | 5.5 |
|-------------------|-----|-----|-----|-----|

Source: [44]

3.7.3 Saturated Zone

The aquifers on Vaalputs and its environs occur in fractured Norabees granite and are of the confined type. The piezometric level at the disposal site is between 50 and 60 metres below surface. The gradient is generally flat indicating slow movement with the regional flow to the north-east having a gradient of less than 1:200. This slow movement is confirmed by the hydrogeochemistry and natural isotope data. Recharge to the underground water is very slow and localised as indicated by the tritium isotope results with very few samples showing water younger than 50 years. Pump testing in boreholes suggests that although the water yields may be as high as 14 000 l/h, the storage in the fractured granite is limited. Groundwater extracted from boreholes in the vicinity of the waste facility tend to represent older waters with some admixture of shallow younger water. The proportions of which may change with time after pumping. This happens in only very few localities where pumping has induced entry of more recent water from higher up the stratigraphic column in more transmissive zones within the aquifer. Packer testing showed transmissive zones above and below the piezometric surface. Dry boreholes also have zones of high permeability below the general depth of water intersection in the area indicating that a large proportion of the cracks within the saturated granite are not interconnected.

Diurnal water level fluctuations measured in monitoring holes appear largely to be associated with changes in barometric pressure on earth tides, confirming the confined nature of the aquifer in the Norabees granite.

Prolonged monitoring and short-term test pumping have suggested that although a large proportion of the cracks are not interconnected, there are some that may be connected suggesting that locally the aquifer may be more homogenous.

3.7.4 Groundwater Monitoring

At present, groundwater levels at 36 strategically located boreholes on Vaalputs farm are monitored on a monthly basis, 4 of which are recorded continuously. This existing network supplies temporal data increasing the knowledge of groundwater flow and recharge [25], [29].

Groundwater samples are taken from 12 boreholes around the immediate vicinity of the trenches. This is to be extended in the future to allow a more regional and temporal appraisal of the groundwater characteristics and quality.

3.8 Environmental Impact Assessment

Steffen, Robertson and Kirsten Consulting Engineers were appointed by AEC as independent contractors to undertake the environmental impact assessment (EIA) for a potential spent fuel demonstration storage (demostore) [23]. The development of a demostore for spent fuel on the Vaalputs national radioactive waste disposal site is a relatively small structural development within an area that has already been disturbed for the low- and intermediate-level waste repository. The environmental impact of the demostore was evaluated according to the Integrated Environmental Management (IEM) approach advocated by the Department of Environmental Affairs. This evaluation was instituted not due to the size of the project, as it will affect a limited area, but due to the hazardous nature of the material to be stored.

From the impact assessment [45], it was concluded that, although there is some risk to the environment if an accident occurred during which radioactivity was released, the risk to the surroundings will be acceptable because the area in which the demostore will be located is sparsely populated and also because of the safety precautions that will be taken to contain such a release. The potential impact of other activities over the life of the project (i.e., during construction, operations, decommissioning and closure) is considered to be acceptable as long as adequate environmental management controls are instituted.

From this study, it was recommended that:

- An environmental management plan be developed to control likely impacts on the environment. Rehabilitation of disturbed areas would be a priority.
- A public consultation programme be instituted to obtain concerns of the interested and affected parties and to feedback progress on the project.

The EIA Regulations, 2014, require that all S&EIR processes must identify and describe feasible and reasonable alternatives [17]. For the siting of the proposed CISF, NRWDI will identify a number of potential sites (areas) within the Vaalputs site boundaries, which will be evaluated against various site selection criteria.

3.9 Background Radiological Characteristics

Radiation is a natural feature of all environments, and the principal contributors are extra-terrestrial (e.g., cosmic) sources and primordial radionuclides in the earth's crust. At the altitude of the Vaalputs site (approximately 1 000 m) the contribution of cosmic radiation to the absorbed dose rate in air is 0.35 mGy/a and the dose equivalent rate is 0.38 mSv/a. The total absorbed dose from external sources for the Vaalputs environment averages around 1.25 mGy/a with 28% contributed by cosmic radiation and 72% by soil radiation. The effective dose equivalent of this absorbed dose is 1.35 mSv/a. Although individual values are variable, the standard deviation of this measured dose is ± 0.19 mGy (95% confidence limit) and reflects the natural variation in primordial radionuclides in this environment.

In addition to external doses, internal doses are accrued from the inhalation and ingestion of these primordial radionuclides or their decay products. Potassium-40 is an important contributor. Due to homeostatic control on the potassium concentration in the body, the internal radiation dose from ^{40}K is constant and independent of environmental concentrations. The average dose equivalent is 0.2 mSv/a.

Other radionuclides of importance are (a) Rn-222 gained through inhalation, and (b) Ra-226,228 and Po-210 gained through ingestion. Rn-222 concentrations are determined by the U/Ra concentrations in surficial materials and values of approximately 3 Bq.m⁻³ are to be expected in this area. If the equilibrium with the Rn-daughters is 0.5 this will result in an effective dose equivalent of 0.13 mSv/a (ICRP-32, 1981).

The highest potential exposure is from the use of the local Norabees granite as building material, which may result in radon concentrations orders of magnitude above the natural levels. Exposure, however, depends on factors such as occupancy and ventilation and cannot readily be predicted. On average, indoor exposure to Rn-daughters is an order of magnitude higher than the outdoor exposure. An average dose of 0.7 mSv/a due to radon is accepted internationally.

Intake through the drinking of borehole water is considered the major pathway.

Concentration of natural uranium in these waters varies 1.2 to 298 µg U/ℓ with median values of 70.4 and 79.4 µg U/ℓ in the two zones closest to Vaalputs. Ra-226 is the main contributor of the U-decay chain to radiation dose. Measures values of Ra in borehole water vary widely from less than 0.01 Bq/ℓ to 5.7 Bq/ℓ, with a mean for 30 boreholes of 0.4 Bq/ℓ or of 0.11 Bq/ℓ if the two outliers are excluded. A daily intake of 1 Bq from 2.5 l of borehole water can be assumed. Using a conversion factor of 2E + 05 Bq/a which is equivalent to 50 mSv/a (ICRP-30, 1979), the dose contribution from Ra-226 in drinking water is 0.09 mSv/a or 0.025 mSv/a if the outliers in borehole water are excluded.

Due to the uncertainties in the radon dose, the effective dose equivalent to the population in the Vaalputs area from natural radiation varies between 1.7 and 2.3 mSv/a. This variation far exceeds the dose limit of 0.25 mSv/a set as the radiation dose contribution to the critical group from the Vaalputs disposal site.

3.10 Vaalputs Suitability

Vaalputs already has excellent features for a radioactive waste disposal site. These include factors such as:

- Remoteness from international boundaries.
- Low population density.
- Low mineral potential.
- Small growth and agricultural potential.
- Low rainfall and groundwater recharge.
- It is an accepted and established low- and intermediate-level radioactive waste disposal site.

The seismic activity in the north-western Cape can be described as moderate and as elsewhere in South Africa the activity appears to be associated with deep and poorly defined crustal features. Neotectonics investigations indicate possible Quaternary movement of faults (truncated Kalahari sand dunes) in the vicinity but this still have to be verified.

Site-specific engineering investigations conducted for a potential spent fuel demonstration store indicated a competent ground profile with no envisaged engineering problems. Seismic information collected from granitic basement were used to simulate the seismic response that could be expected for an overlying clay layer (15 m thick). The calculated site effects indicated no abnormal seismic behaviour.

It was recommended that a horizontal pga of 0.27 g with a 10⁻⁴ annual exceedance probability at an 85% confidence level be adopted for the proposed Vaalputs spent fuel demo site. For a full-scale store placed in a similar environment the figures are expected to be very similar. It was demonstrated that horizontally or vertically positioned casks will not be influenced by the recommended pga.

The EIA conducted for a demostore indicated no unacceptable radiation risk and only a minor physical impact. An EIA for a full-scale store is not expected to differ dramatically from this.