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EXECUTIVE SUMMARY

Eskom is the holder of the Nuclear Installation Licence (NIL-01 variation 19) [1] for the Koeberg Nuclear Power Station (Koeberg), which consists of two 945 MWe pressurised water reactor generating units. The plant started commercial operation in 1984, and the original safety studies assumed a 40-year operational life. Unit 1 and Unit 2 will reach 40 years of commercial operation in 2024 and 2025, respectively. Koeberg has been producing clean and safe electricity for 38 years, conforming to industry standards, utilising internationally benchmarked management systems, and employing suitably qualified and authorised personnel.

Eskom has applied to the National Nuclear Regulator (NNR) for a variation to NIL-01 to operate Koeberg beyond 21 July 2024, for an additional 20 years, to 21 July 2044 for Unit 1 and to 9 November 2045 for Unit 2. The application to the NNR to operate Koeberg beyond the time frame established in NIL-01 is referred to as an application for long-term operation (LTO). The licence application complies with the Regulations on Long-Term Operation [2] and is based on Eskom's safety case, which demonstrates that Koeberg can be safely operated for at least 60 years of commercial operation.

This public information document (PID) serves to provide the public with sufficient information on the radiological risks to safety, health, and the environment due to extending the operational life of Koeberg by 20 years. This will enable the public to participate meaningfully in the regulatory public engagement process.

The Eskom decision to pursue LTO is in line with industry norms. There are currently 133 nuclear reactors worldwide that have been in operation for 40 years or more [3]. In the United States of America (USA), the Nuclear Regulatory Commission has approved an extension from 40 to 60 years of operation for 94 nuclear reactor units, and a further six nuclear reactor units have been approved for 80 years of operation [4]. This is evidence that LTO makes good economic sense and presents no undue risk when approval is obtained through robust regulatory processes.

The LTO safety case provides arguments and documented evidence that demonstrate that there is no undue radiological risk to safety, health, or the environment. The safety case draws on safety assessments conducted in support of LTO. A periodic safety review (PSR) is a detailed safety assessment of 14 safety factors (comprised of various safety requirements) to determine the extent to which Koeberg is aligned with international, national, and regulatory safety requirements and identify safety improvements. Approximately 1 150 safety requirements were assessed. The outcome of the PSR confirmed that the continued safe operation of Koeberg was supported, including LTO.

Effective ageing management practices and processes can prevent the adverse effects of ageing from affecting the integrity of the plant equipment during the period of LTO. South Africa invited the International Atomic Energy Agency (IAEA) to conduct a peer review of the safety aspects of long-term operation (SALTO) for Koeberg. This assessment was aimed at assisting Koeberg with adopting a safe and effective approach to LTO using a well-documented process with inputs from

international experts. An important objective of SALTO was to review the effectiveness and completeness of Koeberg's ageing management programmes and implement improvements to ensure that equipment ageing would be managed adequately. The SALTO assessment confirmed that the continued safe operation of Koeberg was supported, including LTO. Improvements in ageing management programmes, testing, and monitoring of systems, structures, and components (SSCs) will continue prior to LTO and throughout the full period of LTO to ensure safe and reliable operation.

Nuclear Installation Licence NIL-01 has several licence conditions with which Koeberg must comply. These include conditions for radiological protection of persons, environmental protection, radioactive waste management, maintenance and inspections of plant equipment, and many more. It is envisaged that these licence conditions will remain valid during LTO and that Koeberg will continue to comply with the licence conditions. The NNR provides oversight of Koeberg operations through compliance monitoring of the licence conditions and enforcement actions. The strict oversight provided by the NNR has contributed to the continued safe operation of Koeberg and will continue to provide oversight during LTO.

The NNR has set principal safety criteria [5] consisting of risk criteria and dose limits for the protection of workers and the public in all operating conditions and events associated with nuclear power plants. The principal safety criteria contain deterministic and probabilistic risk requirements, and the intent of the principal safety criteria is to ensure that Koeberg operations do not cause undue nuclear safety risks and/or radiological safety risks to workers or the public. The NNR's principal safety criteria are aligned with international best practices.

The PSR confirmed that Koeberg complied with the principal safety criteria and that the public risk was less than 3% of the NNR principal safety criteria, while the risk to workers was less than 20%. These risks are below the level that is considered tolerable [6] and much lower than the risk of death from, for example, road accidents in South Africa.

The radiation dose to which workers and the public are exposed as a result of Koeberg operations is much lower than the dose limits specified by legislation. The annual effective dose limit for members of the public as a result of all authorised nuclear operations in South Africa is 1 mSv per annum, while the individual dose constraint applicable to Koeberg for a representative person is 0,25 mSv per annum [7]. The PSR confirmed that Koeberg complied with the dose limits and that the annual average dose to the public was less than 1% of the legislated dose limit.

The annual effective dose limits for radiation workers are an average effective dose of 20 mSv per year averaged over five consecutive years and a maximum effective dose of 50 mSv in any single year [7]. The PSR confirmed that Koeberg complied with the annual average effective dose limit and annual maximum dose limit for workers as established by legislation.

The PSR also confirmed that occupational and public exposures to radiation were always kept as low as reasonably achievable (ALARA) and below regulatory limits through the application of effective radiation protection principles and processes.

The environmental impact due to current Koeberg operations is minimal and well within regulatory limits. The liquid and gaseous effluent discharged during normal operation are released under controlled conditions and are required to conform to the annual authorised discharge quantities (AADQ), which complies with the maximum annual effective dose limit as set by legislation. The prospective public dose was calculated considering environmental build-up of 60 years for LTO using conservative assumptions. The PSR confirmed that the public dose from the liquid and gaseous discharges would remain well within the dose constraint of 0,25 mSv. This is well below the average background radiation levels of approximately 2,4 mSv per year [9]. The average annual dose for a person living near Koeberg is more than 100 times lower than the dose received from natural background radiation. Therefore, the likelihood of any health effects as a result of Koeberg operations is very low.

The technical justification for LTO was confirmed by the outcomes of the PSR. Some of the conclusions drawn were as follows:

- The current design of Koeberg is adequate when assessed against the licensing basis and national and international standards.
- The programmes associated with maintaining the condition of the plant systems, structures, and components (SSCs) are adequate and well implemented.
- The actual condition of the SSCs important to safety provides confidence in the ability to deliver safety functions for the period of LTO.
- The ageing management programmes, processes, and management methods are largely in line with international standards, and the proposed enhancements will ensure safe operations for the duration of LTO.

The overall nuclear safety performance of Koeberg is at an acceptable level. All deviations identified during the PSR have assigned improvement actions, and the timescales for their implementation are considered appropriate and are commensurate with their safety impact.

Following the Fukushima accident in Japan in 2011 [10], Koeberg performed a safety reassessment to address the lessons learnt from this event, which had a very low probability of occurring. The safety reassessment focused on severe external events (such as earthquakes and tsunamis) that might have an adverse impact on safe operations, and emergency preparedness and response. As an outcome of the safety reassessment, Koeberg has implemented several initiatives to improve its capability to respond to such events (such as additional electrical power supplies, alternative cooling water sources, and mobile equipment to clear debris from an earthquake). A new site safety report is being finalised based on the latest methodologies and operating experience. Additional improvements are planned, which will further enhance Koeberg’s safety during the period of LTO.

Having sufficient, competent staff is important to support LTO. Requirements for staff competency and knowledge management are specified in the NNR regulatory documents ([11] and [12]). Koeberg has the necessary management systems, human resource processes, and training facilities to ensure that sufficient competent staff are available to support LTO. Highly experienced contractors have been sourced to support the short- to medium-term increase in work scope due to LTO while recruitment campaigns are used to permanently fill vacancies as needed. Koeberg's knowledge management programme is being further improved and expanded to bring it in line with international practices. Koeberg's robust human resource, training, and staff development processes are in line with international practices.

Eskom has committed itself to making the required financial resources available to enable safe and reliable operation for LTO. In accordance with the Public Finance Management Act and related enabling legislation, the Eskom Board considers and determines the funding structures of Eskom, having regard to the funding requirements of Eskom, from time to time. Eskom has also made provision to ensure that adequate financial resources are made available, as indicated in its annual financial report, for the decommissioning of Koeberg, including rehabilitation of the associated land as well as managing the spent fuel assemblies and radioactive waste.

Nuclear safety culture (NSC) surveys are performed three-yearly, utilising the internationally recognised Institute of Nuclear Power Operations (INPO) traits for a healthy NSC [13]. The 10 traits of a healthy NSC (each with its own attributes and behaviours) are considered a nuclear industry standard. The surveys were conducted in 2014, 2016, and 2019 and submitted to the NNR. A comparison of the results of the NSC surveys revealed that the score for all traits had improved over the period from 2014 to 2019. Recommendations from the 2019 NSC survey were consolidated into improvement actions and have since been implemented. It was concluded that while opportunities for improvement existed, the NSC at the Nuclear Operating Unit was acceptable for safe continued operation into LTO.

NIL-01 provides regulations regarding transportation, disposal, and storage of radioactive waste. Radioactive low- and intermediate-level waste – short-lived (LILW-SL) and high-level waste (HLW) are generated at Koeberg as a by-product of its operations, maintenance, and modifications. Currently, spent fuel (HLW) is safely stored on site in the spent fuel pools and dry-storage casks. The spent fuel can be transferred to a centralised interim storage facility (CISF), which is under development by the National Radioactive Waste Disposal Institute (NRWDI) and undergoing the necessary approval processes [14]. The spent fuel pools and dry cask storage facilities on site will continue to be utilised for the storage of spent fuel during the period of LTO. The additional dry cask storage capacity needed for this purpose is subject to NNR approval.

LILW-SL is encapsulated or drummed in waste containers that comply with the Vaalputs waste acceptance criteria and are approved by the NNR. The waste acceptance criteria specify the radiological, mechanical, physical, chemical, and biological characteristics of the waste package to ensure that the waste is properly contained and that it can be stored safely. Eskom formally requested the NRWDI to provide additional storage capacity for LILW-SL due to LTO. The remaining reserve storage capacity is still adequate to accommodate waste generated during the LTO period. The additional storage capacity is subject to NNR approval.

The Koeberg waste storage strategies for LILW-SL and HLW are in line with the approaches applied internationally and pose a very low risk to safety, health, and the environment.

In conclusion, it has been demonstrated that there is no undue risk to safety, health, or the environment by continuing the operation of Koeberg for an additional 20 years. The application to operate Koeberg for up to 60 years will be decided by the NNR.

CONTENTS

FIGURES

TABLES

1. PURPOSE

The purpose of this public information document (PID) is to provide members of the public with sufficient information on Eskom's application to the National Nuclear Regulator (NNR) for a variation to the Nuclear Installation Licence (NIL-01) to operate the Koeberg Nuclear Power Station (Koeberg) beyond 21 July 2024, for an additional 20 years, to 21 July 2044 for Unit 1 and to 9 November 2045 for Unit 2. This application is referred to as the long-term operation (LTO) application and was submitted to the NNR in accordance with national legislation and associated NNR requirements. The authorisation for Koeberg to continue to operate for an additional 20 years will be decided by the NNR after due process and once it has satisfied itself that the case for safe continued operations has been demonstrated.

2. SCOPE

The PID contains information on radiological risks to safety, health, and the environment relating to the LTO application, national legislation, and associated NNR requirements.

3. STRUCTURE AND CONTENT

The PID begins with the background to LTO (Chapter 5), followed by the legal basis and regulatory framework for LTO (Chapter 6). Section 6.1 provides an overview of the content of the safety case and references the associated sections in the PID related to the safety case. The PID then provides the applicant information and site description in Chapter 7 and Chapter 8, respectively. This is followed by a description of Koeberg's operation (Chapter 9) to give the reader a basic understanding of the workings of the power plant.

Chapter 10 discusses the risks to safety, health, and the environment, followed by the technical justification and organisational provisions for LTO in Chapter 11 and Chapter 12, respectively. Chapter 11 includes a discussion of the outcomes of the safety assessments performed by Koeberg, mainly related to the effects of plant ageing and the important safety-related programmes such as radiation protection and emergency planning. This includes the role of the International Atomic Energy Agency (IAEA) peer review, the safety aspects of long-term operations (SALTO) process, and the safety review of Koeberg known as the periodic safety review (PSR). These safety assessments were performed to determine whether LTO could be safely supported.

Chapter 13 and Chapter 14 discuss radioactive waste management. Conclusions and a list of references are also provided.

4. DEFINITIONS, ABBREVIATIONS AND ACRONYMS, AND COMPOUND SYMBOLS

4.1 Definitions

Term	Definition
Absorbed dose	The amount of energy deposited by radiation in a mass, measured in gray (Gy), milligray (mGy), or microgray (μGy).
Activation products	The unintentional production of radionuclides in reactor coolant, structural materials, and shielding materials caused by irradiation with neutrons.
Bioaccumulation	The accumulation of radionuclides in an organism that ingests food or water containing radioactive material.
Constraint	A prospective and source-related value of individual dose (dose constraint) or of individual risk (risk constraint) that is used in planned exposure situations as a parameter for the optimisation of protection and safety for the source and that serves as a boundary in defining the range of options in optimisation. i) For occupational exposure, a constraint on individual dose to workers established and used by registrants and licensees to set the range of options in optimising protection and safety for the source. ii) For public exposure, the dose constraint is a source-related value established or approved by the government or the regulatory body, with account taken of the doses from planned operations of all sources under control. iii) The dose constraint for each particular source is intended, among other things, to ensure that the sum of doses from planned operations for all sources under control remains within the dose limit. iv) For medical exposure, the dose constraint is a source-related value used in optimising the protection of carers and comforters of patients undergoing radiological procedures and the protection of volunteers subject to exposure as part of a programme of biomedical research. v) The risk constraint is a source-related value that provides a basic level of protection for the individuals most at risk from a source. This risk is a function of the probability of an unintended event causing a dose and the probability of the detriment due to such a dose. Risk constraints correspond to dose constraints, but apply to potential exposure.
Deterministic effect	Injury of tissue and organs due to cell death. Characterised by a threshold dose and an increase in the severity of the reaction as the dose is increased further.
Deterministic safety analysis	A deterministic safety analysis is aimed at confirming that safety functions and needed systems, structures, and components, in combination with operator actions (where relevant), are capable of, and effective in, keeping radiological releases within acceptable limits and with an adequate safety margin.
Dose	A measure of the energy deposited by radiation in a target.

Term	Definition
Dose rate	The radiation dose delivered (absorbed) per unit time. Measured in millisievert (mSv) per hour.
Effective dose	The addition of equivalent doses to all organs, adjusted to account for the sensitivity of the organ to radiation. Calculated for the whole body, expressed in sievert (Sv), millisievert (mSv), or microsievert (μSv).
Enrichment	Any process that artificially increases the fraction of U-235 in a mixture of uranium isotopes to levels higher than what is found in nature, given that, in nature, U-238 constitutes about 99,274% and U-235 about 0,720%. There are other isotopes such as U-234 and U-236, but these only make up a small fraction; for example, U-234 only constitutes 0,005%. The balance is made up of U-232, U-233, and U-236.
Equivalent dose	The absorbed dose to an organ, adjusted to account for the effectiveness of the type of radiation. Calculated for individual organs, expressed in sievert (Sv) or millisievert (mSv).
Half-life, biological	The time for half of the amount of a radionuclide to be expelled from the body.
Half-life, physical	The time interval required for an amount of a certain radioactive nuclide to decay to half of its original value.
Irradiated fuel	Nuclear fuel that has been exposed to neutron radiation in a nuclear reactor, but not necessarily to design burnup.
Knowledge management	Integrated, systematic approach to identifying, acquiring, transforming, developing, disseminating, using, sharing, and preserving knowledge relevant to achieving specified objectives.
Long-term operation	Operation of the plant beyond an established time frame stipulated by, for example, licence term, design, standards, licence, or regulations, which has been justified by safety assessment, with consideration given to life-limiting processes and features of systems, structures, and components (SSCs).
Nuclear accident	An event or series of events that results in the unintended release of radioactive material or exposure to radiation that may give rise to an excess of 1 mSv public dose or 50 mSv worker dose.
Periodic safety review	A systematic reassessment of the safety of an existing facility carried out at regular intervals to deal with the cumulative effect of ageing, modifications, operating experience, technical developments, and siting aspects. It is aimed at ensuring a high level of safety throughout the service life of the facility.
Projected dose	The dose that would be expected to be received if planned protective actions were to not be taken.
Reference animal or plant (RAP)	A hypothetical entity with the assumed basic biological characteristics of a particular type of animal or plant (as described to the generality of the taxonomic level of family) with defined anatomical, physiological, and life history properties. An RAP can be used for the purposes of relating exposure to dose and dose to effects for that type of living organism.

Term	Definition
Representative person	An individual, who will almost always be a hypothetical construct, receives a dose that is representative of the more highly exposed individuals in the population. The representative person is equivalent to, and replaces, the average number of the critical group.
Risk	The frequency and consequences of an event, as expressed by the "risk triplet" that answers the following three questions: A. What can go wrong? B. How likely is it? C. What are the consequences if it occurs? In the context of radiation, it is the probability of a specified health effect (such as cancer) occurring in a person or group as a result of exposure to radiation.
Safety assessments	In the context of the PSR, the safety assessment is undertaken as a means of evaluating compliance with safety requirements for all the facilities and activities of the plant and of determining the measures that need to be taken to ensure safety.
Spent or used fuel	Nuclear fuel that has been irradiated in a nuclear reactor to the point where the fuel is no longer useful in sustaining a nuclear reaction. The fuel is removed from the reactor core and stored underwater in storage racks in spent fuel pools.
Stochastic effect	Effect resulting from damage in a single cell, such as cancer and heritable effects. The frequency of the event, but not its severity, increases with an increase in dose. For protection purposes, it is assumed that there is no threshold dose.

4.2 Abbreviations and acronyms

Abbreviation/ Acronym	Description
AADQ	Annual authorised discharge quantity
ALARA	As low as reasonably achievable
ALARP	As low as reasonably practical
AMP	Ageing management programme
DMRE	Department of Mineral Resources and Energy
EDF	Électricité de France
EPD	Electronic personal dosimeter
EPRI	Electric Power Research Institute
Eskom	Eskom Holdings SOC Ltd
GSR	General safety requirements
Gy	Gray
HLW	High-level waste
IAEA	International Atomic Energy Agency
I&C	Instrumentation and control
ICRP	International Commission on Radiological Protection
ILW	Intermediate-level waste
INPO	Institute of Nuclear Power Operations
ISO	International Organization for Standardization
LILW	Low- and intermediate-level waste
LILW-SL	Low- and intermediate-level waste – short-lived
LLW	Low-level waste
LPZ	Long-term protective action planning zone
LTO	Long-term operation
MWe	Megawatt (electrical)
MWth	Megawatt (thermal)
Necsa	South African Nuclear Energy Corporation
NIL	Nuclear installation licence
NNR	National Nuclear Regulator
NNRA	National Nuclear Regulator Act
NOU	Nuclear Operating Unit
NRWDI	National Radioactive Waste Disposal Institute
NSC	Nuclear safety culture

Abbreviation/ Acronym	Description
NSRB	Nuclear Safety Review Board
PAZ	Precautionary action zone
PID	Public information document
PP	Position paper
PSR	Periodic safety review
PWR	Pressurised water reactor
RD	Regulatory requirements document
RG	Regulatory guide
SALTO	Safety aspects of long-term operation
SAR	Safety analysis report
SSCs	Systems, structures, and components
SSG	Specific safety guide
SSRP	Safety standards and regulatory practices
Sv	Sievert
TISF	Transient interim storage facility
TLAA	Time-limited ageing analysis
TLD	Thermo-luminescent dosimeter
UPZ	Urgent protective action planning zone
USNRC	United States Nuclear Regulatory Commission
WANO	World Association of Nuclear Operators

4.3 Compound symbols

Compound	Description
UO_2	Uranium dioxide

5. BACKGROUND TO LONG-TERM OPERATION

Globally, it has become a common occurrence to extend the operating licences of nuclear power plants. Experience has shown that nuclear power plants such as Koeberg can be safely operated for more than 40 years. The life extension provides a cost-effective option, enabling an existing nuclear power plant to continue to provide safe, reliable electrical energy in a manner that helps reduce the emission of carbon. In addition to Koeberg playing a significant role in the South African economy, Koeberg provides meaningful skilled employment opportunities for local and regional communities.

In South Africa, the two Koeberg nuclear units are the only baseload electrical generating units in the southern part of the country. They help to stabilise the national electricity grid. Electrical energy from nuclear has many unique benefits for South Africa, and in the current context, Koeberg LTO helps delay significant capital investment in new generation infrastructure. Brownfield life extension projects such as this generally carry lower project risks than those associated with similar greenfield investments, that is, new construction projects. Consistent with the trends noted in most global power markets, extending the life of the existing nuclear power plant in South Africa presents the lowest-cost option for securing baseload electrical generation capacity. Nuclear produces very low carbon emissions and is comparable to offshore wind-driven power generation in this regard [15].

Figure 1 shows the number of nuclear power reactor units currently operating in each country [3]. There are a total of 441 nuclear reactors. The USA has the largest number of operational reactor units by a significant margin with 93 in total, with France in second place with 56 reactor units.

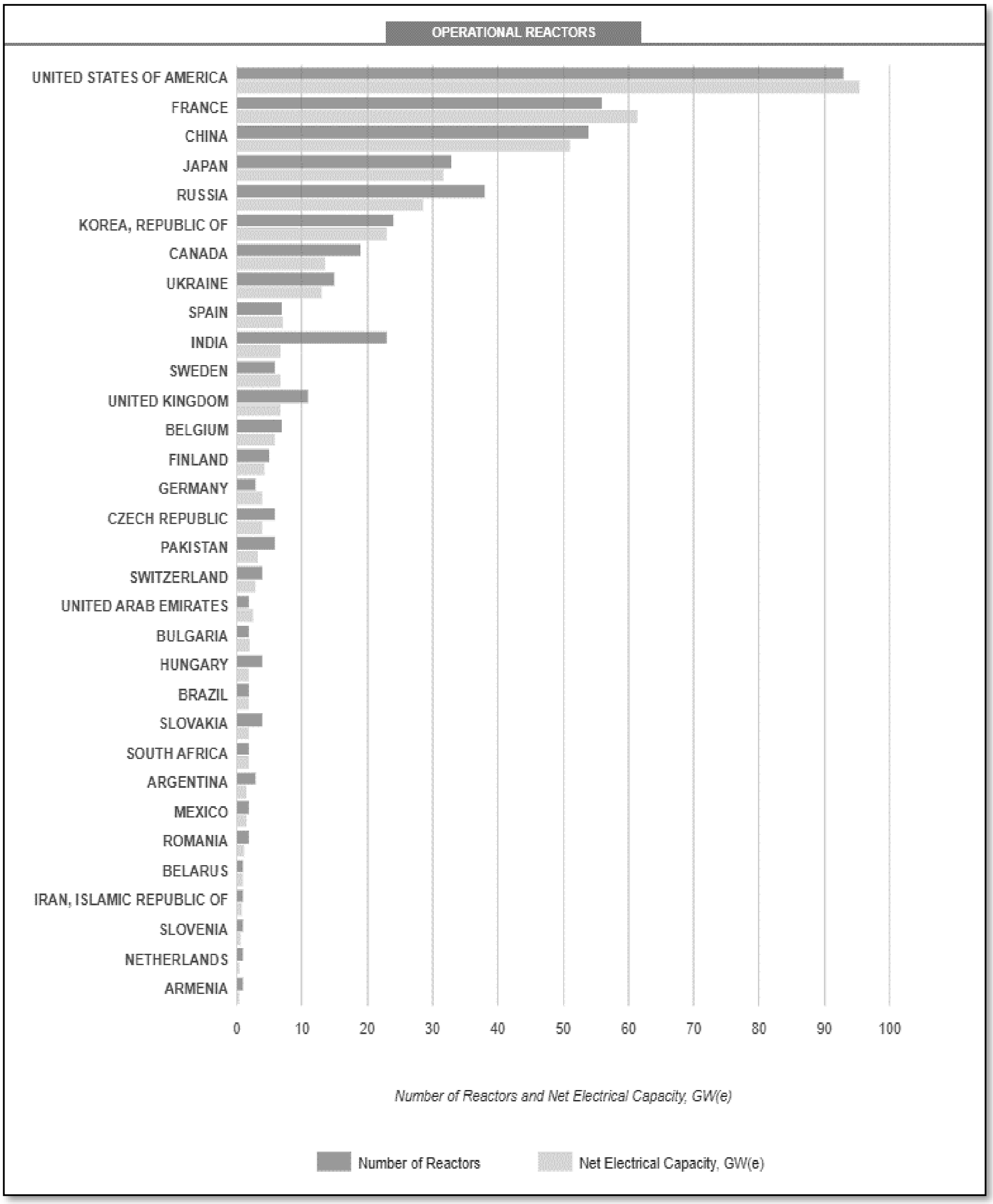

Figure 1: Number of nuclear power reactors and net electrical capacity (GWe) in the world [3]

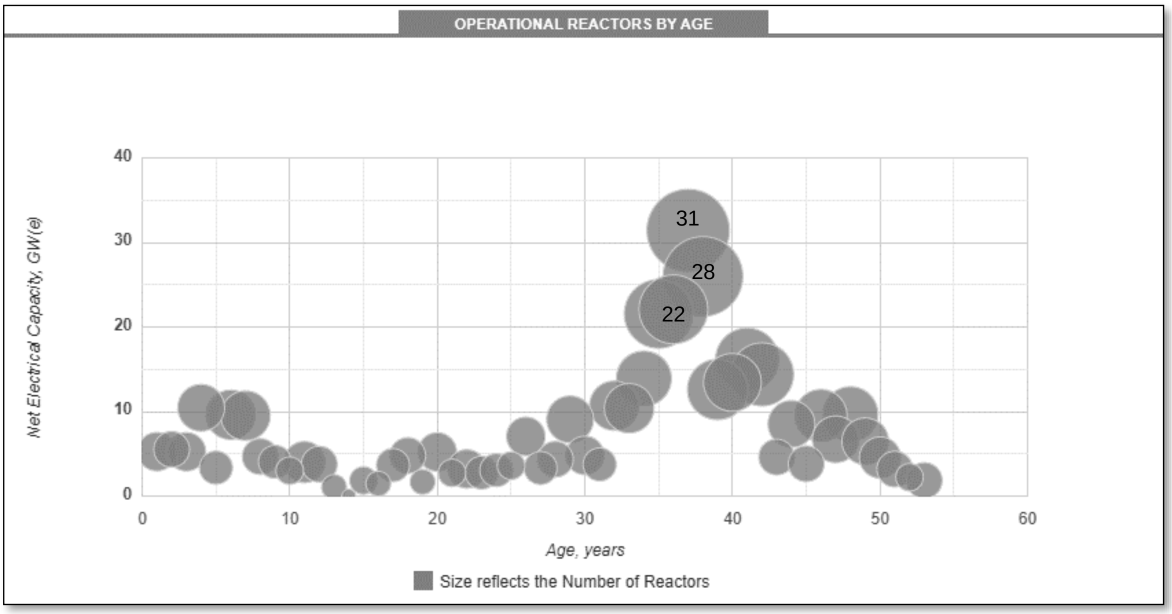

Figure 2: Electrical output and age of nuclear power reactor units in operation [3]

Figure 2 provides the electrical output and the age of the nuclear power reactor units in operation [3]. There are 22 nuclear power reactor units worldwide that have been in operation for 36 years. There are 133 nuclear reactors that have been in operation for 40 years or more, with the oldest operating reactor having been in operation for 53 years (Nine Mile Point Unit 1 in New York). It received approval from the United States Nuclear Regulatory Commission (USNRC) to extend its operating licence to 60 years in 2006. As of January 2022, the USNRC had renewed the operating licence of 94 nuclear reactor power units. It has since issued subsequent licence renewals (to extend the operating life from 60 years to 80 years) for six nuclear power reactors, and a further nine are under review [4].

In France, 21 of its 56 nuclear power reactors in operation are 40 years or older, with Bugey-2 (its oldest unit in operation) having been first connected to the electrical grid in 1978 [3].

As is the case with nuclear regulators internationally, the NNR's decision to approve or deny the LTO application is based on whether Koeberg has demonstrated that there is no undue risk to safety, health, or the environment and that the requirements as set out in the LTO regulations [2] have been met and will continue to be met during the period of LTO. This is demonstrated through a comprehensive assessment of the current and future condition of plant systems, structures, and components that perform safety functions. The assessment must confirm that the programmes and processes, including ageing management programmes that govern the management of safety-related plant equipment, meet regulatory requirements.

Plans to extend the life of a nuclear power station are investigated over many years (~10 years or more) before the current licence period ends. There are many reasons for this; for example, it may be necessary to invest in the replacement of major equipment that studies and operational experience show is necessary for the continued safe and reliable operation for the full period of LTO. This requires time to plan. Eskom's investigation into the feasibility of LTO began around 2010, and initial engagements with the NNR took place soon after that, with the IAEA involvement commencing in 2015.

Like many nuclear power stations internationally, Koeberg has conducted extensive maintenance and some major equipment replacements over the past 10 years to ensure that Koeberg remains in good condition and can benefit from the opportunity to extend its operating life, subject to the NNR approval. Major components in the process of being replaced at Koeberg are the steam generators. Other major components that have already been replaced successfully are spent fuel cooling water storage tanks and the reactor vessel heads. Several modifications and improvements have successfully been implemented at Koeberg to address the lessons learnt from Fukushima such as additional mobile generators to supply electrical power to essential equipment, provision of alternative cooling water supply sources, and mobile equipment to clear debris from an earthquake.

Industry operating experience has shown that there are engineering challenges associated with the replacement of major components and, particularly, steam generators. (See Figure 3 for an illustration of a steam generator.) One example of note is the event at San Onofre Nuclear Generating Station (SONGS) Unit 2 and Unit 3. Based on information from the USNRC site, SONGS Unit 2 and Unit 3 started operation in 1983 and 1984, respectively. The steam generators were replaced on Unit 2 and Unit 3 in 2010 and 2011, respectively, in anticipation of extending the life of the units to 60 years. However, after a short period of operation, in 2012, Unit 3 was shut down in accordance with procedures due to a steam generator tube leak. Unit 2 had already been shut down for refuelling at the time. It was discovered that accelerated wear of the new steam generator tubes had occurred, which was unexpected and not economically feasible to repair. This led to the permanent shutdown of both Unit 2 and Unit 3 at SONGS in 2013. The radiation dose to members of the public as a result of the steam generator tube leak at SONGS was estimated to be less than 0,05% of the annual regulatory limit and posed no danger to the public.

Koeberg manages risks such as these by rigorously adhering to quality and design standards, incorporating operational experience and lessons learnt from events such as that at SONGS, and ensuring that qualified and experienced manufacturers, personnel, and contractors are used to conduct the work.

Figure 3: The new Koeberg steam generators being delivered in South Africa

6. LEGAL BASIS AND REGULATORY FRAMEWORK FOR LTO

The National Nuclear Regulator Act (NNRA) 47 of 1999 empowers the NNR to grant or amend nuclear authorisations (nuclear licences) and exercise regulatory control over nuclear installations such as Koeberg [35]. Regulation No. R.266 on LTO [2], with the associated NNR LTO regulatory guide [12], establishes the requirements for LTO. Eskom is required to lodge an application for LTO in terms of section 21(1) of the NNR Act, and the application must be supported by a safety case to demonstrate the continued safe operation of Koeberg for the period of LTO. The regulatory framework for radioactive waste is provided in section 13.1 of this document.

6.1 The safety case to support the LTO application

The LTO application is supported by a safety case submitted to the NNR for approval. The safety case provides documented evidence and arguments that demonstrate that there is no undue risk to safety, health, or the environment for Koeberg to continue operating for 20 years beyond the initial licensed period of 40 years. The safety case draws on safety assessments conducted in support of LTO. In accordance with the NNR requirements, the safety assessment must include a PSR of Koeberg. The PSR is a detailed assessment of 14 safety factors to determine gaps to international, national, and regulatory safety requirements. The safety factors are listed in Table 1.

Table 1: List of safety factors reviewed during the Koeberg PSR

Subject area	Number	Safety factor title
Plant	SF-1	Plant design
	SF-2	Actual condition of SSCs
	SF-3	Equipment qualification
	SF-4	Ageing
Safety analysis	SF-5	Deterministic safety analysis
	SF-6	Probabilistic safety assessment
	SF-7	Hazard analysis
Performance and operating experience (OE) feedback	SF-8	Safety performance
	SF-9	Use of experience from other plants and research findings
Management	SF-10	Organisation, the management systems, and safety culture
	SF-11	Procedures
	SF-12	Human factors
	SF-13	Emergency planning
Environment	SF-14	Radiological impact on the environment

According to IAEA, periodic safety reviews are an effective method to obtain an overall assessment of actual plant safety. These reviews are used as a means to determine the suitability of a nuclear power plant to continue to operate safely beyond its initial 40-year life. The PSR is discussed further in section 11.4.

Effective ageing management practices and processes can prevent the adverse effects of ageing from affecting the integrity of the plant equipment during the period of LTO. Koeberg's participation in, and partnership with, international organisations such as the World Association of Nuclear Operators (WANO), Électricité de France (EDF), the Electric Power Research Institute (EPRI), the IAEA, and several others provide important benefits for Koeberg. These benefits include the availability of extensive operational experience, operating lessons learnt, and particularly experience on ageing mechanisms and ageing management programmes (which is the main focus of assessment for LTO) as well as access to industry experts through peer reviews. The experience is incorporated into Koeberg's maintenance and inspection regimes to manage or eliminate the effects of ageing on SSCs as well as improve the operational safety and performance of Koeberg.

South Africa invited the IAEA to conduct a SALTO peer review. The reason for selecting the IAEA peer review, among others, was that the IAEA requirements are largely similar to national requirements for LTO and incorporate international best practices. Therefore, this initiative afforded Koeberg the opportunity to adopt a systematic and proven approach to preparing for safe LTO. The scope of the SALTO peer review is shown in Table 2.

Table 2: The SALTO peer review scope

Area	Topic	Description
A	Organisation and functions, current licensing basis, configuration/modification management	Assess the capability of the organisation to manage LTO in terms of management policy, procedures, processes, roles, and responsibilities.
B	Scoping and screening and plant programmes relevant to LTO	Determine the methodology and criteria for selecting SSCs for ageing management. Verify whether plant programmes such as maintenance and inspection programmes are suitable for LTO.
C	Ageing management review, review of ageing management programmes (AMPs), and related time-limited ageing analyses (TLAAs) for mechanical components	Review the effectiveness and completeness of the ageing management programmes of mechanical SSCs important to safety.
D	Ageing management review, review of AMPs, and related TLAAs for electrical and I&C components	Review the effectiveness and completeness of the ageing management programmes of electrical, instrumentation, and control SSCs important to safety.

E	Ageing management review, review of AMPs, and related TLAAs for civil structures	Review the effectiveness and completeness of the ageing management programmes of civil SSCs important to safety.
F	Human resources, competence, and knowledge management for LTO	Assess whether staffing plans, processes, and procedures effectively address the need for sufficient competent staff for the LTO period.

Koeberg was able to draw on the operational experience related to the ageing of SSCs and organisational systems for effective LTO in the presence of international experts in their fields. The outcome of the SALTO review is shared with the NNR.

To demonstrate safe LTO, specific consideration is given to adequate management of the ageing processes or mechanisms that can affect the plant SSCs that are important to safety. The focus on ageing management is to ensure that SSCs will retain their capability to perform their intended safety functions throughout the planned period of LTO.

The main content of the safety case to support the licence application for LTO and satisfy the requirements in R.266 [2] and the NNR regulatory guide on LTO [12] is the following:

- Site-specific characterisation ***(discussed in Chapter 8 of this PID)***
- Risks to safety, health, and the environment ***(Chapter 10)***
- An assessment of plant design adequacy for LTO ***(section 11.1)***
- An assessment of the actual condition of SSCs ***(section 11.2)***
- The outcome of an IAEA support mission on safety aspects of long-term operation (SALTO) focusing on ageing management ***(section 11.3)***
- The outcome of the most recent periodic safety review (PSR), which is conducted on a 10-yearly basis and was submitted to the NNR in June 2022 (***section 11.4)***
- The impact of LTO on the following programmes:
  - Radiation protection arrangements and effectiveness ***(section 11.5)***
  - Nuclear security ***(section 11.6)***
  - Emergency planning ***(section 11.7)***
  - Radioactive waste management ***(Chapter 13)***
- Organisational provisions for LTO such as management systems, knowledge management, human resources and staff competency, finance, and external support organisations ***(Chapter 12)***
- The adequacy of Koeberg's nuclear safety culture ***(section 12.5)***

As part of the safety case, an LTO implementation plan is provided to the NNR on the improvements that will be implemented before and during LTO to ensure continued safe operation for the full period of LTO. Based on the above, the safety case demonstrates continued safe operation for an additional 20 years and confirms that there is no undue risk to safety, health, or the environment.

The safety case is compiled and separately reviewed by a team of experienced engineers (both local and international) before being presented to Koeberg safety oversight committees for concurrence. To ensure that all safety aspects have been considered in the safety case, it is also independently reviewed by a team of national and international experts with extensive nuclear experience before submission to the NNR. Finally, it is submitted to the NNR for a decision on the LTO application.

6.2 The current licensing conditions and licensing basis

The current Koeberg Nuclear Installation Licence (NIL-01 variation 19) [1] is issued in terms of section 21 of the National Nuclear Regulator Act [35]. NIL-01 is valid until 21 July 2024 (both units), after which it should be amended for subsequent licensing stages, including LTO. NIL-01 is granted by the NNR subject to conditions with which Koeberg must comply, currently and throughout the LTO period. These conditions are largely based on IAEA safety requirements that set high standards of nuclear safety.

Koeberg conducts self-monitoring of its compliance with NIL-01 conditions, while the NNR provides independent regulatory oversight to monitor Koeberg's compliance with NIL-01 conditions. This serves as an effective means to ensure safe operation through strict compliance with high safety standards and licence conditions. A copy of NIL-01 is publicly available and can be obtained from the NNR website.

Selected NIL-01 conditions that must be complied with and are pertinent now and for LTO are listed below. These are the main headlines supported by various licence documents, regulatory documents, and national and international standards providing detailed requirements and criteria, where applicable. The licence conditions are paraphrased for simplification and ease of understanding and are not a complete list of all the licence conditions.

- Radiological protection of persons – Koeberg must ensure that radiation doses to persons (workers and members of the public) are within prescribed limits as defined by the NNR.
- Environmental protection and effluent management – Koeberg must monitor and control the discharge of radioactive effluent (liquid and gas) within specified limits as defined by the NNR.

- Radioactive waste management – Koeberg must ensure that radioactive waste is minimised, safely stored, and disposed of or recycled.
- Emergency planning and preparedness – Koeberg must ensure that an emergency plan is established, exercised, and tested.
- Medical surveillance and health register – Koeberg must ensure that all personnel, including contractors involved in activities that affect nuclear safety or security, are fit for duty.
- Safety assessment – Koeberg must review, assess, and reassess safety during all phases of the life cycle. A periodic safety review must be conducted every 10 years and submitted to the NNR.
- Modification to the plant – Koeberg must obtain approval from the NNR for all modifications that affect the nuclear safety of the plant.
- Maintenance and inspections – Koeberg must ensure that SSCs are maintained and inspected to ensure that they are available to fulfil their safety function. Maintenance, inspection, and testing must be carried out by suitably qualified persons.
- Ageing management and LTO – Koeberg must ensure that an effective ageing management programme is developed, implemented, and maintained to ensure that the safety functions of SSCs remain available for its entire operating life.
- Decommissioning – Koeberg must demonstrate to the NNR that sufficient human and financial resources will be available for the full duration of decommissioning.
- Physical security – Koeberg must ensure the safety and security of the Koeberg site, plant, and persons on the site.
- Authorised and qualified persons – Koeberg must ensure that only suitably qualified and experienced persons perform duties that may affect safe operations.
- Quality and safety management – Koeberg must implement an integrated quality and safety management system as well as a nuclear safety culture programme.

Koeberg has established organisational systems, processes, and procedures that are benchmarked against national and international standards in order to comply with the above licence conditions. Compliance with these systems, processes, and procedures is monitored through internal audits by the Koeberg Quality Assurance Department (following an annual audit plan), annual oversight reports from the Nuclear Safety Assurance Department, external reviews such as the WANO peer review (conducted in 2021), the Nuclear Safety Review Board (NSRB), and frequent inspections by the NNR. The suite of procedures and processes is documented in the Koeberg licensing basis manual.

A system of reporting is in place in accordance with the licence requirements. Koeberg is required to provide reports to the NNR on a range of issues on a daily, weekly, monthly, or yearly basis, depending on the nature of the issue and the potential impact on safe operations. Regular reporting enables transparency and accountability, which is considered normal within the nuclear industry.

The NNR oversight to ensure that the Koeberg NIL-01 licence conditions are met and will continue to be met during the period of LTO is discussed next.

6.3 NNR oversight – compliance and enforcement

Koeberg is responsible for nuclear safety, while the NNR is responsible for defining requirements for nuclear safety and providing oversight. As explained on the NNR website, the NNR is mandated to monitor and enforce regulatory safety standards for the achievement of safe operating conditions, prevention of nuclear accidents, or mitigation of nuclear accident consequences, resulting in the protection of workers, the public, property, and the environment against the potentially harmful effects of ionising radiation or radioactive material.

Koeberg is expected to implement an inspection programme to ensure compliance with the conditions of NIL-01. The NNR implements an independent system of oversight with stringent compliance and enforcement actions. The NNR conducts compliance assurance activities to determine the extent to which Koeberg complies with the conditions of NIL-01. The compliance assurance activities involve a combination of audits, routine inspections, non-routine inspections, reviews of routine reports, and reviews of occurrence reports.

Where non-compliance with the conditions of authorisation is found, the NNR may initiate enforcement actions. Enforcement actions are designed to respond to non-compliances with specified conditions and requirements. The enforcement actions are commensurate with the seriousness of the non-compliance and may take the form of written warnings, penalties, curtailment of operations, suspension of the authorisation, or – ultimately – withdrawal of the authorisation. In all cases, Eskom, the holder of the authorisation, must remedy the non-compliance by performing a thorough investigation in accordance with an agreed timescale and taking all necessary measures to prevent recurrence.

Effective oversight by the NNR has contributed to the continued safe operation of Koeberg. The regulatory framework and NNR oversight, with the envisaged additional regulatory requirements associated with LTO, will continue to be effective during LTO.

7. APPLICANT INFORMATION

The applicant's full name	Eskom Holdings SOC Limited
Physical address	Megawatt Park Maxwell Drive Sunninghill 2157
Company registration number	2002/015527/30
Date of incorporation	2002
Registered address	PO Box 1091 Johannesburg 2000
Physical address of the nuclear installation	R27 off West Coast Road, Melkbosstrand, Western Cape, 7441 The site is located approximately 27 km north of Cape Town in the Western Cape. Access to Koeberg is via the R27 or, alternatively, via Otto du Plessis Drive. Koeberg is located on Farm Duynefontyn 1552.
Details of any holding or subsidiary companies	Eskom Holdings SOC Limited is wholly owned by the state.
Details of any foreign involvement or control of nuclear installation by foreign corporations/governments	Not applicable

8. SITE DESCRIPTION

Koeberg is situated in the Western Cape in the Blaauwberg District of the City of Cape Town Metropolitan Municipality, about 27 km north of Cape Town. It is situated on the Cape Farm Duynefontyn 1552 (the consolidation of Cape Farm Duynefontyn 34 and Farm 1375) and the adjacent farm Kleine Springfontyn 33. The site is fully owned by Eskom and is surrounded by a private nature reserve, namely, the Witzands Aquifer Nature Reserve on the north-east side, the Duynefontein residential area in the south, and the Atlantic Ocean on the west side.

The R27, known as the West Coast Road, is a regional route that runs in a north-south to north-west direction on the eastern boundary of the site. The main access road leads from the R27 to Koeberg, and an alternative access road is via Duynefontein to the south.

The Duynefontyn site hosting Koeberg has been zoned appropriately for generating nuclear electricity and associated activities.

A 400 kV power line connects the area to the national grid and the main source of electricity in Mpumalanga, with Koeberg feeding electricity into the grid for local use and exporting nationally via the grid system, depending on demand.

The City of Cape Town supplies potable water to Koeberg and areas of Bloubergstrand, Melkbosstrand, Van Riebeeckstrand, and Duynefontein via various pipelines from the Voëlvlei Dam between Hermon and Tulbagh and the 40 000 m^3 capacity Melkbos Reservoir.

There are no rivers on the site itself, but there are ecologically important wetlands to the south of Koeberg and on the northern part of the site.

The closest major airport to the site is Cape Town International Airport, which is located 40 km to the south-south-east. The railway line to Namaqualand, which runs approximately 24 km east of the site, is the closest railway line to the site.

Cape Town Harbour (25 km south) is the largest commercial harbour in the region, with Yzerfontein Harbour, a small craft harbour, located 25 km to the north-west. The site in relation to the regional context is illustrated in Figure 4.

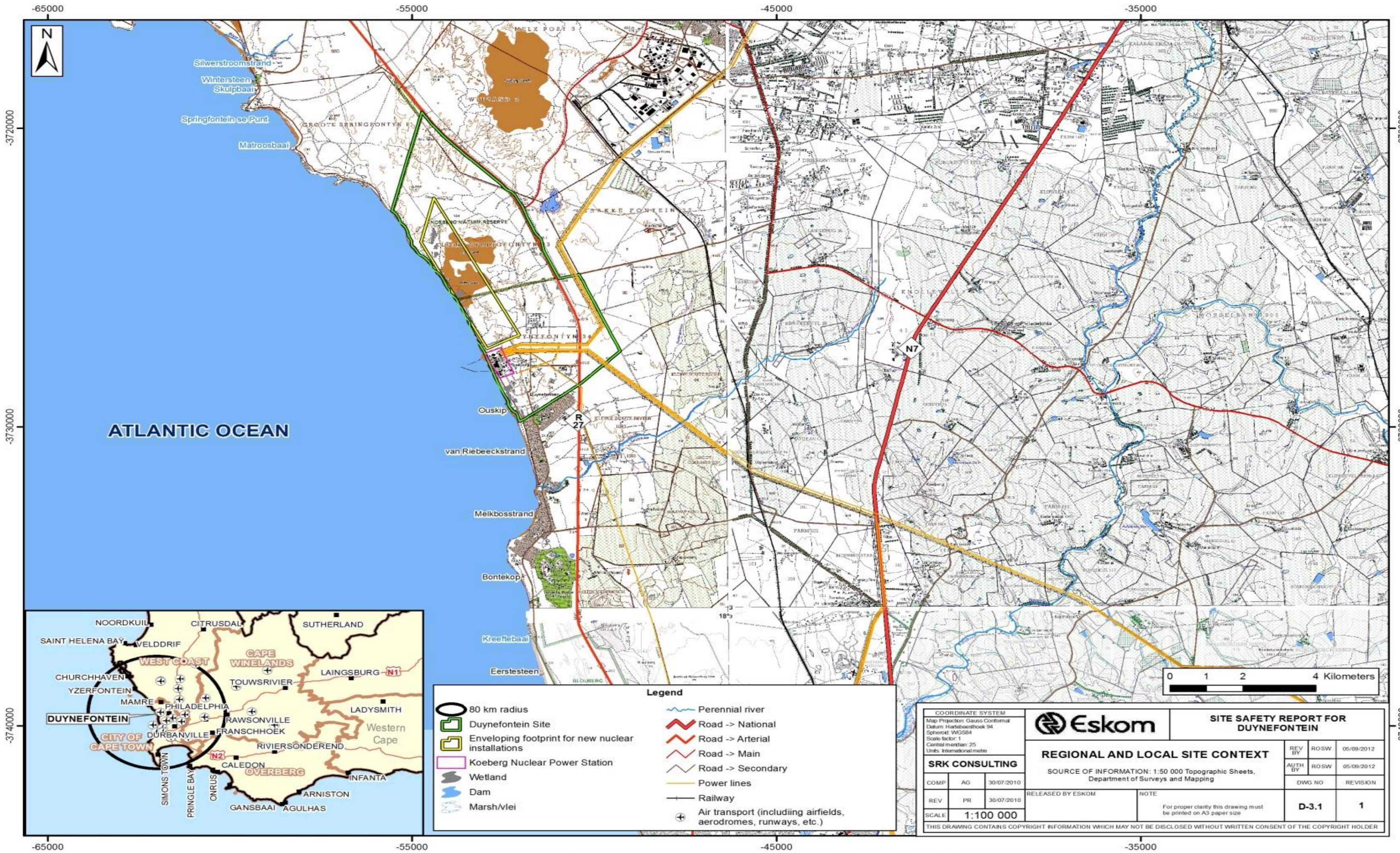

Figure 4: Regional and local site context

8.1 Site suitability

The Duynefontyn site has been extensively evaluated over the years in terms of all the site characteristics that could affect the safety of Koeberg and influence the transfer of radioactive material released to people and the environment. These studies include, inter alia:

- geological, seismological, geotechnical, hydrological, and meteorological characteristics;
- climate change considerations;
- population growth and distribution;
- land and adjacent sea use;
- nearby transportation, industrial, and military facilities; and
- potential radiological impact on people and the environment.

Site evaluation studies performed previously showed that no disqualifiers had been found that would render the site unsuitable for continued nuclear use. These studies are currently being updated, taking into consideration lessons learnt from Fukushima and ensuring the most up-to-date and accurate understanding of the site using the latest available information, regulatory requirements, and analysis methods.

Site evaluation studies are performed utilising international, national, and regulatory safety requirements, including Regulations on Licensing of Sites [17], Interim Guidance for the Siting of Nuclear Facilities [18], and IAEA Site Evaluation for Nuclear Installations [19]. The report is being finalised for submission to the NNR.

9. DESCRIPTION OF KOEBERG'S CURRENT OPERATIONS

This section provides an overview of Koeberg's operations.

9.1 The Koeberg Nuclear Power Station

Koeberg is not a unique design. It is similar to many other nuclear reactor units worldwide (mainly in France) and shares a similar design concept with more than 100 reactor units currently in operation worldwide. The technology is, therefore, well known and understood, which contributes to its reliability and safety. Koeberg construction commenced in 1976 and comprised two 920 MWe, pressurised water reactor (PWR) generating units. The PWR technology used at Koeberg was based on a design by Westinghouse and built by Framatome. Figure 5 shows a schematic of power generation utilising a PWR design.

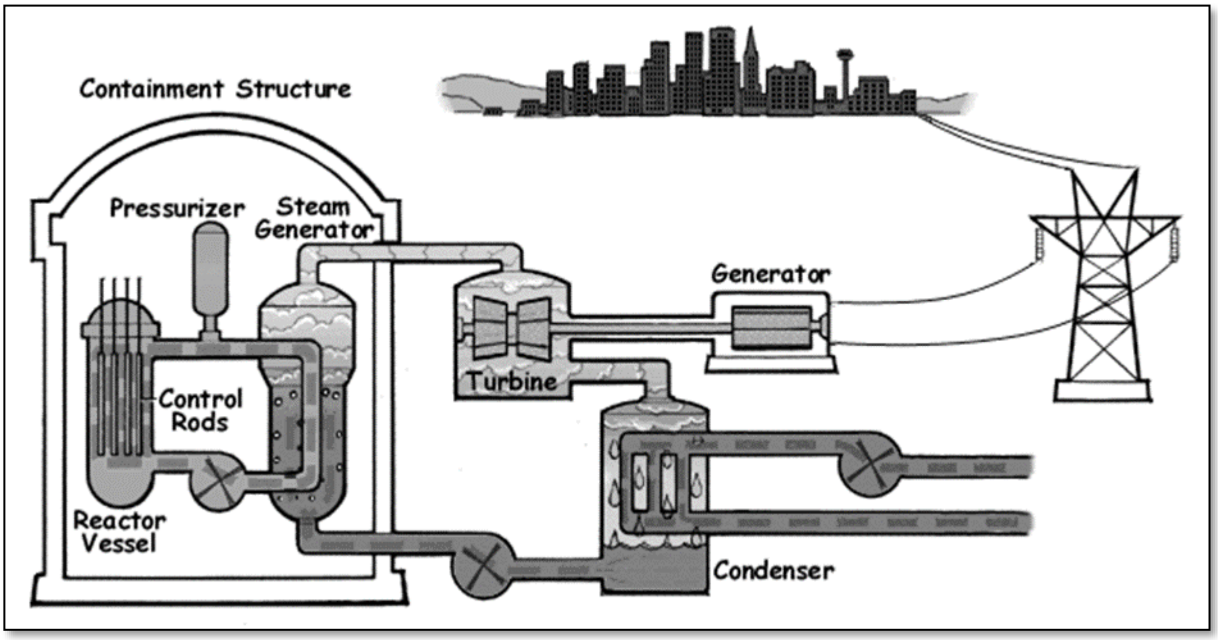

Figure 5: Schematic of a typical pressurised water reactor nuclear plant [21]

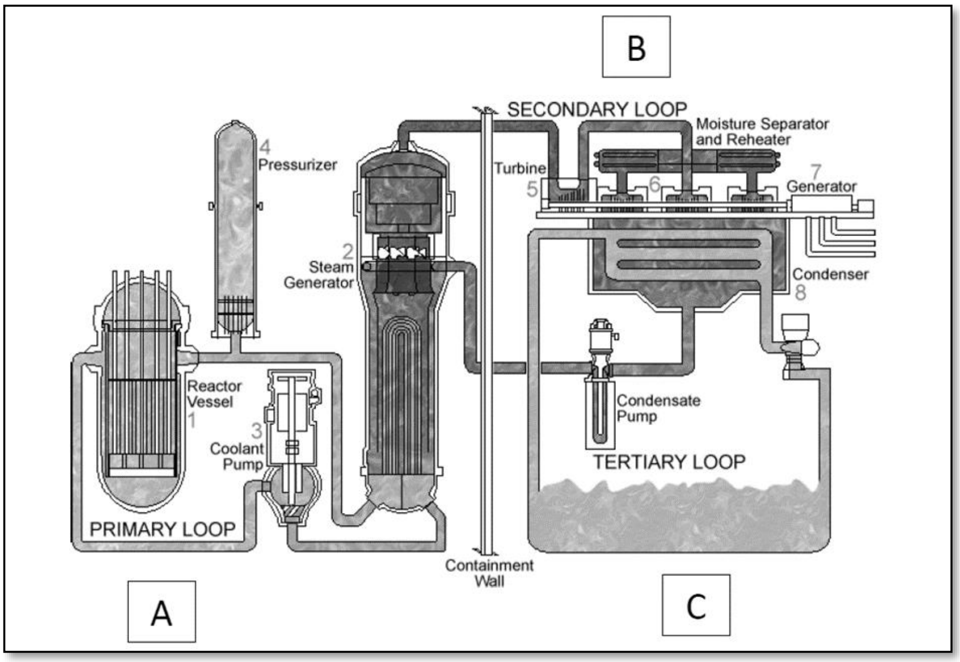

Figure 6: Configuration of the systems of a PWR plant design [22]

A PWR generating unit comprises a three-loop system (primary, secondary, and tertiary loops), in which the systems are separated from each other, as shown in Figure 6, with minimal mixing between cooling water of adjacent systems. This separation confines the radioactivity in the primary system, which serves as a barrier to the release of radioactive effluent.

Each reactor unit comprises a nuclear island, a turbine island, and water intake and discharge structures. The main parts of the nuclear island are as follows:

- The reactor building is also referred to as the containment. It contains the reactor and all the pressurised coolant loops, components, and systems required for safe reactor operation. It is a leak-tight, pressure-retaining building that retains radioactivity released by the reactor core in the unlikely event of an accident and protects the reactor system from external events such as severe weather and even missiles. It is constructed from very thick, reinforced concrete with a steel liner. During normal operation, the reactor building is kept under slight negative pressure. The primary system consists of three steam generators, three reactor coolant pumps, a pressuriser, and the reactor pressure vessel, which holds the nuclear fuel. The generic layout of the primary system is shown inFigure 7.
- The fuel building, which houses the facilities for storing and handling new fuel (before loading into the reactor) and used fuel (removed from the reactor). The fuel building also contains the equipment for the fuel pool cooling and purification system and the steam generator emergency feedwater system.
- The electrical equipment rooms, which contain all the means for controlling the unit (the control room and operations facilities, electric power supplies, and the instrumentation and control system).
- A nuclear auxiliary building housing the auxiliary systems required for normal reactor operation and supporting safety systems. This building houses the equipment of the chemical and volume control system, the gaseous waste processing system, the reactor coolant effluent processing system, backup reactor safety systems, and the boron recycle system.
- Two geographically separate buildings, each housing a diesel generator (emergency backup power supply).
- The temporary interim storage facility (TISF), currently under development and subject to NNR approval, to house additional fuel storage casks used for the dry storage of nuclear spent fuel, and the old steam generators until radioactive waste management plans have been approved for the final destination of this material.

The entire nuclear island is mounted on a seismic dampening system. The system protects the nuclear island structure from horizontal movement during an earthquake and allows the reactor unit to be safely shut down.

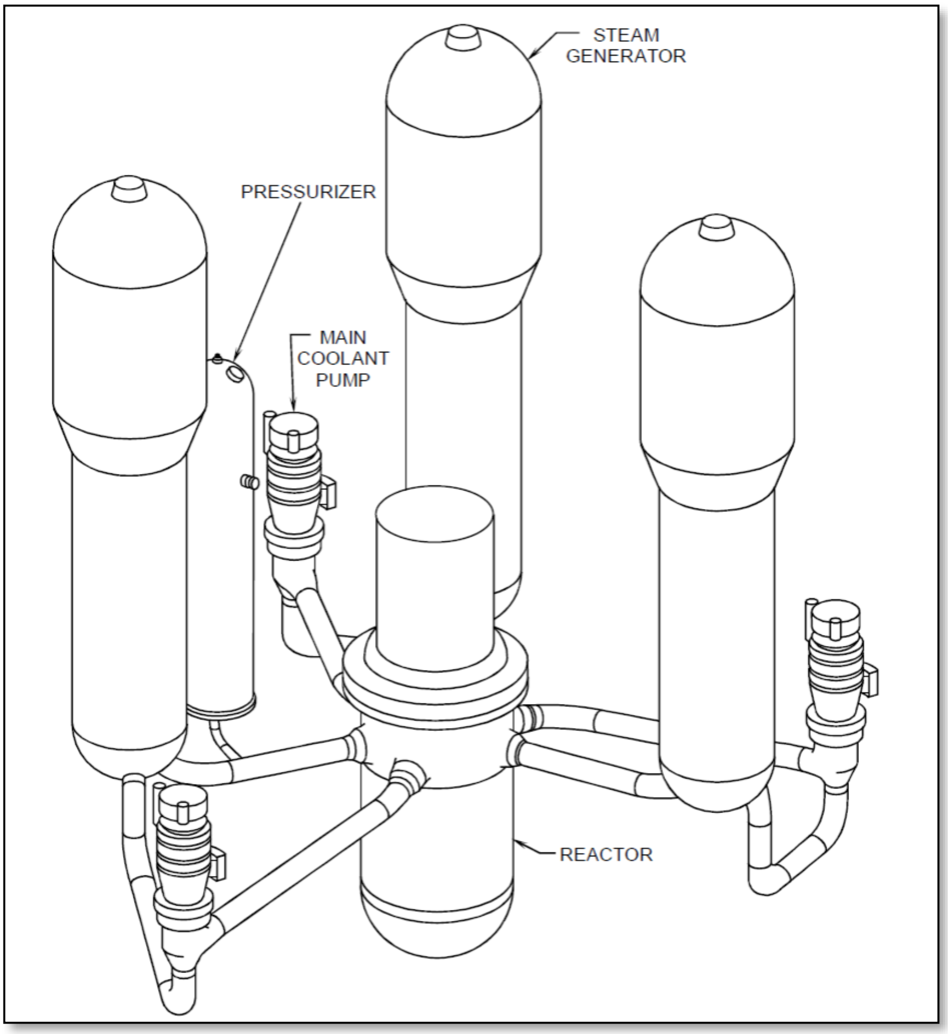

Figure 7: Illustration of generic arrangement of SSCs in a three-loop nuclear plant [23]

9.2 Electricity generation from nuclear power plants

9.2.1 Nuclear fission

Koeberg relies on low-enriched uranium as the source of fuel to produce heat. The heat generated during nuclear reactions results from a process called "fission". Fission entails the splitting of nuclei of atoms by smaller particles, called neutrons. When a relatively large fissile atomic nucleus is struck by a neutron, it splits into two or more smaller fission products and emits energy and neutrons in the process. Thereafter, the free neutrons trigger further fission, and the fission process continues in a chain reaction. The process of splitting the atoms and the subsequent release of energy is called nuclear fission (Figure 8).

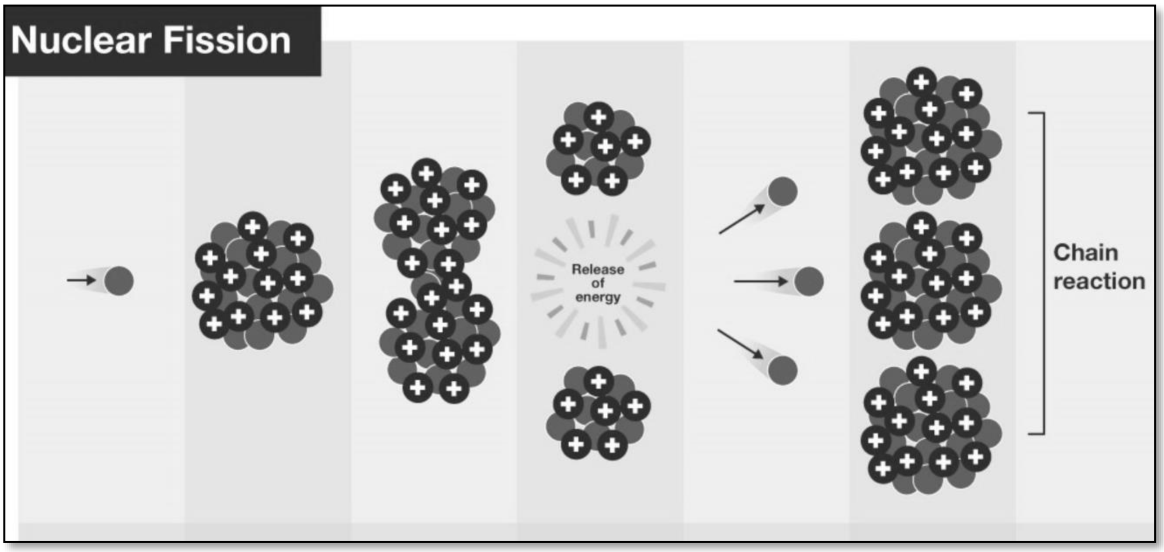

Figure 8: Nuclear fission reaction [24]

The fission process is carefully controlled by using boric acid dissolved in the primary system (reactor coolant) water and reactor control rods to ensure that design limits are not exceeded. The primary system water is circulated through the primary system to remove the heat energy from the reactor and maintain the temperature within design limits. The hot water leaves the reactor through the hot leg of the reactor and flows into the steam generator. In the steam generator, the primary circuit water is cooled as it transfers its heat to the secondary circuit. From the steam generator, the primary circuit water is then pumped back into the reactor core through the cold leg of the reactor by the reactor coolant pumps, where it is again heated up by the energy released from the nuclear fission process. Each Koeberg unit has three such primary circuit loops, that is, three steam generators and three primary pumps. One of the primary circuit loops has a pressuriser that maintains the primary system pressure high enough to prevent the water in the primary circuit from boiling, hence the name pressurised water reactor.

In the process, heat is transferred between the primary and the secondary systems. In the secondary side of the steam generator, the water is allowed to boil to be converted into steam. This steam is then used to drive the turbine, which drives the generator that generates (produces) electricity. After passing through the turbine, the steam is condensed into water in the condenser so that it can be pumped back to the steam generators, completing the secondary circuit. Water from the cold Atlantic Ocean is pumped through the condenser in the third, or tertiary, water circuit, and the residual heat extracted from the steam in the condenser is transferred to the Atlantic Ocean.

Koeberg, therefore, operates using three separate water circuits: the primary, the secondary, and the tertiary systems. The purpose of separating the three systems is to ensure that the water from the primary system is completely isolated from the tertiary system by the secondary system, preventing any interaction between the primary system and the tertiary system, as the tertiary system is open to the environment.

9.2.2 Radioactive material utilised

The Koeberg nuclear reactors produce and control the release of energy through the fission process (that is, splitting of atoms) using mainly uranium-235 (U-235) isotopes, in the form of uranium oxide (UO_2) pellets, as fuel. The UO_2 pellets are stacked in tubes to form fuel rods, which are loaded into the reactor core as fuel assemblies, illustrated in Figure 9. In the reactor core, the U-235 isotope fissions or splits, producing heat in a continuous process called a chain reaction.

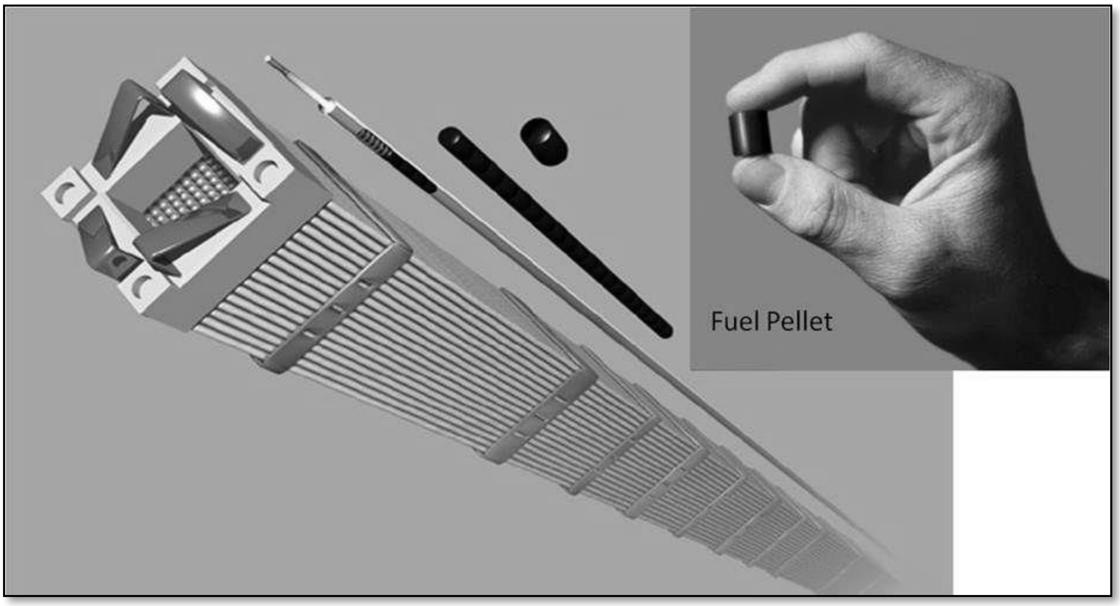

Figure 9: Illustration of a typical PWR fuel assembly, with the fuel rod, control rod, and fuel pellet elements shown separately

Water is used as the moderator to slow down the neutrons released from the fission process so that they can cause more fission, whereas control rods and dissolved boron in the primary coolant are used to absorb neutrons to control the rate of reaction within the reactor core.

The fuel rods consist of uranium, enriched to a maximum of 4,95% U-235, in the form of cylindrical pellets of uranium dioxide, sealed in fuel cladding. The fuel cladding is manufactured from a proprietary alloy of zirconium because of its favourable mechanical properties, high corrosion resistance, and low neutron absorption. Fuel rods are pressurised internally with helium during fabrication to reduce stresses during operation and prevent clad flattening. The cladding provides the first barrier to contain radioactive material inside the fuel rod. Fuel rods may contain burnable absorbers in the form of boride-coated fuel pellets or uranium oxide fuel pellets mixed with gadolinium oxide, or a combination of these, for reactivity control in the core.

The concentration of fission products and heavy elements will increase during operation, to the point where it is no longer feasible to continue to use the fuel. When removed from a reactor, the used fuel will continue to emit both radiation and heat. Refuelling shutdown cycles are typically between 12 and 24 months. During a refuelling shutdown, only one-third of the fuel assemblies is replaced, that is, two-thirds of the used fuel assemblies are reloaded along with one-third of new (fresh) fuel assemblies.

From the reactor core, the used fuel assemblies are placed in the spent fuel pool to allow heat and the radiation to decrease to acceptable levels before they are transferred into dry spent fuel storage casks. In the spent fuel pool, the water provides shielding against radiation and absorbs the heat being emitted by the fuel. The used fuel assemblies are kept in the spent fuel pools for at least 10 years to allow for cooling so that the spent fuel has very low energy left when transferred to the dry-storage casks.

10. RISKS TO SAFETY, HEALTH, AND THE ENVIRONMENT ASSOCIATED WITH LONG-TERM OPERATION

Koeberg has continued to operate safely since it was first commissioned in 1984. This is achieved through robust plant design, the application of rigorous safety programmes (for example, maintenance), consistent compliance with processes (for example, quality assurance), as well as sharing experiences with international organisations such as WANO and the IAEA. The NNR also performs a crucial role in ensuring the continued safe operation of Koeberg by providing strict and systematic regulatory oversight.

10.1 Nuclear safety risks

The risk of a nuclear accident resulting in the release of radioactivity to the environment or the risk to the public due to normal operation is very low. This section discusses the nuclear safety risk limits established by the NNR, the concept of defence in depth (DiD) used at Koeberg to keep risks at an acceptable level, and accident management.

10.1.1 Nuclear safety risk limits

The NNR specifies principal safety criteria (risk limits) with which Koeberg must comply [5]. Principal safety criteria are limits on the annual risk to members of the public and workers due to exposure to radioactive material as a result of normal or accident conditions at Koeberg. Probabilistic safety analysis (PSA) is a quantitative systematic and structured methodology to identify and analyse potential risks in design and operations in order to develop solutions to mitigate their impact on the plant and the population. The PSR assessed the current PSA and verified that Koeberg complied with the principal safety criteria and that an effective system of risk management was implemented at Koeberg to ensure that operational activities did not challenge the principal safety criteria.

The maximum annual risk to an individual member of the public and workers from accident conditions at Koeberg must not exceed the limit of 5 x 10^{-6} fatalities per annum and 5 x 10^{-5} fatalities per annum, respectively. The PSR demonstrated that Koeberg complied with the principal safety criteria and kept the peak public risk at less than 3% of the NNR criteria (approximately 1,17 x 10^{-7} fatalities per annum) and the workers' peak site risk at less than 20% of the NNR criteria (approximately 7,56 x 10^{-6} fatalities per annum).

To appreciate the concept, one may consider the risk of a fatality due to a motor vehicle accident (either as a driver, passenger, or pedestrian) in South Africa. The annual road safety report for 2019 reported that 12 921 people died in 2018 due to road accidents [33]. Based on a population of 60 million people, the average risk is that 22 people for every 100 000 inhabitants (or 2,2 x 10^{-4} per annum) will likely die in a road accident in South Africa every year. That means that a member of the public is more than 1 000 times more likely to die in a road accident than from nuclear accident conditions at Koeberg.

No human activity and, in particular, no method of electricity generation is free of risk. According to the IAEA, it is a fundamental requirement that the risks posed by a nuclear plant are demonstrably as low as reasonably practical (ALARP) as shown in Figure 10, taking into account economic and safety requirements. The maximum risk to any member of the public from a new nuclear power plant is set at 1 x 10^{-5} fatalities per annum [6]. The Koeberg risk is lower (safer) than this and in the acceptable risk region of the ALARP diagram in Figure 10.

It should be noted that while these principal safety criteria are set by the NNR, it is highly unlikely that anybody will experience health effects or death due to extending the operations of Koeberg for an additional 20 years. No nuclear accidents have occurred since Koeberg has been in operation. There is no undue risk to members of the public or workers due to Koeberg operations.

Koeberg will continue to comply with the principal safety criteria during the period of LTO.

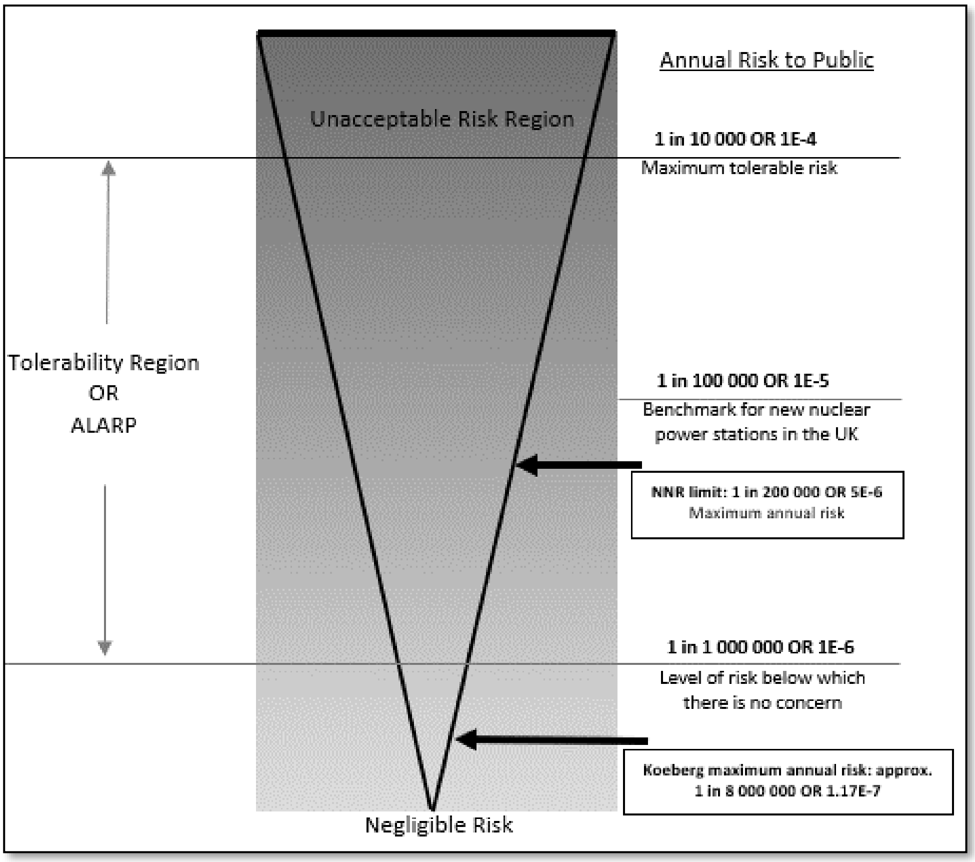

Figure 10: Managing risk as low as reasonably practical (ALARP) adapted from [6]

10.1.2 Defence in depth

The USNRC defines "defence in depth" as an approach to designing and operating a nuclear power plant that prevents and mitigates accidents that release radiation. The defence in depth concept is utilised extensively in the nuclear industry to keep the risk of an accident at acceptable levels. The result of using this approach is having available multiple, redundant layers of defence (also referred to as provisions) to compensate for potential human and mechanical failures. No single failure at Koeberg will result in an accident, irrespective of how important the failed component is to the safe operation of the nuclear power plant. If a failure were to occur, the problem could be detected and alternative means provided or corrections made to prevent or mitigate an accident.

Table 3: Levels in defence in depth [25]

DiD level	Objective	Essential means
Level 1	Prevention of abnormal operation and failures	Conservative design and high quality in construction and operation
Level 2	Control of abnormal operation and detection of failures	Control, limiting, and protection systems and other surveillance features
Level 3	Control of accidents within the design basis	Engineered safety features and accident management
Level 4	Control of severe plant conditions, including prevention of accident progression and mitigation of the consequences of severe accidents	Complementary measures and accident management
Level 5	Mitigation of radiological consequences of significant releases of radioactive materials	Off-site emergency response

The PSR evaluated all five levels of defence in depth at Koeberg. The objective of the analysis was to determine the adequacy, acceptability, and robustness of the defence in depth levels at Koeberg. The five levels of defence in depth are defined in the IAEA INSAG-10 [25] and given in Table 3. It was confirmed that Koeberg had sufficient provisions available to ensure that its levels of defence in depth were effective currently and, through ongoing maintenance and improvements, would remain effective during the period of LTO. Improvements to current provisions for defence in depth are planned and have been submitted to the NNR for approval as part of the outcomes from the PSR.

10.1.3 Accident management

Accident management is an essential component of defence in depth. It encompasses the procedures and plans needed to restore a plant to a safe state and prevent or minimise the risk of releasing radiation into the environment. Koeberg has a full set of emergency operating procedures and severe accident management guidelines available for use in the unlikely event of an accident in order to prevent damage to the nuclear fuel and prevent or limit possible radioactive releases to the environment.

In accordance with national and international standards, Koeberg has multiple safety systems to deal with a range of abnormal and accident conditions to ensure that there is no undue risk to the public. These abnormal and accident conditions are referred to as design basis accidents because the design of the plant can withstand these events without exceeding authorised limits. For example, Koeberg is designed to withstand an earthquake, with an epicentre at the fault zone, 8 km from Koeberg, that measures 7 on the Richter scale (that is, a major earthquake). It is also capable of withstanding a tsunami with a wave height of 8 m.

At Fukushima, the conditions and events were more severe than the design basis conditions and caused an accident more severe than a design basis accident. For example, the tsunami was higher than the 5,5 m-high barrier wall and caused flooding of the Fukushima emergency diesel generators of five of its six nuclear reactor units [10]. With the electrical grid destroyed during the earthquake, Fukushima had no electrical power (or backup power) for its safety systems to five of its nuclear reactor units.

The event at Fukushima has shown that conditions more severe than those postulated as design basis accidents can occur, even if the likelihood is very low. These are known as design extension conditions.

Koeberg has implemented several modifications to address the lessons learnt at Fukushima, and additional improvement actions are included in the PSR integrated improvement plan. Examples of modifications that have been implemented at Koeberg that address design extension conditions are additional mobile diesel generators, mobile pumps for alternative sources of cooling water to the spent fuel pools, mobile equipment to clear debris from severe earthquakes, and autocatalytic recombiners to reduce the risk of a hydrogen explosion. Additionally, Koeberg's severe accident management guidelines make provision for mobile backup emergency diesel generators in the event of a loss of the main electrical power supply from the national grid and the backup emergency diesel generators. More work is planned as part of continuous improvement efforts and to further reduce the risk of severe accidents, which is already within regulatory risk limits (see Figure 11).

As discussed in section 10.1, the outcome of the PSR demonstrated that Koeberg complied with the principal safety criteria specified in RD-0024 [5]. The risk of damage to the nuclear fuel in the reactor from a nuclear accident at Koeberg improved over time as safety improvements were implemented as indicated by the reduction in core damage frequency in Figure 11 for the period 2005 to 2019. The core damage frequency is the likelihood that an accident can cause the nuclear fuel in the reactor to be damaged and is now less than 1E-5 (1×10^{-5} per annum) for Koeberg.

In summary, the probability of damage to the nuclear fuel in the reactor at Koeberg is now very low and comparable with that set for new nuclear power plants [6]. This is due to ongoing improvements in safety. Koeberg's risk is expected to remain within the principal safety criteria for the period of LTO.

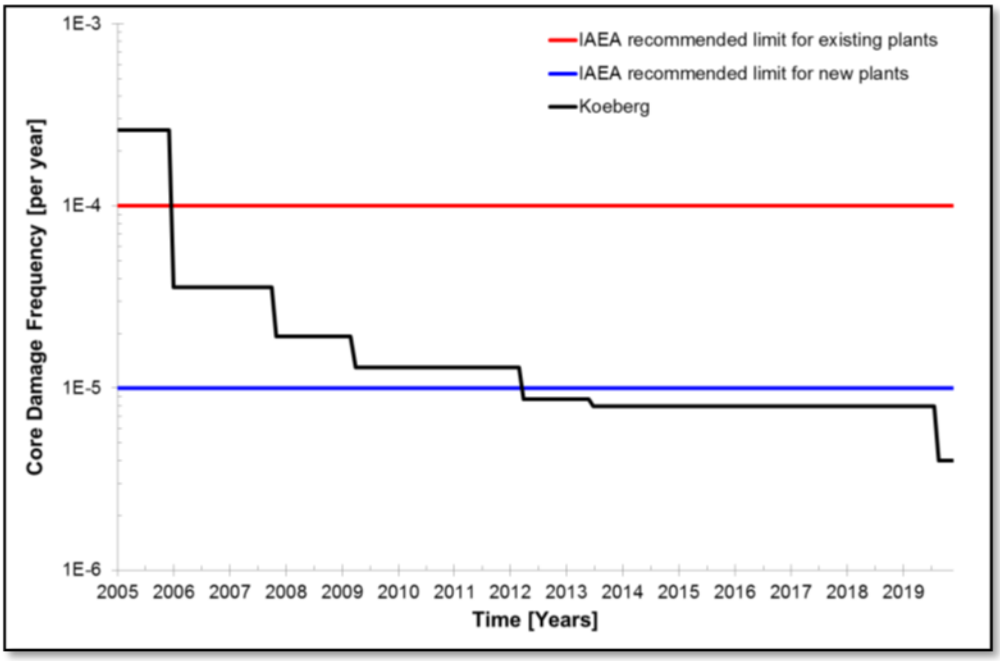

Figure 11: Core damage frequency per year

10.2 Human health risks from exposure to radiation

The radiological impacts on human health are discussed in this section. This section will demonstrate that there is no undue risk to public health from continued safe operation for an additional 20 years because radioactive effluent during LTO is expected to remain well below regulatory limits (see section 10.2.3). Occupational dose may increase slightly due to an increase in work linked to LTO (for example, steam generator replacements and reactor vessel head replacement); however, since the current occupational dose levels are well below regulatory limits, the occupational dose limits are not expected to be challenged during LTO (see section 10.2.4 and section 11.5).

10.2.1 Radiation in everyday life

The following text is taken from the IAEA fact sheet on radiation [9]:

Naturally occurring radioactive materials are present in the earth's crust, the floors and walls of our homes, schools, and offices, and in the food we eat and drink. There are radioactive gases in the air we breathe. Our own bodies – muscles, bones, and tissue – contain naturally occurring radioactive elements.

We also receive exposure from man-made radiation (such as X-rays), radiation used to diagnose diseases and for cancer therapy. Fallout from nuclear explosives testing, and small quantities of radioactive materials released to the environment from coal and nuclear power plants, are also sources of radiation exposure to humans.

Radioactivity is the term used to describe disintegration of atoms. The atom can be characterised by the number of protons in the nucleus. Some natural elements are unstable. Therefore, their nuclei disintegrate or decay, thus releasing energy in the form of radiation. This physical phenomenon is called radioactivity. The radioactive decay is expressed in units called becquerels. One becquerel equals one disintegration per second.

The time that it takes for half the radionuclides to disintegrate or decay is called half-life. This differs for each radioelement, ranging from fractions of a second to billions of years. For example, the half-life of iodine-131 is eight days, but for uranium-238, which is present in varying amounts all over the world, it is 4,5 billion years. Potassium-40, the main source of radioactivity in our bodies, has a half-life of 1,42 billion years.

The term “radiation” is very broad and includes such things as light and radio waves. In our context, it refers to “ionising” radiation, which means that because such radiation passes through matter, it can cause it to become electrically charged or ionised. In living tissues, the electrical ions produced by radiation can affect normal biological processes. The common ionising radiations generally talked about are as follows:

1. Alpha radiation consists of heavy, positively charged particles emitted by atoms of elements such as uranium and radium. Alpha radiation can be stopped completely by a sheet of paper or by the thin surface layer of our skin (epidermis). However, if alpha-emitting materials are taken into the body by breathing, eating, or drinking, they can expose internal tissues directly and may, therefore, cause biological damage.
2. Beta radiation consists of electrons. They are more penetrating than alpha particles and can pass through 1 cm to 2 cm of water. In general, a sheet of aluminium a few millimetres thick will stop beta radiation.
3. Gamma rays are electromagnetic radiation similar to X-rays, light, and radio waves. Gamma rays, depending on their energy, can pass right through the human body, but can be stopped by thick walls of concrete or lead.
4. Neutrons are uncharged particles and do not produce ionisation directly, but their interaction with the atoms of matter can give rise to alpha, beta, gamma, or X-rays, which then produce ionisation. Neutrons are penetrating and can be stopped only by thick masses of concrete, water, or paraffin.

To reduce the harmful effects of radiation, various shielding materials are used to protect the public from undue radiation exposure, as shown in Figure 12. Although we cannot see or feel the presence of radiation, it can be detected and measured in the minutest quantities with quite simple radiation measuring instruments.

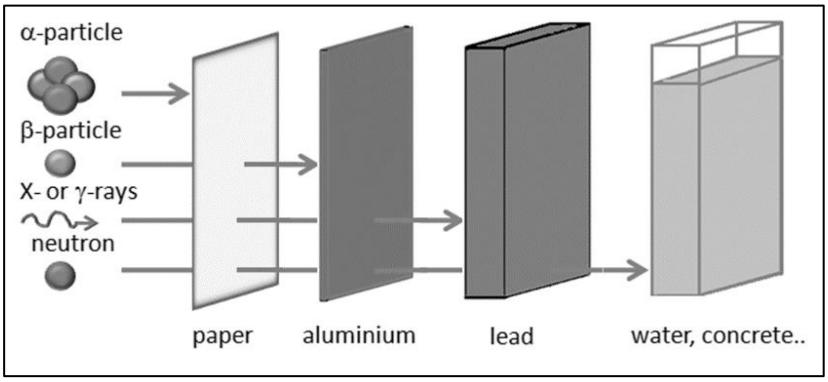

Figure 12: Types of ionising radiation together with their respective shielding materials

10.2.2 Radiation dose and biological hazards from exposure to radiation

The radiation dose that workers and the public are exposed to as a result of Koeberg operations is much lower than the dose expected to cause harm.

The absorbed dose is the energy imparted by radiation to a mass of tissue and is measured in gray (Gy). The biological effects of ionizing radiation vary with the type and energy. A measure of the risk of biological harm is the equivalent dose of radiation that the tissue receives. The unit of equivalent radiation dose is the sievert (Sv). Since one sievert is a large quantity, radiation doses normally encountered are expressed in millisievert (mSv) or microsievert (µSv), which is one-thousandth and one-millionth of a sievert, respectively. The older unit for equivalent radiation dose is the rem (roentgen equivalent man). Conversion: 1 rem = 0,01 Sv; 1 Sv = 100 rem.

For example, one chest X-ray will give about 0,1 mSv of radiation dose, while a computer tomography (CT) scan of the full body will expose a person to about 10 mSv [26]. On average, radiation exposure due to all natural sources amounts to about 2,4 mSv per year [9]; however, this figure can vary, depending on the geographical location, by several hundred per cent. (For example, in the United States of America, it is about 3 mSv per year from natural background radiation [26].)

Effective dose takes into account the total weighted sum of the equivalent doses in all the tissue and organs. Different tissues and organs have different sensitivity to radiation, so the effective dose is the dose received by the whole body.

Hazards associated with radiation exposure depend on the type of radiation, the duration over which it is delivered, and the amount of energy deposited in the tissue. At high enough levels of exposure, ionising radiation can cause changes in cells, cellular damage, or cellular death along with associated adverse health effects (for example, skin burns and cataracts). These are known as deterministic effects. Deterministic effects usually occur at high doses. No deterministic effects are expected below an absorbed dose of 100 mGy above natural background radiation exposure [8].

Stochastic effects of radiation include cancer and heritable effects. Stochastic effects are delayed and manifest themselves a certain time after being exposed to radiation and often many years later. Doses above 100 mSv can increase the risk of cancer. However, at low doses of radiation (below 100 mSv [8]), there is still considerable uncertainty about the overall effects. With all the knowledge collected on the effects of radiation, there is still no definite conclusion as to whether exposure due to natural background levels of radiation exposure carries any health risk.

Basic approaches to radiation protection are largely consistent all over the world. The International Commission on Radiological Protection (ICRP) recommends that any exposure above the natural background radiation should be kept as low as reasonably achievable (ALARA), but below the individual dose limits. The individual dose limit for radiation workers averaged over five years is 100 mSv, and that for members of the general public is 1 mSv per year (which is less than the dose from natural background radiation).

These dose limits are recommended by the ICRP and adopted by the nuclear power plant industry. They have been established based on a prudent approach by assuming that there is no threshold dose below which there would be no adverse health effects. It means that any additional dose will cause a proportional increase in the chance of a health effect. This relationship has not yet been established in the low dose range (below 100 mSv); however, as a precautionary approach, it is considered that any dose may give rise to a health effect.

The ICRP advocates three fundamental principles of radiological protection: *justification*: more good than harm must be derived from a radiation exposure situation; *optimisation*: the dose should be kept as low as reasonably achievable; and *dose limits*: the total dose for any individual should remain within limits.

In general, which is also true for Koeberg, the average annual dose received by radiation workers and the public is considerably lower than the individual dose limits. It is, therefore, extremely unlikely that any person (public or worker) will suffer any health effects due to extending operations at Koeberg for 20 years.

10.2.3 Radiological impact on the public

Exposure can be categorised into occupational exposure (exposure of workers incurred as a result of their work), medical exposure (exposure of patients as part of their diagnosis or treatment), and public exposure (exposure of members of the public to radiation as a result of being exposed to all kinds of sources of radiation, man-made or natural).

Radiation exposure may be internal or external and can be acquired through various exposure pathways, for example, inhalation, ingestion, or direct (refer to Figure 13). Internal exposure occurs when a radionuclide is inhaled or ingested, whereas external exposure may occur when an individual is exposed to a radiation field from an external source such as a chest X-ray.

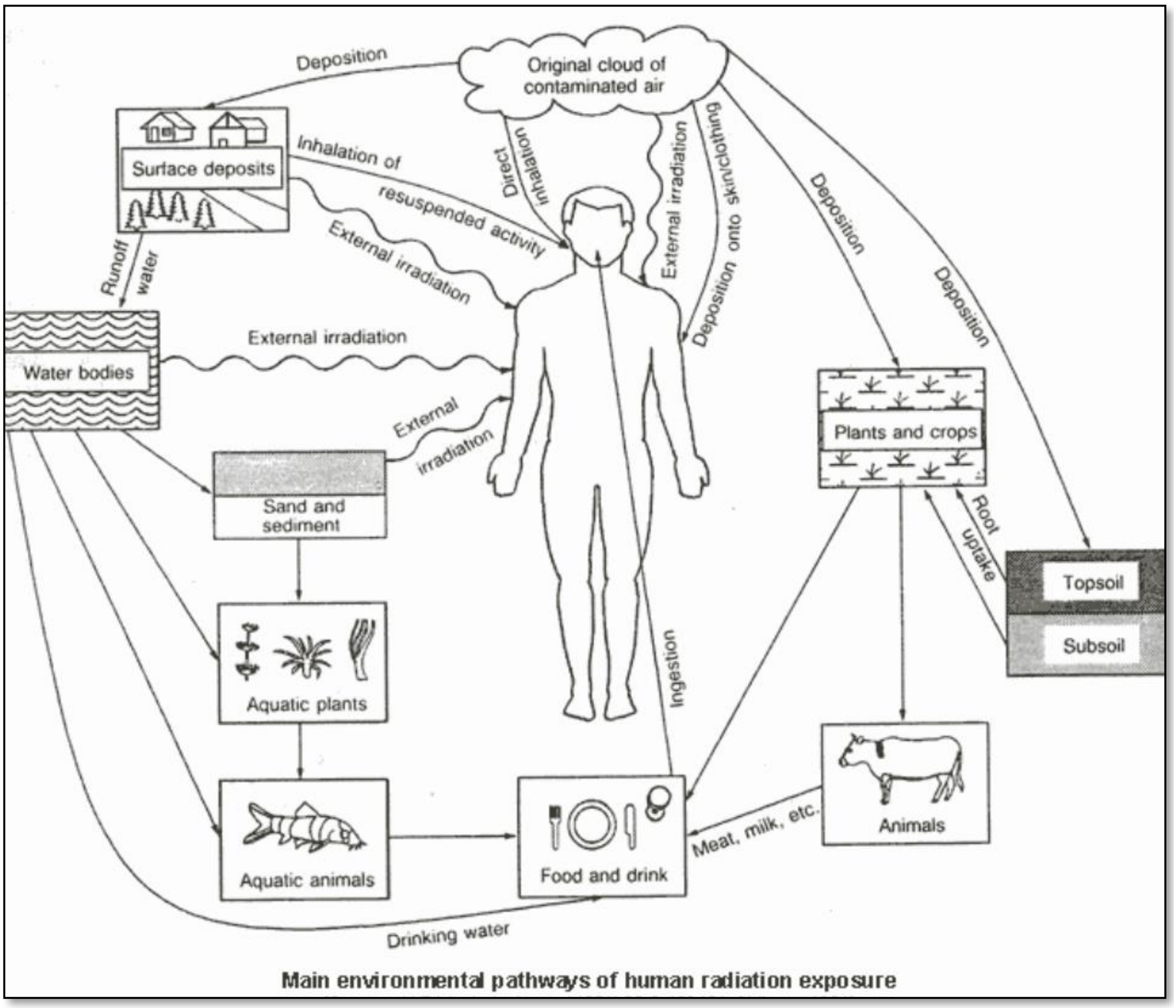

Figure 13: Exposure pathways [28]

The health risks associated with exposure to radiation as a result of Koeberg operations are very low because the amount of dose that the public is exposed to is very small. The effective dose limit set by legislation for members of the public as a result of all authorised actions is 1 mSv per annum, while the individual dose constraint applicable to Koeberg for a representative person is 0,25 mSv per annum [7]. The 0,25 mSv dose constraint is intended to ensure that the sum of all sources that may contribute to the exposure of the representative person remains within the dose limit of 1 mSv per annum.

The safety standards and regulatory practices (SSRP) [7] issued in terms of the NNR Act require that measures commensurate with the magnitude and likelihood of exposure must be implemented to ensure that exposures associated with Koeberg operations are kept as low as reasonably achievable (ALARA), economic and social factors considered. It means that all reasonable steps should be taken to adjust the radiation protection so that it is optimised, and this can include defining the radiation source, the options available to achieve the desired outcome, monitoring and measurement methods, and shielding.

Additionally, as part of normal operations, Koeberg discharges both liquid and gaseous effluent to the environment under controlled and monitored conditions to ensure that the risks to the public are kept ALARA. The liquid and gaseous releases are limited to the annual authorised discharge quantities (AADQs), which ensure compliance with the maximum annual effective dose limit. AADQs are regulatory limits, and the impact on the environment is minimal and considered safe at discharges below these limits. At Koeberg, the dose associated with the radioactive effluent discharges is calculated quarterly and annually and reported to the NNR. The public dose as a result of Koeberg's radioactive effluent discharge is shown in Figure 14 for the period 2009 to 2020.

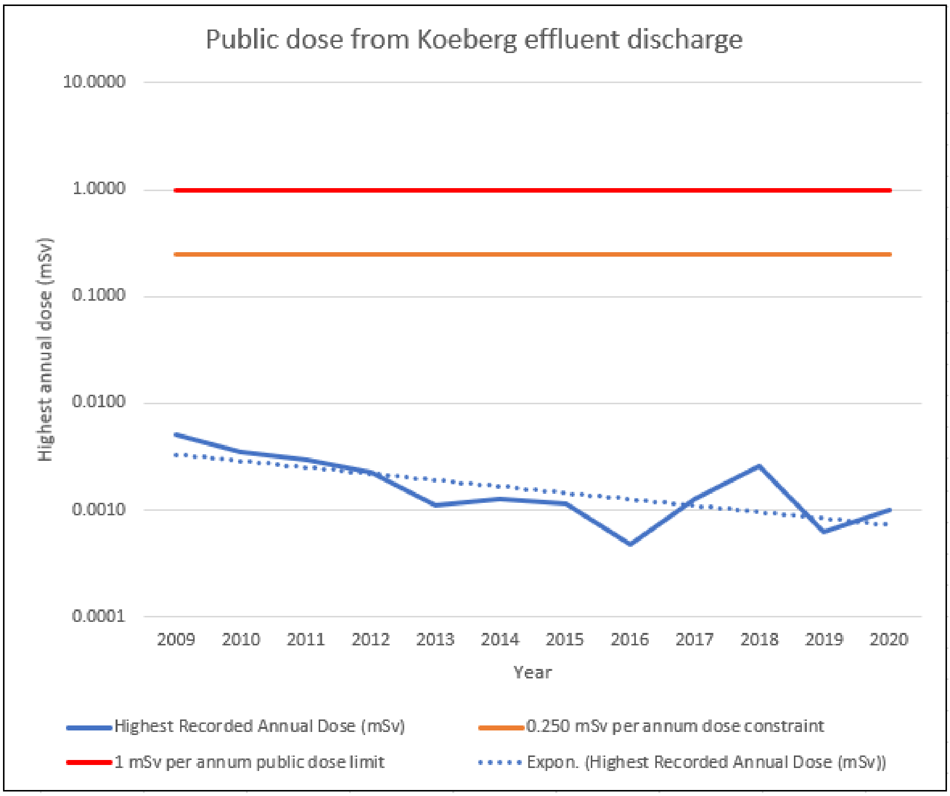

Figure 14: Public exposure as a result of Koeberg operations

The results show that the radiation dose is significantly lower than the 0,25 mSv per annum dose constraint for radioactive effluent discharges. The dose trend reduces (improves) over time due to a reduction in radioactive discharges attained mainly through improvements in fuel cladding reliability. This improving trend (reduction in radioactive discharges) over time is an example of the benefits that nuclear power plants get from their ethos of sharing operational experience between themselves and, in this case, nuclear fuel manufacturers to improve safety and performance. The retrospective dose assessment shows that, over the past decade, the public dose remained less than 1% of the legislated public dose limit of 1 mSv per annum.

The public dose (referred to as the retrospective dose assessment) is based on actual nuclide discharges measured during the reporting period at the station, taking into account factors such as habit data representative of the Duynefontyn site, as well as the Koeberg power generating history, and the environmental dispersion conditions that existed during the reporting period.

The Koeberg operations are not expected to change during LTO; therefore, future discharges are not expected to be adversely affected, and the projected annual public dose is expected to remain well below the regulatory limits during LTO. (Also see section 10.3.)

10.2.4 Occupational exposure to radiation

While it is expected that the occupational dose will increase in the short term mainly due to additional work to refurbish some plant systems and components, this is not expected to be significant, and the regulatory dose limits for workers will not be exceeded at any time during LTO.

Employees and contractors recruited to work for Eskom as radiation workers undergo an extensive medical examination to determine whether they are fit to work in a radiation environment. Prior to working in the radiation zone, employees are trained and certified as radiation workers. This enables the employees to learn and understand the risks associated with exposure to high levels of radioactivity and be informed of measures that are in place to protect them. Radiation workers are issued with an electronic personal dosimeter and a thermo-luminescent detector indicated in Figure 15 and Figure 16, respectively. These instruments are worn to monitor their radiation exposure levels (radiation dose) when working in areas where they are exposed to radiation (referred to as controlled zones).

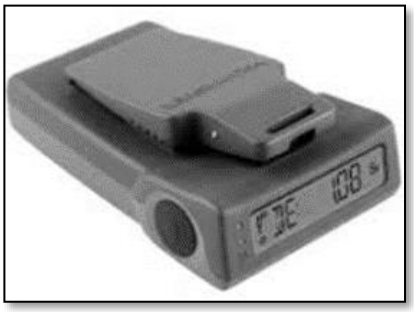

Figure 15: Electronic personal dosimeter (EPD)

Figure 16: Thermo-luminescent dosimeter (TLD)

Radiation workers who perform work in a controlled zone are issued with personal protective equipment commensurate with the protection required to prevent contamination and with dosimetry to measure their dose.

To minimise the harmful effects of radiation when handling radiation sources, the aspects of “time, distance, and shielding” that support the ALARA principle of radiation protection are applied, which may be explained as follows:

- The more time one spends in the vicinity of a radiation source, the higher the dose received and, hence, the greater the potential health risks.
- The shorter the distance between the radiation source and the person handling it, the higher the dose received and the greater the potential health risks.
- The thicker the shielding material one uses for a given type of radiation, the better the protection is from the harmful effects of radiation.

For occupational exposure in planned exposure situations, the highest individual dose limit is 20 mSv per annum averaged over a defined five-year period (100 mSv in five years), with a provision that the effective dose does not exceed 50 mSv in any single year. The worker doses at Koeberg are within regulatory limits; for example, the maximum individual dose was 17 mSv in 2011 (limit of 50 mSv). Figure 17 provides the highest worker doses received over the period 2009 to 2020. There is a reducing (improving) trend over the period.

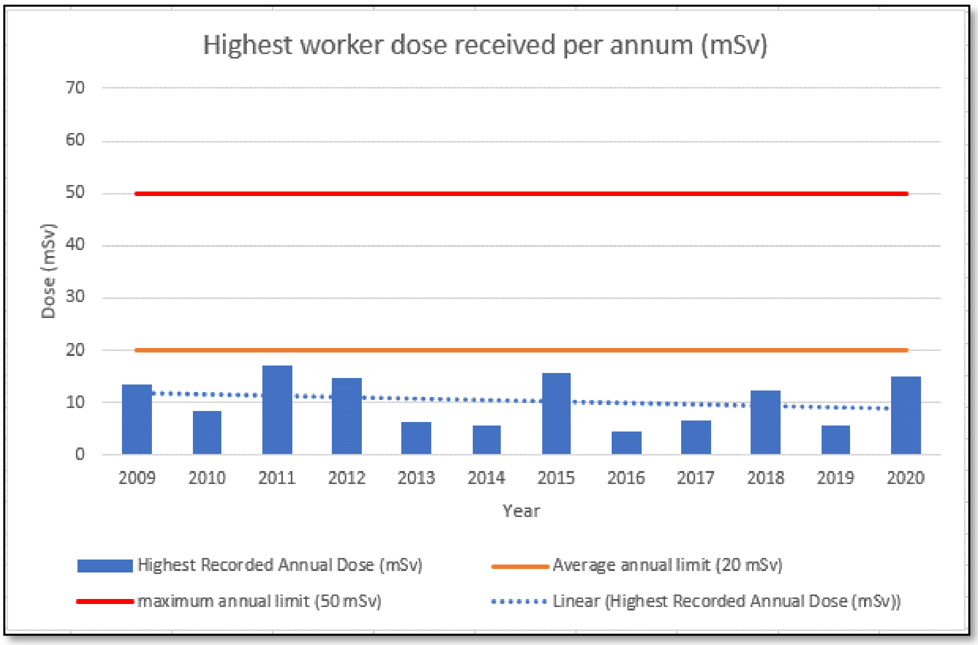

Figure 17: Highest worker dose received per annum

An ALARA target of 4 mSv is set for the average annual dose for workers [5]. The target is much lower than the effective dose limit of 20 mSv per annum for workers averaged over five consecutive years. Koeberg has consistently met the dose target of 4 mSv over the review period from 2009 to 2020, as shown in Figure 18. The average dose is less than 1 mSv per worker per annum. Additionally, the trend is improving (reducing) over time due to dose reduction initiatives implemented at Koeberg.

The regulatory limits and targets for occupational dose are expected to remain unchanged during the period of LTO, and the occupational dose is expected to remain within the regulatory limits and targets for the full period of LTO.

The PSR assessed the radiation protection programme and found it consistent with international, national, and regulatory requirements. The fundamental principles of radiological protection (justification, optimisation, and dose limits) will be strictly applied to ensure that dose is only received if there is a benefit and there is no undue risk to workers or the public.

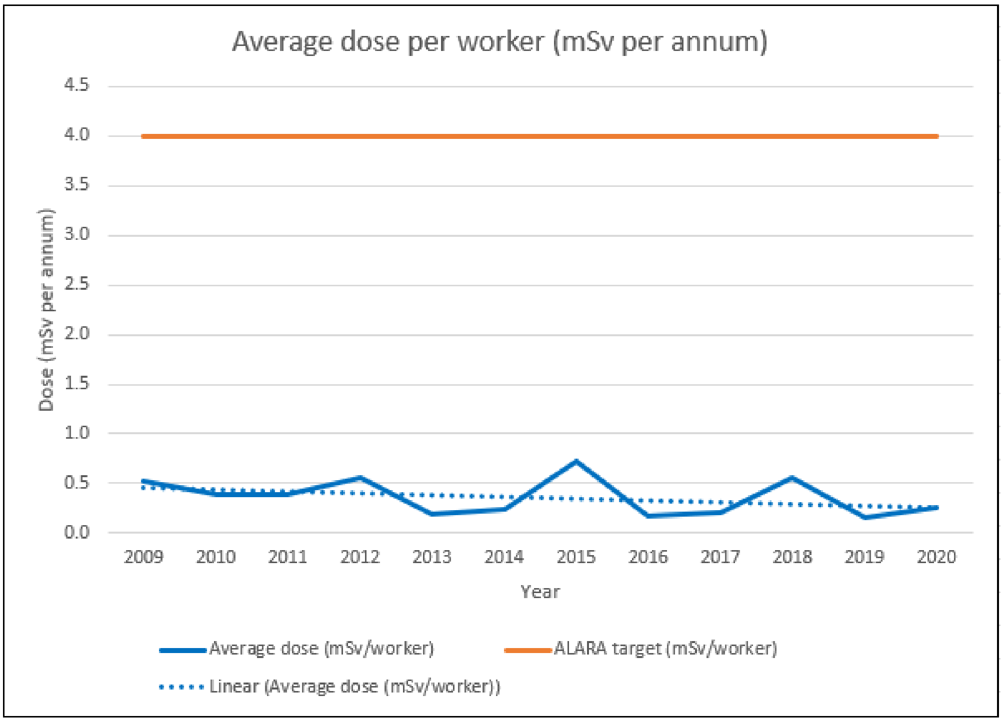

Figure 18: Average dose per worker per annum (mSv)

10.3 Impact of LTO on the environment

Koeberg is committed to a zero-harm environmental policy and ensuring that radiation safety receives the highest priority. Its environmental management system complies with ISO 14001 (an international standard that specifies requirements for an effective environmental management system). Its integrated management system complies with ISO 9001 (an international standard that specifies requirements for a quality management system) and RD-0034 (NNRs regulatory document on quality and safety management requirements for Koeberg) [11].

The impact of plant operations on the various environmental pathways has been assessed for LTO to confirm that radioactive and non-radioactive environmental discharges remain within limits set and adhere to the principles established by the relevant regulatory authorities.

Koeberg has an effective programme for monitoring the impact of its radiological effluent on the environment, as required by safety standards and regulatory practices (SSRP) promulgated in terms of the National Nuclear Regulator Act [7]. The Koeberg processes and programmes to control emissions are well established and ensure that discharges are kept within regulatory limits and are ALARA. The following sections will show that the environmental impact due to current Koeberg operations is minimal and well within regulatory limits and is expected to continue to be well within regulatory limits for the full duration of LTO.

10.3.1 Operational limits for discharges to the environment

As part of normal operations, Koeberg discharges both liquid and gaseous effluent to the environment under controlled and monitored conditions to ensure that the dose to the public is kept ALARA. The liquid and gaseous releases are required to conform to the annual authorised discharge quantities (AADQs), which comply with the maximum annual effective dose limit set out by the SSRP [7].

As mentioned in section 10.2.3, the effective dose limit for members of the public as a result of all authorised actions is 1 mSv per annum, while the individual dose constraint applicable to Koeberg for a representative person is 0,25 mSv per annum [7]. The latter dose constraint is intended to ensure that the sum of all sources that may contribute to the exposure of the representative person remains within the dose limit of 1 mSv per annum.

The Koeberg effluent and environmental monitoring programmes were reviewed during the PSR. The PSR confirmed that the annual estimated public dose using effluent data and environmental concentrations over the past decade had been below 1% of the 1 mSv per annum public dose limit, which is well below natural background radiation levels. Since the regulatory dose limits are in line with international standards, it is not expected to change during LTO, and there is no need to change the effluent and environmental monitoring programmes specifically for LTO.

However, initiatives are under way to improve on-site groundwater monitoring and include additional nuclides in the effluent monitoring and dose assessment. This is based on recommendations from the recent PSR in order to better identify and characterise radioactive discharges.

10.3.2 Radioactive liquid and gaseous waste monitoring to control releases

Koeberg has a large dry containment structure, which prevents the release of radionuclides to the environment in the event of an accident. However, the normal operation of the power plant does require the release of some radioactive effluent under controlled conditions using Koeberg’s radioactive effluent monitoring systems. Although most of the radioactivity is contained within the fuel pellets and cladding, a small fraction of the radioactivity escapes the fuel rods and contaminates the reactor coolant. Apart from the radioactivity from the fuel, the primary system coolant also has radioactive contaminants from neutron activation.

Radioactive gaseous effluent management

The gaseous waste management system collects the radioactive gases from the reactor coolant in the primary circuit. The gases are removed and routed to two gas storage tanks.

The storage tanks allow the short-half-life radioactive gases to decay if time allows, usually leaving only relatively small quantities of long-half-life radionuclides to be released into the atmosphere under controlled conditions and within allowable limits.

LTO will not increase the amount of radioactive gaseous effluent because the main source is the nuclear fuel, and the fuel cladding reliability has improved over time, resulting in reduced quantities of radioactive gas released into the primary circuit. The improvements in fuel cladding reliability are due to improvements in its design and manufacture processes.

Radioactive liquid effluent management

Radioactivity in the primary system is one of the main sources of liquid radioactive effluent. The other main source is the activation of coolant in the reactor cooling system. The radioactive effluent is managed by the liquid effluent management systems and subsystems. The extent and types of treatment depend on the chemical and radionuclide content of the effluent. Increased effluent treatment may reduce the radioactivity discharged, but this process has limitations, as some radionuclides such as tritium are practically inseparable. A trade-off is sometimes required in this regard by applying the principle of ALARA.

The design and actual condition of the liquid waste treatment systems were reviewed during the PSR. The PSR found the design of the waste treatment systems to be adequate for the period of LTO. Continuous improvements will, however, be considered for the gaseous and liquid effluent waste management systems as part of Koeberg's efforts to continually reduce the amount of discharge to the environment.

10.3.3 Impact on the environment due to major plant refurbishment for LTO

As mentioned, Koeberg has undertaken and will continue to undertake various major refurbishment activities to ensure that Koeberg is in good condition and will continue to operate safely and reliably for the full duration of LTO, subject to NNR approval.

The material composition of the replacement components (such as the steam generators) may differ from the original components, which may lead to a change in composition of the radioactive products found in radioactive effluent. A temporary increase in the volume of radioactive effluent, mainly during the installation phase, may also occur. Each replacement project of this kind considers this to ensure that only a minimum amount of radioactive effluent is discharged and that the effect on the AADQs is understood and kept within limits.

The exposure of the material of the new steam generators to the reactor cooling water circuit will temporarily result in higher reactor coolant system radioactivity. This impact was assessed, and it was concluded that the potential increase in effluent was minimal and remained well within the AADQs. The impact on public dose was also determined to be minimal and well within the regulatory limits.

The replacement of large components can result in the need for large laydown areas and new facilities for equipment storage or fabrication. Large cranes may be required. All these activities are screened for potential impact on the environment. To date, two such projects have triggered the need for an environmental authorisation in terms of the National Environmental Management Act 108 of 1998. The first project is the extension of the car park to accommodate a larger workforce needed for large component change-out projects, and the other project is the replacement of the high-voltage yard that has yet to commence. The car park extension has no radiological impact, and there is no need for NNR approval.

10.3.4 Impact on the environment caused by ageing plant

For LTO, there is a strong focus on managing the detrimental effects of ageing on plant equipment. Plant equipment utilised for effluent treatment and discharge was assessed during the PSR review. The only plant equipment that may affect the environment because of ageing is the liquid waste treatment system evaporators and civil structures, where the civil structures form a barrier between radioactive material and the environment.

The evaporators are not operating optimally, but the current system performance remains adequate because the downstream demineralisers compensate for the reduced performance of the evaporators. Actions identified during the PSR are planned to improve the performance of the evaporators.

Civil structures deteriorate as they age, especially when exposed to a harsh environment. Mitigation in the form of monitoring the condition of the civil structures and regular planned maintenance is implemented to limit the possibility of unplanned releases to the environment via civil structures.

10.3.5 Radioactivity in the environment due to LTO

The build-up of radioactivity in organisms is known as bioaccumulation. Some radionuclides (radioactive chemicals) released into the environment have higher bioaccumulation factors than others (the tendency of a chemical to accumulate in living organisms). The radionuclide half-life (the time required for half the radioactive atoms to decay) and the biological half-life (the time it takes for half of the radionuclide to be expelled from the organism) are important considerations when determining the impact on the environment. An environmental monitoring programme is in place, which tracks the radionuclide concentration in samples taken from the environment around the Koeberg site (see section 10.3.7).

As explained above, build-up of radioactivity occurs in the environment from radionuclides having a longer half-life. Taking radioactive decay into account, equilibrium in the radioactivity in the environment is reached before 40 years of operation for radionuclides with half-lives less than 10 years. There is no further build-up in radioactivity due to bioaccumulation during LTO for these short-half-life nuclides.

Radionuclides with half-lives longer than 10 years and with high bioaccumulation factors may pose a risk to the environment due to LTO. These are carbon-14 (half-life of 5 730 years), strontium-90 (half-life 29 years), caesium-137 (half-life 30 years), and nickel-63 (half-life 96 years). However, considering the estimated build-up of radioactivity in the marine environment, there is only a small increase in build-up expected due to LTO for some more important long-lived nuclides, as shown in Table 4. The impact of this build-up on reference plant and animal species has been shown to be minimal.

Table 4: Estimated increase in radioactivity in marine environment for 60-year compared to 40-year operation for important nuclides with long half-lives

Radionuclide	Percentage increase in sea sediment	Percentage increase in crustacean and fish	Percentage increase in seaweed	Percentage increase in mollusc
C-14	1,2	0,0	0,0	0,0
Cs-137	2,3	0,0	0,0	0,0
Ni-63	5,8	0,3	0,1	0,0
Sr-90	1,3	0,0	0,0	0,0

The prospective public dose has been calculated considering environmental build-up of 60 years for LTO. Unlike the retrospective public dose calculation, which is based on actual samples and effluent discharge values, the prospective public dose has been determined based on assumptions of, for example, effluent discharge quantities in the future. The prospective dose for LTO has been conservatively estimated using worst-case assumptions to be 0,094 mSv per annum, which is below the dose constraint of 0,25 mSv per annum.

The radiological environmental surveillance programme tracks the radionuclide concentration in environmental samples and trends any important environmental build-up for normal operations. The radiological surveillance programme will detect meaningful changes in bioaccumulation trends during the LTO period should they occur.

Studies have been performed to determine the dose impact on plants and animals. The dose impact of the build-up of radionuclides for a 60-year period has been assessed. Assessment has shown that the dose to reference plants and animals is below the dose screening value of 40/400 µGy/h of the IAEA and UNSCEAR (the United Nations Special Committee on the Effects of Atomic Radiation).

10.3.6 LTO impact on land use around Koeberg

The environmental monitoring programme at Koeberg is implemented to monitor all important exposure pathways. These pathways can change from time to time depending on changes in human activity around the power station and if important modifications are made to the plant. In line with regulatory requirements, an annual review of land use within 10 km of the power station is performed. The objective of the land survey is to identify new land uses, changes in receptor locations, or new routes of exposure.

In the PSR review period (2009 to 2019), no new sources or pathways were highlighted that required a sampling location to be assessed. Agricultural activity around the power station seems to be relatively static, given the poor quality of land for agriculture around the power station and the restrictions on development in terms of the emergency plan.

The possibility of a large desalination plant in the vicinity of Koeberg has been assessed and not found to be an important land-use change from a public dose perspective.

Any potential changes will be identified during the annual review and their impacts will be assessed as and when required. Nevertheless, no new developments are anticipated to occur during the LTO period that may be expected to introduce new exposure pathways.

10.3.7 Environmental monitoring programme

Koeberg has an environmental monitoring programme to assess the radiological consequences of any radioactive releases to the environment. The programme satisfies the NNR regulatory requirements and those of the IAEA. Sampling done by the Koeberg environmental survey laboratory includes inhalation, ingestion, and direct exposure pathways. Samples taken at various locations and frequencies include the following:

- Air
- Drinking water
- Surface water
- Milk
- Fish
- Soil
- Sea sediment
- Broadleaf vegetables
- Food produced in the area
- Direct radiation readings using thermo-luminescent dosimeters

The sample results are reported to the NNR quarterly and annually. The results of all samples taken over the reporting period of the last PSR (2009 to 2019), and attributed to the operation of Koeberg, were below 10% of the reporting levels and no concern to the environment or the public.

The environmental monitoring programme tracks the radionuclide concentration in environmental samples and will continue to identify any important environmental build-up during the LTO period.

11. TECHNICAL JUSTIFICATION FOR LONG-TERM OPERATION

This chapter summarises the technical justification for LTO. It documents the main technical outcomes from the assessments, focusing on the SALTO ageing management and periodic safety review outcomes. Additionally, physical and cybersecurity will be discussed to a limited extent, given the sensitivity of the topic.

11.1 Design of Koeberg

Koeberg's design is similar to many other nuclear power reactors worldwide and, particularly, in France. It is part of a fleet of 900 MW, three-loop, pressurised water reactors constructed by Framatome in the 1970s and 1980s mainly in France and operated by the French power utility, Électricité de France (EDF). It has a history of reliable, safe operation. The Koeberg plant design was assessed during the PSR to determine whether the plant systems, structures, and components important for safe operation were appropriately designed compared to current design standards in order to prevent and mitigate events that could jeopardise safety. Overall, it was found that the current Koeberg design was adequate when assessed against the licensing basis and national and international standards. The licensing basis is the suite of documents, procedures, and criteria that must be complied with in terms of NIL-01 issued by the NNR.

The Koeberg plant design has been improved over the years by taking into consideration updated technology, local and international operational experience (lessons learnt), as well as the latest safety standards. Modifications implemented to improve the safety and reliability of Koeberg include replacement of the refuelling water storage tanks, replacement of the reactor vessel heads, replacement of the turbine protection and control system, replacement of the reactivity control rod system, upgrade of the radioactivity monitoring system, upgrade of the spent fuel pool cooling system, and many more. Other modifications are being planned, such as the steam generator replacement.

Following the Fukushima accident in Japan in 2011, Koeberg performed a safety reassessment as directed by the NNR. The safety reassessment focused on severe external events (such as earthquakes and tsunamis) that could adversely affect safe operations and emergency preparedness and response. Several modifications and improvements were identified to address the lessons learnt from the Fukushima accident. Koeberg has already implemented improvements to respond to severe external events, such as additional mobile electrical power supplies and alternative sources of cooling water for the spent fuel pool. More improvements are planned to fulfil commitments made to the NNR.

A high level of safety is achieved by Koeberg's three physical barriers that contain the radioactive material. The first barrier is the nuclear fuel cladding made from advanced materials to withstand high temperatures and pressures. The second barrier is the reactor coolant system designed to transfer heat from the nuclear fuel to the secondary systems that drive the turbines. The reactor coolant system is able to control temperature, pressure, and the nuclear reaction. The third barrier is the containment building, which houses the reactor coolant system. It has been designed and built with an inner steel liner and a concrete outer layer reinforced with steel tendons.

A safety margin can be defined as the amount by which a normal operating parameter can increase before failure occurs. Nuclear power plants such as Koeberg are designed with wide margins to failure in order to reduce the risk and severity of a nuclear accident. Safety margins are achieved through the use of proven materials and design codes, testing of components, and making conservative assumptions. Koeberg's safety system design caters for the possibility of failure of a plant component that is important to safety without it resulting in the loss of the system to perform its safety function (known as the single failure criterion).

The Koeberg design caters for redundancy and diversity of safety systems by incorporating an independent duplicate of each system known as Train A and Train B for each unit (redundancy). It has backup systems of alternative designs such as feedwater systems driven by electric motors and a separate feedwater system driven by a steam turbine (diversity). Diversity protects against common mode failure.

The PSR also concluded that the design of the plant was founded on general safety principles that were largely consistent with relevant good practice. The organisational structures, processes, and procedures for plant design are considered to be adequately robust to maintain the ongoing integrity of the plant design in support of continued safe operation of Koeberg.

11.2 Actual condition of the systems, structures, and components

The actual condition of SSCs important to safety was evaluated in the PSR to demonstrate compliance with the current licensing basis, benchmark Koeberg practices against the latest standards and international guidelines with regard to all plant activities involving the ageing management of SSCs, and assess its performance and reliability during LTO. The PSR reached the following conclusions:

- The current safety standards and practices with regard to SSC condition, maintenance, surveillances, in-service inspections, and testing conform to both national and international safety codes, standards, and practices.
- The mature ageing management programmes (maintenance programmes, surveillances, in-service inspections and testing programmes, etc.) are comprehensive and well implemented, which ensures that the required safety functions of SSCs important to safety are fulfilled over LTO. Although an increase in component failures was observed due to ageing effects and obsolescence, none of the SSCs important to safety required urgent consideration when compared to international failure trends, and failures were well managed by the ageing management programme.
- All maintenance, surveillance, inspections, tests, and calibration activities are well executed with strict adherence to processes, procedures, and planned schedules. Where activities in the schedule could not be performed due to a lack of spares or obsolescence, necessary waivers and justifications have been put in place to ensure that nuclear safety is not compromised.
- The review of existing records confirmed that all information recorded was complete and accurately represented the actual condition of SSCs important to safety.
- Specific focus has been given to major components and structures that will not be replaced for LTO based on inspections, monitoring, operational experience, and maintenance such as the reactor pressure vessels (RPVs), containment buildings, aseismic bearings, switchboards, and electrical cables. Further details are provided on these components below.
  - The RPV has been subjected to a comprehensive inspection programme and engineering analysis conducted by the original equipment manufacturer. The analysis indicates that the RPV is fit for purpose for the full period of LTO. Inspections and monitoring of the RPV will continue throughout LTO in accordance with regulatory requirements.
  - The containment buildings are subject to ongoing inspections and maintenance. The most recent, 10-yearly integrated leak rate test conducted in 2015 confirmed the leak tightness and structural integrity of the containment buildings.

    Engineering analysis indicates that the structural integrity will be maintained for the full period of LTO. Ongoing maintenance and modifications such as the impressed current cathodic protection (ICCP) will ensure ongoing structural durability to mitigate the harsh marine environment.

- The nuclear island buildings are supported by anti-seismic bearings, which are designed to enable Koeberg to withstand the forces of an earthquake. The bearings are subjected to a comprehensive monitoring programme for indications of deterioration, and to date, no significant defects have been found. In addition, testing of the anti-seismic bearings is currently in progress to verify that the bearings' characteristics are suitable for entire period of LTO. Monitoring and inspections of the anti-seismic bearings will continue throughout the period of LTO.
- Electrical switchboard replacements are not expected due to their current reliability and the availability of spare parts. Ongoing periodic testing of the switchboards provides confidence in the operability of the switchboards for the period of LTO.
- Large-scale electrical cable replacement is not anticipated for LTO due to their current reliability, condition, and industry experience. Some cables required to operate during harsh conditions will be requalified through further testing and analysis to confirm their capability to operate for the full period of LTO.

- As mentioned earlier in this document, the steam generators are planned for replacement. The old steam generators are susceptible to stress corrosion cracking of the tubes. This is managed through inspections and plugging of the tubes. However, to ensure continued safety and reliability for the full period of LTO, new steam generators are being installed that are not susceptible to this failure mechanism.
- The PSR review concluded that there were no fundamental impediments to LTO related to plant design or the actual condition of SSCs important to safety, assuming timeous resolution of the identified deviations in accordance with the PSR Integrated Implementation Plan.

11.3 SALTO ageing management assessment

Effective ageing management practices and processes can prevent the adverse effects of ageing from affecting the reliability of SSCs during the period of LTO. The SALTO ageing management assessment was conducted by a team of local and international experts. It was aimed at determining the completeness of the existing Koeberg ageing management practices and processes utilising international, national, and regulatory safety requirements.

The nature and rate of the adverse effects of ageing depend on factors such as the design, material condition, construction, mode of operation, and environment within which the equipment operates. A comprehensive understanding of the manner in which SSCs deteriorate over time (age) and the impact of ageing on the reliability of the SSCs to perform their function is important for the development of a systematic ageing management process. Therefore, ageing management evaluation starts with identifying all plant systems, structures, and components important to nuclear safety (such as reactor pressure vessels, primary system components, and high-pressure piping). Particular attention is paid to the structures and components that are difficult to replace; their designs, actual condition, and ageing management programmes are validated to ensure that they can operate reliably for the full period of LTO.

An extensive database of operating experience on ageing of nuclear plant equipment, similar to equipment used at Koeberg, is available and can be used together with Koeberg's own in-house experience on equipment ageing. The database of information available to Koeberg on equipment ageing has been obtained from EDF ageing experience and the IAEA International Generic Ageing Lessons Learned (IGALL). This provides extensive information on proven ageing management practices and preparedness for LTO. Ageing mechanisms are, therefore, well known and understood. This information is used to inform the ageing programmes and processes used at Koeberg so that the ageing mechanisms can be detected, prevented, eliminated, or managed through ongoing monitoring.

The regulatory guide on Ageing Management and Long-Term Operations of Nuclear Power Plants [12] prescribes the activities needed to ensure effective ageing management programmes. The ageing management activities at Koeberg are in line with the requirements of the regulatory guide [12] and include the following activities:

- Review of the adequacy and effectiveness of Koeberg ageing management programmes against specific attributes specified in [12]
- Comparison of the ageing management programmes to the applicable IAEA IGALL knowledge base
- Identification of SSCs that have a limited operating life and revalidation of the remaining life for safe operation. These are safety analyses that use assumptions based on time or duration of operation and are referred to as time-limited ageing analyses (TLAAs)
- Evaluation of the suitability of the ageing management programmatic processes such as the equipment reliability process, ageing management database, technological obsolescence programme, etc.
- Assessment of the suitability of the plant change processes necessary for evaluating ageing effects such as evaluating whether replacement components can withstand the effects of ageing, obsolescence, and ageing management programmes
- Identification and implementation of improvement actions within appropriate timelines to resolve the findings identified during the SALTO assessment

Koeberg has completed the ageing management evaluation, and the outcome has confirmed that LTO can be supported. Improvements in ageing management programmes, testing, and monitoring of SSCs will continue prior to LTO and throughout the full period of

LTO to ensure safe, reliable operation. These activities include the completion of the few remaining TLAAs, characterisation of the aseismic bearings, and testing of electrical cables.

11.4 Periodic safety review

PSR is an NNR licence requirement that is conducted every 10 years. It is aimed at comprehensively assessing and benchmarking the nuclear power plant design, documentation, management systems, and adopted programmes, processes, and procedures against current national and international safety standards and operating practices to determine the overall safety of the nuclear power plant and provide assurance that it is safe to continue operating. One of the outcomes of a PSR is the identification of safety improvements to be implemented before the next PSR to continuously enhance the safety of the nuclear power plant.

The first PSR resulted in a wide-scale adoption of plant administrative processes, management practices, and the implementation of plant safety modifications geared to improve the level of nuclear safety and reduce the risk to the public and workers. The conclusion of the first PSR led to the NNR's acceptance of the final safety analysis report and significant improvements in the safety design of Koeberg.

The second PSR of Koeberg focused on comparing key elements of the plant design and operational practices with those of very similar plants operated by the French utility, EDF. Apart from the plant safety upgrades, the other major outcomes of the PSR included additional safety studies, a comprehensive update to the ageing management practices of the plant, and the need for the re-evaluation of the siting studies that were originally used to inform the Koeberg design before the construction of the plant.

Following the Fukushima accident in Japan, Koeberg performed a safety reassessment focusing on extreme external events (such as earthquakes and tsunamis) that might have an adverse impact on safe operations and the emergency preparedness and response to deal with such low-probability, but high-consequence, events. Several improvements have been implemented as a result of this review, and more improvements are planned.

The third PSR performed in support of LTO assessed more than 1 150 requirements against specific criteria representing the current national and international standards. This was done in conjunction with local and international experts including technical support from the IAEA. The following are some of the important conclusions drawn from the third PSR:

- The current design of the plant is adequate when assessed against the licensing basis and national and international standards. The plant design processes and procedures are adequately robust to maintain the ongoing integrity of the plant design and safety case.

- The programmes associated with maintaining the condition of the SSCs are adequate and well implemented. The actual condition of the SSCs important to safety provides confidence in the delivery of safety functions until the next PSR, including LTO.
- The equipment qualification programme is well aligned with international standards and capable of ensuring qualified equipment throughout LTO.
- The ageing management programmes, processes, and management methods are largely met, and LTO can be achieved with the proposed enhancements.
- The deterministic safety analysis concluded that adequate compensatory measures existed for the deviations that affected the deterministic safety analysis. The objective of deterministic safety analysis is to confirm that safety functions can be fulfilled.
- The overall probabilistic safety assessment results are within the regulatory limits defined in RD-0024 (requirements on risk assessment and compliance with principal safety criteria) for peak and average risk to the public.
- The hazards (internal and external) are understood, and there are means to mitigate the hazards.
- The overall nuclear safety performance of Koeberg is at an acceptable level.
- Koeberg adequately meets all the consolidated requirements relating to the use of experience (lessons learnt) from other plants and research findings. The review concluded that there were no areas that compromised nuclear safety or LTO.
- An integrated management system in line with international standards has been implemented that includes a comprehensive quality assurance programme.
- The administrative and working-level procedures are generally mature and effective. All NNR requirements related to procedures are addressed and met. The document set is comprehensive in meeting IAEA and Western European Nuclear Regulators Association (WENRA) standards.
- The human resource processes and procedures are well documented and in line with international standards. A workforce plan is in place that provides for sufficient staff for safe operation and LTO.
- Emergency planning (EP) and response arrangements are adequate and appropriately documented to ensure continued safe operation of the plant, both currently and for the duration of LTO.
- The environmental impact of the plant is not significant compared to other sources of radiation, and the measures in place to control effluent discharges and monitor effluent and the environmental impacts are appropriate and meet expectations.

- The strengths provide evidence that examples of organisational excellence exist. For example, the strength in the area of international operational experience can support Koeberg in continuing safe operation, including LTO.
- Based on the impact of the cumulative risk posed by the gaps identified during the review, suitable improvement actions have been determined, and the timescales for their implementation are considered appropriate and are commensurate with their safety impact.

Two main types of gaps were identified. Firstly, gaps related to activities that needed to be resolved before entering LTO, such as the update of equipment ageing management programmes. Secondly, there were gaps that needed to be closed before the next PSR. The improvement actions to address these gaps have been included in an integrated improvement plan, submitted to the NNR for approval, and will be tracked and monitored until all improvement actions have been completed.

After analysing the gaps and strengths and considering the timely implementation of the improvement actions, the PSR concluded that continued safe operation, including LTO, was supported.

11.5 Radiation protection programme

An assessment of the radiation protection programme against regulatory and international requirements was conducted during the PSR. The assessment confirmed that the radiation protection processes and procedures were in line with regulatory and international requirements. Processes and procedures exist for monitoring and controlling the release of radioactive effluent to the environment and occupational exposure. The dose limits for occupational and public exposure were determined to be well within the limits prescribed by the NNR. (See section 10.2.3 and section 10.2.4.)

Besides the PSR, the radiation protection programme benefits from international experience through other reviews such as technical support missions (one conducted in 2016) and peer reviews (one conducted in 2021). The technical support mission and peer reviews were conducted by WANO. Both reviews were favourable, with improvement actions serving to further enhance the radiation protection programme.

The radiation protection programme makes provision for regular monitoring of the plant area dose rates to monitor possible increase in dose rates due to changes such as plant operating conditions, radioactive contamination, and a build-up of activation products. Plant areas are signposted, and access is appropriately controlled, depending on the dose rates. Areas with high dose rates are locked or barricaded to prevent access to personnel. Dose rates in controlled areas (plant areas where workers may be exposed to radiation) that workers frequent for maintenance or operational reasons are more closely monitored, and plans and initiatives are implemented (such as flushing of systems, decontamination, and shielding) to keep the dose rates as low as possible.

Dose rates measured in the plant areas have remained stable over time based on the regular plant area survey results. Figure 19 and Figure 20 provide the dose rate index of the Unit 1 and Unit 2 steam generator plant areas, respectively. These trends provide a representative sample of increasing or decreasing dose rates, particularly in high dose rate areas of the plant. The dose rate index for the steam generator areas remained approximately between 0,2 and 0,5 on both reactor units over the review period 2009 (Refuelling Shutdown 117) and 2019 (Refuelling Shutdown 124) for Unit 1 and 2009 (Refuelling Shutdown 217) and 2020 (Refuelling Shutdown 224) for Unit 2.

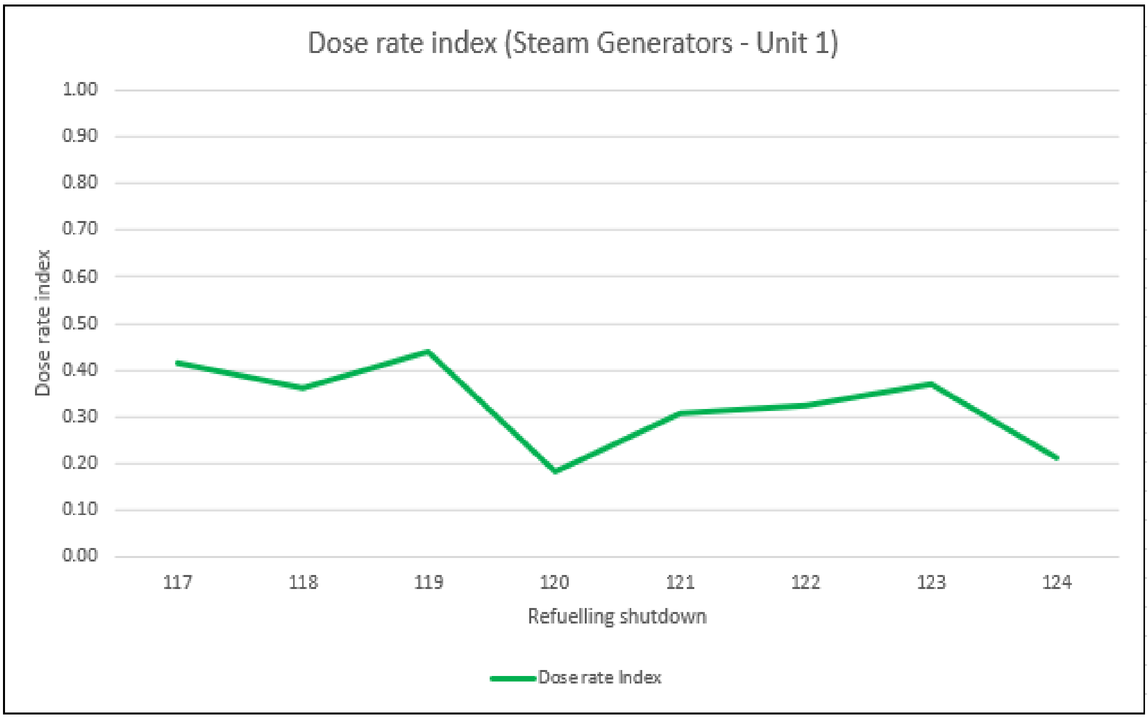

Figure 19: Dose rate index for Unit 1 steam generators

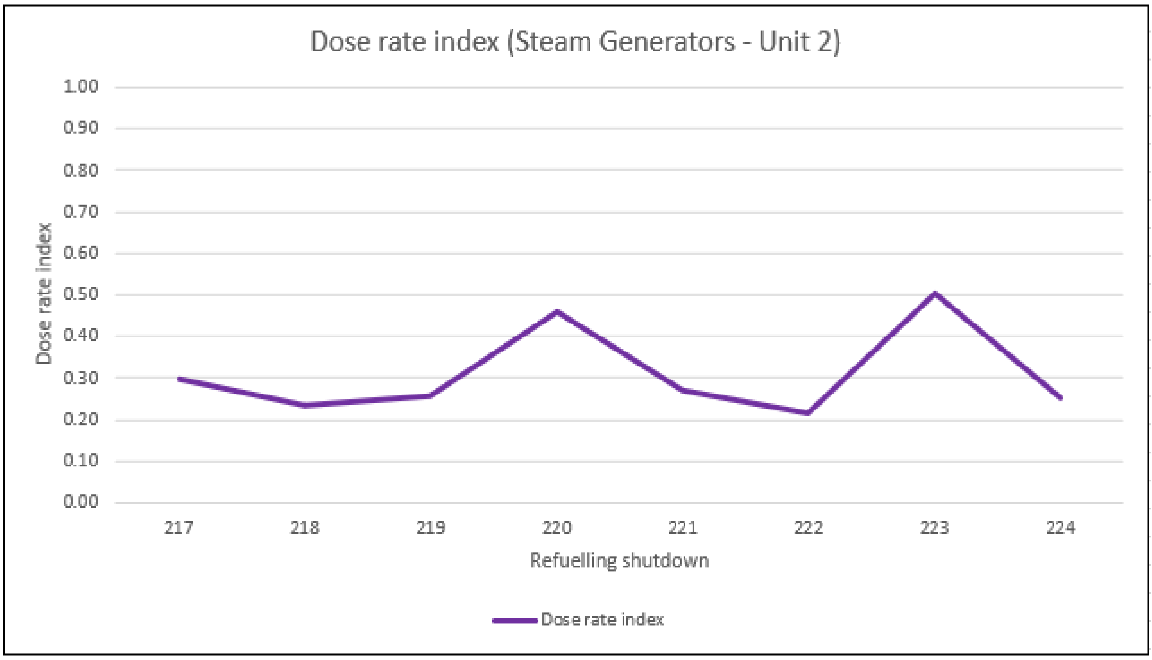

Figure 20: Dose rate index for Unit 2 steam generators

Initiatives to reduce dose rates have been implemented (such as zinc injection and changes in operating strategies), which have assisted in reducing dose rates in plant areas or keeping them stable. The replacement of the steam generators will also result in a significant decrease in dose rates in the reactor building during maintenance periods (refuelling shutdown). Given the already low occupational dose trends (see section 10.2.4), it is expected that the occupational dose will remain well within the regulatory limits during the period of LTO.

The radiation protection programme is not expected to change and will remain effective through the period of LTO. Continuous improvements will result from ongoing reviews and inspections by Koeberg, international organisations, as well as the NNR. Koeberg will continue to ensure that competent staff, sufficient radiation detection instruments, tools for the safe handling of radioactive material, and personal protective equipment are available to manage radiation hazards at Koeberg.

11.6 Physical and cybersecurity

The Koeberg physical and cybersecurity programme will continue to minimise the vulnerability to any possible threats. Effective security standards, procedures, and systems, including physical protective systems, are implemented and continually reviewed and improved based on operational experience, changing conditions, inspections, and NNR oversight.

Security processes include cybersecurity measures to ensure that Koeberg is adequately protected against unauthorised access and cyberattacks.

The physical and cyber nuclear security programme is effective and supports safe continued operation. The ongoing audits, reviews, and assessments of the physical and cybersecurity programme and resulting improvements will ensure that it will remain effective for the full period of LTO.

11.7 Emergency planning and preparedness

In accordance with NIL-01, Koeberg is required to have an emergency plan to mitigate the effects of radioactive releases in the unlikely event of an accident. The existing emergency plan is well established, in line with regulatory [30] and international requirements, and exercised annually with the NNR in attendance. Improvement actions are identified and implemented to ensure that the emergency plan preparedness and response arrangements remain effective.

The criteria for implementing protective actions are determined and set in advance. Emergency planning zones are demarcated around the Koeberg site, which represent the areas that may be affected by a release of radioactivity in the unlikely event of an accident. Protective actions such as evacuation, sheltering, thyroid blocking, and relocation are implemented to limit the impact on the public caused by external radiation exposure, inhalation of airborne radioactivity, and ingestion of contaminated foodstuff.

The Koeberg emergency planning zone radii are defined as follows in the Integrated Koeberg Emergency Plan:

- Precautionary action zone (PAZ): this zone extends from the Koeberg site boundary to a distance of approximately 5 km from the reactors, the southernmost point of which extends to approximately 8 km from the reactors.
- Urgent protective action planning zone (UPZ): this area extends from a radius of approximately 5 km to 16 km from the reactors.
- Long-term protective action planning zone (LPZ): this area extends from a radius of approximately 16 km to 80 km from the reactors.

The PAZ is a designated area where specific protective actions are implemented immediately on the declaration of a general emergency. The goal is to substantially reduce the risk of deterministic effects by implementing protective actions before (or as soon as possible after) a release of radioactivity into the environment. The UPZ is a predesignated area where preparations are made to promptly shelter people *in situ*, perform environmental monitoring, and implement protective actions based on monitoring results within a few hours following a release. The LPZ is a predesignated area around Koeberg where preparations are made to implement protective actions to reduce the longer-term dose to the public, that is, reduce the risk of stochastic effects. These are typically longer-term protective actions such as preventing ingestion of locally grown food in specific areas that may have been affected.

Appropriate agreements with local, provincial, and national authorities and international organisations are in place to ensure that emergency preparedness and response are effective. Koeberg has made arrangements for obtaining assistance during an emergency from EDF, Framatome, WANO/INPO, and the IAEA. The arrangements and responsibilities of each organisation are documented in the Koeberg integrated emergency plan.

Koeberg has an emergency control centre, a technical support centre, and an operations support centre that serve as a base from which emergency teams can provide technical, operational, and logistical support to manage the emergency. These are fully equipped with facilities and information such as communications, meteorology, and plant information and are protected from radiation.

The emergency planning staff are trained on the emergency planning procedures and obtain practical experience during emergency plan exercises.

In accordance with the local regulatory requirements, it is required that the emergency plan be subject to reviews, technical audits, and assessments. The Koeberg emergency plan benefited from the lessons learnt from the Fukushima nuclear accident. An assessment was done by Koeberg following the Fukushima accident to determine improvements in managing accidents caused by severe events (such as tsunamis and earthquakes), as directed by the NNR. Several improvements to Koeberg's emergency plan procedures have been made in order to improve Koeberg's emergency preparedness and response to such events (such as standby personnel procedures, severe weather guidelines, protective actions, and intervention-level procedure improvements).

The emergency plan was reviewed during the third PSR, and the size of the emergency planning zones was reassessed, taking into consideration a range of potential accidents and the impact that these may have on the public and the environment. It was confirmed that the current emergency planning zones remained adequate for an effective emergency plan.

Furthermore, the PSR confirmed that Koeberg had adequate plans, staff, facilities, and equipment for dealing with emergencies and that arrangements had been adequately co-ordinated with local and national authorities and were regularly exercised. This will continue to be the case during the period of LTO, while improvements are addressed as they are identified.

12. ORGANISATIONAL PROVISIONS FOR LONG-TERM OPERATION

12.1 Management system

The NOU is mandated by Eskom to implement the Eskom Nuclear Policy to achieve Eskom's nuclear objectives of safely delivering world-class nuclear energy today, tomorrow, and into the future. The policy requirements are managed through an operational plan, which is reviewed annually.

The nuclear management policy and the nuclear safety and quality manual were reviewed against international and national requirements during the latest periodic safety review. The review concluded that the current policy and management system were adequate for plant operation and that the policy met the NNR requirements stipulated in RD-0034 [11].

The Koeberg management system outlines the organisational structure, levels of authority, and requirements to which all functional units within the NOU should adhere to ensure compliance with regulatory requirements and achieve high levels of nuclear safety.

12.2 Arrangements for financial resources

Continued operation for an additional 20 years constitutes a formal commitment to ensure that financial provisions remain adequate for the LTO and decommissioning periods.

Through its revenue provisions, Eskom SOC Ltd commits itself to making the required financial resources available to enable safe and reliable plant operation for the LTO period. The Eskom Board assesses and reviews Eskom's financial status annually and provides the necessary financial resources for plant operations. In accordance with the Public Finance Management Act (PFMA) and related enabling legislation, the Eskom Board considers and determines the funding structures of Eskom, having regard to the funding requirements of Eskom from time to time (refer to the Memorandum of Incorporation of Eskom Holdings SOC Ltd available on the Eskom website).

Subject to the provisions of the PFMA (and, in particular, section 66 of the PFMA), the Board may raise or borrow funds from time to time for Eskom or secure the payment of such sums as is in accordance with its Corporate Plan and the borrowing programme submitted to the Shareholder.

12.3 Human resources

To ensure sufficient human resources to support ongoing operations, Eskom has a full suite of human resource processes and procedures aligned with international good practice. Included in the suite of human resource processes and procedures are a human resource strategy and a workforce plan that take into consideration factors such as retirements, resignations, and new staff recruitments to ensure sufficient competent staff for LTO.

Koeberg is proud of having been a significant player in developing new talent in the nuclear power sector over the past 38 years. This has been achieved through world-class human resource processes, student training programmes, and facilities for artisans, technicians, and engineers. Many of these trainees have gone on to achieve success at Koeberg and in the broader international nuclear fraternity, and many remain available to support Koeberg.

In anticipation of LTO and the need for additional staff, Koeberg has embarked on a recruitment campaign to permanently fill vacancies, from within Eskom and the external market. Highly experienced contractors have also been sourced to support the short-term increase in work scope due to LTO.

Koeberg is confident that its strategies and plans are adequate to ensure the continued availability of competent human resources for the entire period of LTO.

12.4 Competence and knowledge management

The NOU has a training and qualification programme to ensure that personnel are trained, qualified, and assessed as competent to accomplish the assigned duties. There are specific qualification requirements for critical and unique or uncommon job categories where specialised technical skills are required, with special emphasis on the operator training programme. The operator training programme is internationally accredited and is regularly reviewed by international oversight bodies. The Koeberg-specific training programme was developed in accordance with international requirements, mainly the Institute of Nuclear Power Operations (INPO) systematic approach to training.

Koeberg has two full-scale simulators for operator training. Control room operators and operating shift managers receive extensive training and examination on the simulators, culminating in an operator's licence issued by the NNR. This is followed by regular requalification training and assessment to ensure ongoing competence.

The Koeberg technical training facilities and programmes for artisans, technicians, and engineers include theoretical and practical training components. These are followed by examinations and assessments appropriate for specific job categories. The NOU's management training programme is aimed at leadership and management development as well as soft skills development for employees in leadership positions.

Knowledge management is essential for accumulating and retaining nuclear knowledge to support safe, reliable, and cost-effective operation. As mandated by the NNR in RG-0027 [12], and for Eskom to ensure sufficient knowledge throughout the lifetime of the plant, knowledge management processes have been implemented. These are being further developed and continue to evolve as improvements are implemented and the programme is expanded across the entire organisation. The Koeberg knowledge management processes utilise an integrated approach advocated by the IAEA to identify, capture, evaluate, retrieve, and share all of Koeberg's information assets (such as databases, documents, policies, procedures, and previously uncaptured expertise and experience in individual workers) [34]. Various other human resource processes at Koeberg such as succession planning, talent management, training, and job shadowing are utilised in support of the Koeberg knowledge management programme. The intent is to enable the workforce to collectively create new knowledge and ensure that critical knowledge is available to staff who need it to support safe, reliable operation during LTO.

12.5 Safety culture

According to the IAEA, a nuclear safety culture (NSC) is that assembly of characteristics and attitudes in organisations and individuals that establishes that, as an overriding priority, nuclear plant safety issues receive the attention warranted by their significance. Eskom has adopted the INPO safety culture principles and traits. These safety culture principles and traits have been incorporated into policy documentation and form the basis for the assessment, improvement, and enhancement of the nuclear safety culture at Koeberg.

To provide assurance that Koeberg's operations are continually based on the adopted safety culture principles, the health of Koeberg's safety culture is monitored annually and assessed over a three-yearly review cycle. Additionally, as part of the management responsibilities, nuclear safety performance is monitored and reported at various levels of the organisation.

Nuclear safety culture surveys are conducted three-yearly, utilising INPO 12-012 (Traits of a healthy NSC) [13]. The surveys were conducted in 2014, 2016, and 2019 and submitted to the NNR. The 10 traits of a healthy NSC (each with its own attributes and behaviours) are clustered into three broad categories (see Table 5). A comparison of the results of the NSC surveys revealed that the score for all traits had improved over the period from 2014 to 2019.

Recommendations from the 2019 NSC survey have since been implemented. The improvement actions relate to communication and engagement strategies on nuclear safety across all levels of the organisation, visible and consistent rewards and recognition for good behaviours, and organisational leadership team development. These will be assessed for effectiveness during the annual NSC self-assessment.

Based on the NSC surveys, NSC at Koeberg is acceptable and appropriately monitored for continued safe operation into LTO.

Table 5: Traits of a healthy nuclear safety culture

Traits of a healthy nuclear safety culture (INPO 12-012)	
Individual commitments to safety	Personal accountability Questioning attitude Effective safety communication
Management commitment to safety	Respectful work environment Leadership safety values and actions Decision-making
Management systems	Continuous learning Problem identification Environment for raising concerns Work processes

13. RADIOACTIVE WASTE MANAGEMENT AND DECOMMISSIONING STRATEGY

Koeberg generates gaseous, liquid, and solid radioactive waste as by-products of its operations. Radioactive waste is defined as waste that contains or is contaminated with radionuclides at concentrations or activities greater than clearance levels established by the NNR. It needs to be managed in a way that protects people and the environment from the adverse effects of radiation, which can persist over long periods.

This section demonstrates that waste management is in place and adequate for LTO. A waste management legislative framework exists, and Koeberg's waste management procedures and processes are in alignment with international, national, and regulatory safety requirements. Financial provision is made for decommissioning. The storage of all types of radioactive waste produced at Koeberg is done safely.

13.1 Regulatory framework for radioactive waste

In South Africa, activities that involve nuclear energy and radioactive waste are regulated under the Nuclear Energy Act 46 of 1999, the National Nuclear Regulator Act 47 of 1999 [35], the National Radioactive Waste Disposal Institute Act 53 of 2008 [36], the National Environmental Management Act 107 of 1998, and other appropriate legislation as stipulated in the National Radioactive Waste Management Policy and Strategy [37]. The Eskom nuclear installation licence provides conditions regarding transportation and disposal of radioactive waste.

In terms of the National Radioactive Waste Management Policy and Strategy, the South African government has the responsibility to establish appropriate structures for managing radioactive waste at a national level. For this purpose, the National Committee on Radioactive Waste Management has been established to oversee the implementation of the policy and strategy, whereas the National Radioactive Waste Disposal Institute

(NRWDI) has been assigned the responsibility of managing radioactive waste disposal on a national basis. In accordance with the NRWDI Act [36], Eskom, as the generator of radioactive waste, is "… responsible for technical, financial and administrative management of [its] waste within the national regulatory framework at [its] premises and when such waste is transported to an authorised waste disposal facility".

The nuclear installation licence requires that Eskom implement programmes for the minimisation and safe management of radioactive waste and that the safety of radioactive waste storage options must be assured for the envisaged storage period. The Radioactive Waste Management Policy [37] requires waste generators to develop site waste management plans covering all radioactive waste streams on the site for approval by the Minister of Mineral Resources and Energy.

The above legislation is expected to remain valid for LTO.

13.2 Classification of waste

Radioactive waste may be classified for different purposes, and different classification schemes may be used in the successive steps in waste management. In South Africa, the Radioactive Waste Management Policy [37] classifies radioactive waste based on the categories shown in Table 6.

Table 6: Classification of radioactive waste

Waste classification	Description
High-level waste (HLW)	Heat-generating radioactive waste with high long- and short-lived radionuclide concentrations, for example, spent fuel
Low- and intermediate-level waste – long-lived (LILW-LL)	Radioactive waste with low or intermediate short-lived radionuclide and intermediate long-lived radionuclide concentrations, for example, waste from processing fuel such as fuel cladding. These have very long half-lives.
Low- and intermediate-level waste – short-lived waste (LILW-SL)	Radioactive waste with low or intermediate short-lived radionuclides/or low long-lived radionuclide concentrations, for example, objects that are contaminated such as maintenance tools, cleaning rags, etc. These have mainly short half-lives.
Very-low-level waste (VLLW)	Radioactive waste containing very low concentrations of radioactivity, for example, contaminated or slightly radioactive material

Waste classification	Description
NORM-L	Potential radioactive waste containing low concentrations of naturally occurring radioactive material (NORM)
NORM-E	Radioactive waste containing enhanced concentrations of NORM

The design of the waste storage facility depends on the type of radioactive waste, its characteristics and associated hazards, the volume, and the anticipated storage period. At Koeberg, appropriate procedures are in place to ensure that all radioactive waste is properly identified, quantified, characterised, and classified. The procedures provide the necessary steps leading to safe clearance, authorised discharge, disposal, transport, and storage of the radioactive waste.

Only LILW-SL and HLW are applicable to Koeberg. LILW-SL comes from many different sources. It is mainly waste from maintenance operations (for example, equipment, tools, cleaning rags, etc.) or from the operation of facilities, such as waste from treating liquid or gaseous effluents at nuclear facilities (for example, filters and resins from the treatment of water from reactors). Spent nuclear fuel is classified as HLW.

13.3 Management of radioactive waste at Koeberg

The PSR review evaluated Koeberg waste management practices to determine the effectiveness of the programmes in ensuring that the waste was minimised and stored safely. The review did not identify deviations from international, national, or regulatory safety requirements in the procedures and processes used to manage the radioactive waste at Koeberg.

LILW-SL and HLW radioactive waste are generated at Koeberg as a by-product of its operations and maintenance processes. Radioactive waste is also produced as a result of major refurbishment and modifications as old components are scrapped. Additional refurbishments will need to be done before and during LTO, subject to approval by the NNR. The Koeberg Radioactive Waste Management Plan outlines the radioactive waste streams generated by Koeberg and is approved by the Department of Mineral Resources and Energy.

Individualised waste management plans are produced for major replacement components (such as the spent fuel pool water storage tanks that have been replaced and the steam generators that are planned to be replaced in the short term). These plans are approved by the National Committee on Radioactive Waste Management. The waste management plans aim to minimise the radioactive waste and provide for its safe storage and disposal.

Spent fuel is stored as HLW radioactive waste (discussed in section 13.4). The total spent fuel produced since commissioning is shown in Table 7. Approximately 55 spent fuel assemblies require storage after each unit refuelling cycle (which may vary depending on factors such as the duration of refuelling cycles). The total volume of spent fuel (HLW) is comparatively much less than, for example, coal: 1 kg of nuclear fuel (U-235) contains two to three million times more energy than 1 kg of coal. The total volume of spent fuel for 60 years of operation of Koeberg can theoretically be contained in a cube of approximately 10 m x 10 m x 10 m. Realistically, the storage area will be much larger to allow for cooling, shielding, packaging, and monitoring.

Table 7: Total spent fuel produced from commissioning to 2022

	Dry storage casks	Spent fuel pool Unit 1	Spent fuel pool Unit 2	Total spent fuel assemblies
Quantity of fuel assemblies	336	1 229	1 116	2 681

Figure 21 represents the running 12-monthly totals of the volume of LILW-SL waste produced at Koeberg for the PSR period. The volume of steel drums produced was steady, averaging about 170 m^3 per year, while the volume of concrete drums produced decreased over the PSR review period. The volumes of waste produced compare reasonably well with the industry average, except for low-level waste resin, intermediate-level waste filters, and total wet solid waste, which are higher than in the USA and France. The main variance can be attributed to different approaches applied to the treatment of low-level waste resin, which Koeberg treats as waste, but is either cleared or disposed of as very-low-level waste in the USA and France.

Radioactive waste generated at Koeberg is stored in such a way that it can be retrieved for clearance, processing, and/or disposal later or, in the case of effluent, for authorised discharge if it meets regulatory limits. The concept of “delay and decay”, “concentrate and contain”, and “dilute and disperse” is applied before the waste is transported to the radioactive waste disposal site. This ensures that the dose to the public and the environment is kept as low as reasonably achievable.

The radionuclide inventory of radioactive waste shipped to the disposal facility is recorded and tracked.

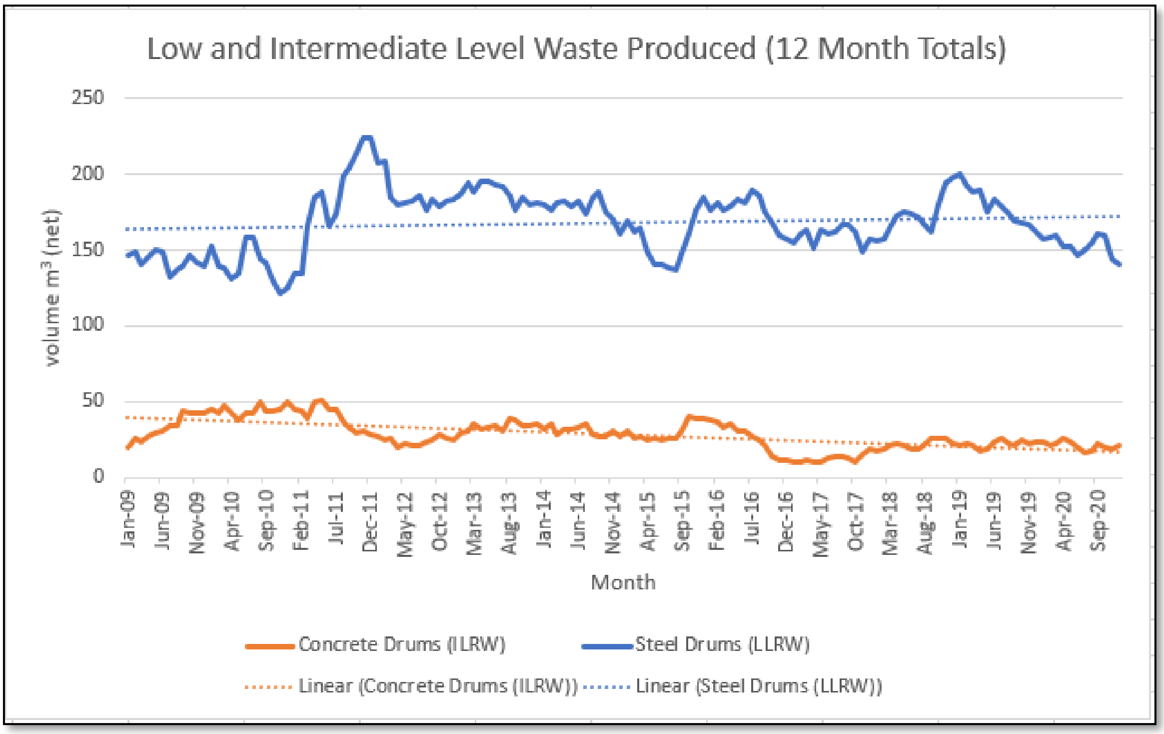

Figure 21: Low- and intermediate-level waste produced at Koeberg

13.4 Storage of high-, intermediate-, and low-level waste

Currently, spent fuel (HLW) is safely stored in the unit spent fuel pools and dry-storage casks at Koeberg. A spent fuel management strategy has been developed to address the long-term storage and final disposal of spent fuel. Spent fuel will continue to be stored in the spent fuel pools for at least 10 years to reduce the energy to acceptable levels before transferring the fuel to dry-storage casks on the Koeberg site. The spent fuel pools and dry-storage casks provide a safe and reliable means of storage for HLW and are aligned with current international strategies. Figure 22 and Figure 23 show a fuel assembly being moved into storage in a spent fuel pool and dry-storage casks, respectively.

Koeberg is making provision for the temporary interim storage facility (TISF), subject to NNR approval, to house additional fuel storage casks used for the dry storage of nuclear spent fuel.

Figure 22: Fuel assembly being moved into storage in a spent fuel pool similar to Koeberg

Figure 23: Dry fuel storage casks for storage of nuclear fuel assemblies

Public engagement, as well as engagement with affected stakeholders, will take place during the various stages of the spent fuel management process. A centralised interim storage facility (CISF) is under development and will provide the next phase of storage for spent fuel. Until the CISF has been established by the National Radioactive Waste Disposal Institute, Koeberg will ensure that spent fuel is safely stored on site. For this purpose, the dry-storage space (casks) is being expanded, subject to NNR approval (referred to as the transient interim storage facility). The Radioactive Waste Management Policy and Strategy for the Republic of South Africa [37] allow for a dry-storage period of up to 100 years. Thereafter, the spent fuel will be encapsulated and disposed of in a deep geological repository.

Over time, Koeberg will continue to monitor world practice and new developments to ensure that the best possible disposal methods are applied to store spent fuel. Koeberg will prepare technical and financial plans detailing, to the extent possible as they evolve, its plans for the long-term management of spent nuclear fuel (see section 13.6, decommissioning plans).

LILW-SL radioactive waste is encapsulated or drummed in waste containers that comply with the Vaalputs waste acceptance criteria and are approved by the NNR. The waste acceptance criteria specify the radiological, mechanical, physical, chemical, and biological characteristics of the waste package to ensure that the waste is properly contained and can be stored safely. For instance, the type, dimensions, and mass of the drums are standardised as far as practicable to ensure uniformity, compatibility, and safe handling during all waste management processes.

While awaiting transport to Vaalputs, the LILW-SL is stored in the low-level waste building on the Koeberg site. Provision is made for the regular monitoring, inspection, and maintenance of the waste and of the low-level waste building to ensure their continued integrity. Where any deterioration in the condition of the building is noted during the inspections, a full repair is conducted in accordance with qualified procedures. This practice will continue into the period of LTO.

The Vaalputs waste disposal site operates under its own nuclear licence conditions. It is located in the Northern Cape and has been designed with sufficient capacity for handling the LILW-SL radioactive waste from Koeberg. Disposal at the site is carried out in terms of its nuclear licence. In 2019, Eskom formally informed the NRWDI that Koeberg had decided to embark on LTO, subject to NNR approval, and requested the NRWDI to extend the Vaalputs service provision period to cater for LTO. The remaining reserve storage capacity at Vaalputs remains adequate to accommodate waste generated during the LTO period and is subject to NNR approval.

The NRWDI website provides detailed information on the safe storage of radioactive waste. The area has suitable geological characteristics such as low seismic activity. The Vaalputs waste storage trenches are 8 m deep, surrounded by clay, and 50 m above the water table. When the trenches are full of waste drums, they are backfilled and capped with 2 m of compacted clay to exclude rainwater before being covered with sand and replanted with the original vegetation. Figure 24 illustrates the waste storage site at Vaalputs.

Figure 24: Vaalputs waste disposal facility [29]

13.5 Radioactive waste for LTO

Radioactive waste will continue to be managed in accordance with the Koeberg NIL-01 [1] and the National Radioactive Waste Management Policy and Strategy [37] during the period of LTO.

The type of waste that will be generated due to LTO will be similar to the type of waste generated to date. Waste is currently safely stored on site or at Vaalputs. A strategy exists for the safe storage of all types of waste generated by Koeberg for the full period of operation, including LTO.

The PSR confirmed that Koeberg waste management processes and procedures were aligned with national, international, and regulatory requirements for gaseous, liquid, and solid waste management.

13.6 Decommissioning plan and financial resources

The provision of a decommissioning plan to the NNR is one of Koeberg NIL-01 conditions. A decommissioning plan must be submitted to the NNR before commencement of decommissioning activities, and Koeberg must demonstrate that sufficient human and financial resources are available for the full decommissioning process.

The "DECON" (immediate decontamination and dismantling) decommissioning option, with "Greenfields" decommissioning end-point, has been selected by Koeberg as the most-preferred option. Eskom has developed a decommissioning plan, which considers 60 years of operation, in accordance with the NNR regulatory guide on decommissioning nuclear facilities [32].

Eskom has made provision to ensure that adequate financial resources are made available, as indicated in its annual financial report, for decommissioning of Koeberg, including rehabilitation of the associated land and managing the spent fuel assemblies and radioactive waste. The financial provisions are reviewed annually.

14. TRANSPORTATION OF RADIOACTIVE WASTE AND RADIOACTIVE MATERIAL

South Africa is a member state of the IAEA and subscribes to the transport regulations set out in the IAEA Safety Requirements, Specific Safety Requirements, SSR-6 for the safe transport of radioactive materials [31]. These requirements have been incorporated into the Koeberg licence conditions (NIL-01). Authorisation from the NNR must, therefore, be obtained before any radioactive material is transported.

The objective of adopting the IAEA transport regulations and incorporating them into NIL-01 is to ensure the safe transport of radioactive material and radioactive waste. Koeberg achieves the safe transport of radioactive waste by complying with the requirements set out in the IAEA transport regulations, which include methods of containment of the radioactive content, shielding, and control of external dose rate. The requirements are satisfied by meeting the performance standards for the waste package design and administrative controls.

During the period of LTO, nuclear fuel and radioactive equipment used for maintenance will continue to be transported by sea (shipment) to the Cape Town harbour in specially designed, robust steel containers. Radioactive waste (LILW) generated during LTO will be transported by road to Vaalputs radioactive waste disposal site. This will be done in compliance with IAEA transport regulations [31].

15. CONCLUSION

Koeberg has been operating safely for more than 36 years and has operated and maintained the condition of the plant within industry-expected norms. Throughout this period, Koeberg has been revising and updating its operations and management practices through benchmarking, safety assessments, and various peer reviews, as well as the implementation of multiple plant upgrades. Koeberg's safety performance and standards are, therefore, at a level that is expected of more modern nuclear power plants.

It has been demonstrated that there is no undue risk to safety, health, or the environment. Koeberg operates well within the regulatory limits, including risk limits (principal safety criteria), public and occupational dose limits, and effluent discharge limits. The dose limits are set well below the levels at which biological harm is expected. Monitoring systems and robust management processes (including ALARA principles) are in place to ensure that Koeberg will continue to operate well within the risk, dose (public and occupational), and effluent discharge limits during the full period of LTO.

The preparation for LTO is performed in accordance with international, national, and regulatory safety requirements. In particular, there is full compliance with the LTO regulations [2]. A comprehensive PSR and SALTO were completed in preparation for LTO. The PSR provided an overall assessment of the safety of Koeberg and concluded that continued safe operation, including LTO, was supported. Ageing management at Koeberg was assessed during the PSR and SALTO, and it was confirmed that the ageing management programmes could safely support LTO. Safety improvements identified during the PSR and SALTO will be implemented in appropriate timelines.

Site evaluation studies performed previously showed that no disqualifiers had been found that would render the site unsuitable for continued nuclear use. These studies are currently being updated, taking into consideration lessons learnt from Fukushima and ensuring the most up-to-date and accurate understanding of the site using the latest available information, regulatory requirements, and analysis methods.

Koeberg has the necessary management systems, human resource processes, and training facilities to ensure that sufficient, competent staff are available to support LTO. Koeberg's knowledge management processes enable its workforce to collectively create new knowledge and ensure that critical knowledge is available to staff who need it. Koeberg's operating performance and nuclear safety culture are acceptable.

In accordance with the Public Finance Management Act and related enabling legislation, the Eskom Board considers and determines the funding structures of Eskom, having regard to the funding requirements of Eskom, from time to time. Eskom has committed itself to making the required financial resources available to enable safe and reliable operation for the LTO period.

A plan exists for the safe storage and disposal of radioactive waste generated for the full period of operations, including LTO.

Koeberg provides effective self-assessments and monitoring of its activities, while the NNR provides strict oversight and compliance monitoring. This joint rigour provides confidence that Koeberg will continue to produce safe, clean electricity for the full period of LTO.

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