



FEASIBILITY STUDY REPORT FOR THE CENTRALISED INTERIM STORAGE FACILITY (CISF) PROJECT

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EXECUTIVE SUMMARY

Overview

This Feasibility Study report was prepared by the National Radioactive Waste Disposal Institute (NRWDI) with the objective of (1) determining the technical feasibility of establishing (i.e., siting, designing, constructing and operating) the proposed centralised interim storage facility (CISF) on the Vaalputs national radioactive waste disposal facility site (in Northern Cape Province) for long-term storage of spent nuclear fuel arising from the country's nuclear reactors and (2) developing cost and schedule estimates for the CISF establishment.

The study has provided a review of centralised interim storage of spent fuel, covering the storage framework and systems in various countries as well as technological options for centralised storage. It then focused on site selection for a CISF, looking at the framework for siting (laws and regulations), site alternatives in site selection, Vaalputs site characterisation and justification and environmental impact assessment. The study further identified design alternatives for the CISF and established design criteria, requirements and characteristics; site structure and layout and storage facility and auxiliary structures; and cask operations methods and configurations.

The study further established cost estimates for the CISF based on the three identified design alternatives and discussed estimating approach and reference for cost; basis of cost estimates; pre-operation, operation and decommissioning costs; and concluded with a cost comparison.

In the study, financing and commercial aspects relating to the CISF establishment are considered and discussed. The discussion covered methods for spent fuel storage financing; financial review of implementing organisation; financial requirements of spent fuel storage project; survey of financing sources; and commercial analysis of storage services. The study then focused on staffing and training requirements, including recruitment and qualification of personnel for the CISF, and concluded with describing project development, focusing on the seven project stages that guide the development of the CISF project and are based on the Framework for Infrastructure Delivery and Procurement Management (FIDPM).

Design Alternatives

The three CISF design alternatives were identified, analysed and compared:

- (1) An aboveground storage of spent fuel in vertical concrete casks and horizontal concrete modules, i.e., ACCM (Aboveground Concrete Casks and Modules);
- (2) An underground storage of spent fuel in underground vertical cylindrical concrete silos, i.e., UCMS (Underground Concrete Modular Silos); and
- (3) An enclosed storage of spent fuel in a surface modular vault dry storage system, i.e., ESMV (Enclosed Surface Modular Vaults).

The applied method of analysis of the alternatives is the multi-criteria analysis (MCA) and its resulted indicated that ACCM is the most preferred alternative upon which the CISF project development should be based.

Comparison of the alternatives in terms of the pros and cons:

Alternative	ACCM	UCMS	ESMV
Description	 Aboveground Concrete Casks and Modules	 Underground Concrete Modular Silos	 Enclosed Surface Modular Vaults
Pros	• Quickest and easiest to implement – already licensed • Performance capabilities are known • Can be constructed in phases allowing earlier operations	• No tip over due to an earthquake • Ground provides radiation shielding • Ground shields canisters from view • Already licensed for a limited number of licensed canisters • Reduces security staffing • Can be constructed in phases allowing earlier operations	• Controlled storage environment (indoors) compared to outdoor storage • All operations are maintained within structure • Shields canisters from view easing security concerns • Provides good radiation shielding using the earth • Removes a seismic tip over event since canisters are locked in place • Lower building / crane height
Cons	• Multiple overpack designs to fabricate, maintain and monitor • Canister transfer facility may be required for a high throughput operation • Overpacks may need to be bolted to pad to mitigate a hypothetical tip-over at high seismic sites • Some licensing revisions may be required • Equipment is needed to accommodate 13 storage systems • Multiple systems complicate pad analysis	• Obtaining single storage license difficult with multiple vendor proprietary designs • Canister transfer facility may be required for high throughput operation • Large sections of storage area construction required up front • One size fits all requires design and installation of shims • Horizontal canisters require lifting cage to place in vertical position • Possible horizontal to vertical canister fuel orientation concerns	• Storage concept with commercial canisters unproven • Large nuclear structure increases engineering and initial capital costs • Requires long design and licensing time • Thermal performance capability limited to the design of current transport casks • Obtaining single storage license difficult with multiple vendor proprietary designs • One size fits all requires design and installation of shims • Horizontal to vertical canister fuel orientation concerns • Entire vault needs to be constructed to be operational

Comparison of the alternatives in terms of costs:

WBS Element	Cost Estimates (2021 ZAR '000)		
	ACCM	UCMS	ESMV
Siting	21 431	21 431	21 431
System Development	47 275	58 763	69 933
Safety Assessment	27 654	27 654	27 654
Licensing & Approvals	11 211	12 573	12 573
Stakeholder Management	38 183	38 183	38 183
Facility Design & Construction	1 699 553	1 869 182	1 688 655
Programme Management	95 086	106 192	109 359
Total	1 940 393	2 133 978	1 967 789

Comparison of the alternatives in terms of multi-criteria analysis:

Criteria/Attributes	ACCM	UCMS	ESMV
	Score 1, 2, 3, 4 or 5		
Health & Safety	3,3	3,6	4,1
Environmental Protection	3,3	3,1	3,7
Safeguards & Security	2,6	4,1	3,7
Policy & Strategy	4,0	3,4	3,7
Societal Acceptance	3,0	2,9	3,1
Cost & Affordability	4,3	1,6	3,0
Executability & Deliverability	4,4	2,6	2,7
Economic Benefit	3,3	3,7	3,9
Total Average Score	28,1	25,0	28,0

Project Schedule

A project schedule was developed and it indicates that the development of the CISF project is guided by the FIDPM and its seven project stages, starting with prefeasibility stage and concluding with the closeout stage. The feasibility study has confirmed that the CISF is doable and that it can only be established and operational by 2030 if all the necessary support such as funding and human resources are secured. The largest, longest and most capital-intensive stage of the CISF project is the Works Stage, as it involves licensing, construction, commissioning and related activities.

PROJECT STAGES	2021/22				2022/23				2023/24				2024/25				2025/26			
	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
Feasibility Stage																				
Feasibility Study																				
Design Development Stage																				
Site Investigations																				
Preliminary Design																				
Scoping & EIA Reports																				
Environmental Authorisation																				
Design Documentation Stage																				
Detailed Design																				
Safety Case Development																				
Works Stage																				
Licensing																				
PROJECT STAGES																				
Works Stage (contd.)																				
Licensing																				
Construction																				
Commissioning																				
Handover Stage																				
Training																				
Handover																				
Closeout Stage																				

The following conclusions and recommendations are drawn from the analyses and discussions in various chapters of the study.

Conclusions

- (1) The development of the CISF project is guided by the FIDPM and its seven project stages, starting with prefeasibility stage and concluding with the closeout stage. The feasibility study has confirmed that the CISF is doable and that it can only be established and operational by 2030 if all the necessary support such as funding and human resources are secured. The largest, longest and most capital-intensive stage of the CISF project is the Works Stage. It involves licensing, construction, commissioning and related activities, and it is complete when the Works Completion Report is approved.
- (2) The CISF concept is technically feasible and potentially economically viable. The study did not identify any obvious institutional deficiencies that would prevent completion of such a project. Storing South Africa's spent fuel in a single, safe, reliable, secure facility could enhance safeguards, physical protection and non-proliferation benefits.
- (3) Spent fuel storage in dry storage facilities (casks, modules, silos, vaults) on and away from the reactor site is not a new concept but has been in practice for decades. However, the concept has been bedevilled by a number of technical issues such as fuel behaviour (hydrogen effects, fuel drying, high burnup fuel, transport implications), fuel design and monitoring, and aging of facilities. All these remain a subject of research.
- (4) Vaalputs already has excellent features for a radioactive waste disposal site and these include factors such as: remoteness from international boundaries, low population density, low mineral potential, small growth and agricultural potential, and low rainfall and groundwater recharge. The site is an accepted and established low- and intermediate-level radioactive waste disposal site.
- (5) The ACCM design alternative is the most attractive of the considered CISF options in terms of cost. However, this option is not only the most favourable in terms of cost but also the most preferred in terms of the other qualitative considerations addressed in the study than the other alternatives. It is the quickest and easiest to implement because it is already licensed. Its performance capabilities are known, and it can be constructed in phases allowing earlier operations. These qualities are very important in light of the tight schedule and timelines the project is facing.
- (6) Information on alternative financing mechanisms for establishment of a CISF for long-term interim storage of spent fuel exist. The study addresses the financing requirements in the life cycle of the CISF from pre-operation phase (planning, siting, design, development and construction), through operation phase, to decommissioning phase. This information is intended to contribute to timely, systematic and comprehensive consideration of the financial aspects of CISF planning and development beginning at an early stage in this process.
- (7) An effective organisational human resource management strategy and its implementation through HR processes in the organisation is critical to the success and sustainability of the CISF programme. There is significant investment required to ensure the availability of a competent workforce for each phase of the programme.

Recommendations

- (1) The CISF must, at a minimum, comply with the national regulations and with internationally accepted other requirements. For that reason, it should be in accordance at least with: (1) Joint Convention on the Safety of Spent Fuel Management and the Safety of Radioactive Waste Management, and (2) International Basic Safety Standards for Protection against Ionising Radiation and for the Safety of Radiation Sources.
- (2) State of the art technology for the CISF should be used to adhere to the ALARA principle and in order to enhance public acceptance. It is recommended that equipment should be available for repackaging defective fuel at the CISF in order to keep radioactive effluents reasonably low.
- (3) It is recommended that the measures taken for safeguards and physical protection should be based on experience and sound knowledge of the latest developments in these areas. Design and operations of the CISF should take into account the optimisation of safeguards and security concerns, including international terrorist activities and actions of sabotage. In addition, the consequences resulting from future changes in properties of the spent fuel should be considered.
- (4) All types of spent fuel related items should be accommodated by a properly designed CISF, i.e., spent fuel from various types of power reactors, spent fuel from research reactors and residues from reprocessing, e.g., vitrified high-level waste. Criteria for acceptance will be developed depending upon the expected types of spent fuel or other materials to be stored. Defective fuel may also be accommodated at the CISF, provided technology is available dealing with such defects.
- (5) During the successive phases of construction, operation and decommissioning of the CISF, a different set of industrial services is needed. These could include production of heavy mechanical equipment, maintenance workshops for equipment, etc. Easy access to such services could be an advantage, especially if the CISF offers additional services such as repackaging, consolidation, etc.
- (6) Human resources of different levels of qualification are needed for operation, maintenance and security. The infrastructure needed to provide acceptable living conditions for these employees and their families must either exist or need to be established within acceptable distance from the CISF.
- (7) As part of the licensing procedure, a systematic safety assessment will be carried out. Such a safety assessment should cover the entire lifetime of the facility, demonstrating that the safety measures to manage the fuel will ensure compliance with the design values for: radiation exposure to personnel, radiation exposure to the public, and radioactive discharges. With this safety assessment, the overall feasibility of all handling, transport and other procedures affecting radiation protection and safety must also be demonstrated.
- (8) Due to licensing being a time-consuming activity owing to the extensive analysis required for supporting safety design of the facility, some planning may be required to assess the timelines and ensure that licensing activities are taken up sufficiently in advance and in

parallel with other project activities, where feasible, such that any negative impact on project schedule is minimised. Hence, the need for the development of a safety case is addressed in the Documentation Stage.

- (9) Due to the extended storage periods (up to 100 years) and considering the rapid changes of information technology, the transfer of data in a usable form to future generations could become difficult. Special attention must be paid to the standardisation of data formats, content of the information, and data management. The facilities should implement and maintain a data processing and preservation system that would accept the data from the spent fuel generators and create and keep the history data records.
- (10) A decommissioning plan should be prepared prior to construction of the CISF, subject to regular updating throughout the operational period. The respective parties should agree upon responsibilities and funding for decommissioning in advance.
- (11) In determining whether to establish the CISF, the costs and liabilities to all affected parties must be weighed against benefits. Costs will be incurred for all activities over many years from site selection for the facility (including phased development or capacity extension of an existing facility) through construction, licensing procedure, start-up, operation, transport, maintenance and decommissioning of the facility. Thus, economic considerations would normally be an important (but not the only) driving force for a centralised storage solution.
- (12) Since CISF storage is not the final stage in the disposition of spent fuel, retrieval is important at any time during the storage period and in particular at the end of the lifetime of the CISF. To this end, fuel handling and loading systems and equipment would be an integral part of the storage system, the need for spent fuel handling during long-term storage may arise from the transfer to another storage system for various reasons. The lifetime of the CISF should be determined based on the necessary storage period prior to any future disposition, be it reprocessing or disposal.

ABBREVIATIONS AND ACRONYMS

Abbreviation / Acronym	Explanation
ACCM	Aboveground Concrete Casks and Modules
ALARA	As Low As Reasonably Achievable
CISF	Centralised Interim Storage Facility
DGR	Deep Geological Repository
DFFE	Department of Fisheries, Forestry and Environment
DMRE	Department of Mineral Resources and Energy
EIA	Environmental Impact Assessment
EIR	Environmental Impact Report
EPRI	Electric Power Research Institute
ESMV	Enclosed Surface Modular Vaults
FIDPM	Framework for Infrastructure Delivery and Procurement Management
GISF	Generic Interim Storage Facility
HLW	High-Level Radioactive Waste
IAEA	International Atomic Energy Agency
LLW	Low-Level Radioactive Waste
MTHM	Metric Ton Heavy Metal
MTR	Materials Test Reactor
MTU	Metric Ton Uranium
MVDS	Modular Vault Dry Storage
Necsa	South African Nuclear Energy Corporation
NEMA	National Environmental Management Act No.107 of 1998
NNR	National Nuclear Regulator
NRWDI	National Radioactive Waste Disposal Institute
PFMA	Public Finance Management Act No.1 of 1999
PM	Project Manager
PPPFA	Preferential Procurement Policy Framework Act No. 5 of 2000
PWR	Pressurised Water Reactor
SAR	Safety Assessment Report
TAC	Technical Advisory Committee
TISF	Transient Interim Storage Facility
UCMS	Underground Concrete Modular Silos
ZAR	South African Rands

CHAPTER 1: INTRODUCTION

1.1 Background

The National Radioactive Waste Disposal Institute (NRWDI) is tasked with performing a feasibility study for the establishment of a Centralised Interim Storage Facility (CISF) for long-term storage of spent nuclear fuel from the country's nuclear reactors, hereinafter "the CISF project". This project is conducted and managed by NRWDI as part of its mandate provided by the NRWDI Act 53 of 2008 and in terms of the Framework for Infrastructure Delivery and Procurement Management (FIDPM) guidelines and project stages [1].

In 2017, the Minister of Energy (now Mineral Resources and Energy) established a Steering Committee for the CISF project to advise the Minister on the policy oversight and direction for the project in line with the Radioactive Waste Management Policy and Strategy for the Republic of South Africa of 2005, hereinafter "the Policy". The Committee consisted of the parties or entities that are directly affected by the project, namely, Eskom, NRWDI, the South African Nuclear Energy Corporation (Necsa) and the Department of Mineral Resources and Energy (DMRE).

The formation of the CISF Project Steering Committee was a response to the request made to the Minister by both Eskom and NRWDI to initiate the project as a long-term solution to the anticipated shortage of spent fuel storage capacity at Eskom's Koeberg nuclear power plant, hereinafter "Koeberg". The main risk posed by the diminishing storage capacity was identified to be premature shutdown of the plant due to inability to load and unload fuel. In the meantime, Eskom proposed a risk mitigation strategy that included a contingency plan to build a transient interim storage facility (TISF) on the Koeberg site on a modular basis to address the problem in the short term until the CISF has been established and operational.

One of the Committee's tasks, based on its terms and references, was to clarify roles and responsibilities for the CISF project. The Committee established that the project is a functional responsibility of NRWDI in terms of the NRWDI Act 53 of 2008. The Committee developed a report with a set of recommendations on how to proceed with the CISF project, which was submitted to the Minister for consideration. The Minister responded to the Committee's report in May 2019 by granting NRWDI the authorisation to proceed with the CISF project management.

Following the Ministerial authorisation, the Committee tasked NRWDI with developing a CISF project prefeasibility study in line with the FIDPM guidelines and project stages. The prefeasibility study was completed in February 2021 with a recommendation that the project should advance to the feasibility stage, which would include a feasibility study to generate detailed information needed for decision making on the successful implementation of the CISF project [2]. After reviewing and endorsing the prefeasibility study report, the Committee mandated NRWDI to proceed to the feasibility stage and perform the feasibility study.

The role of this feasibility study is to objectively examine the viability of the CISF project proposal as established in the prefeasibility study report, generate detailed information needed to decide on the successful implementation of the CISF project, provide the basis for a long-

term commitment and investment, and support the detailed design of the facility. The feasibility study is a comprehensive document aligned with conclusions from the prefeasibility study.

1.2 Objectives of Study

The objectives of this study are (1) to determine the technical feasibility of establishing (i.e., siting, designing, constructing and operating) the proposed CISF on the Vaalputs national radioactive waste disposal facility site (in Northern Cape Province) and (2) to develop cost and schedule estimates for the CISF establishment.

1.3 Scope of Work

The prefeasibility study proposed an aboveground dry cask-based storage facility as the preferred option for the CISF without providing detailed evaluation of dry storage alternatives. This feasibility study covers the evaluation of dry storage alternatives or concepts for the CISF. The following is the scope of work for the study:

- Evaluate the technical feasibility of establishing each of the dry storage alternatives or concepts for the CISF;
- Perform a comparative evaluation of the safety, environmental and economic issues associated with selected dry storage alternatives;
- Develop cost and schedule estimates for the selected dry storage alternatives; and
- Prepare a written report documenting the results of the above investigations.

1.4 Problem Statement

The problem statement for the CISF project is established in terms of the need or demand analysis from the utility perspective, policy perspective and international obligation.

1.4.1 Utility Perspective

Like all commercial nuclear power plants in the world, when Koeberg was constructed in South Africa, its spent fuel storage pools were originally not designed to store all spent fuel inventory to be generated throughout the operating lifetime of plant. The original design of the at-reactor pools was meant for the spent fuel that is permanently discharged from the reactors to be cooled underwater for at least 10 years and thereafter to be shipped to a spent fuel reprocessing facility for recycling [3], [4]. However, for many utilities in the world the economics of reprocessing soon turned out unfavourable and that resulted in a drive to expand storage capacity at reactors or on site and/or construct independent storage facilities off site.

For Eskom too, the economics of reprocessing and recycling could not be justified for the limited volumes of spent fuel linked to the limited size of the current nuclear power programme in South Africa compared to countries engaged in spent fuel reprocessing, which possess larger economies of scale. Therefore, from the onset of Koeberg's commercial operation in 1984 and 1985, Eskom did not accept reprocessing as an option but has ever since relied on storage of spent fuel in the pools at the reactors and followed a strategy of increasing its storage capacity to be able to store spent fuel generated over the operating lifetime of Koeberg.

The first expansion of storage capacity of the Koeberg spent fuel pools was achieved in 1987 by means of re-racking the pools with high-density racks, which increased the pools' capacity to

store up to 728 pressurised-water reactor (PWR) spent fuel assemblies. This allowed storing of spent fuel for 11 to 16 years of operation with standard fuel, depending on the load factor (and outage duration) [3]. The second storage capacity increase was accomplished between 1999 and 2000 when the pools were re-racked to the limit with ultra-high-density racks. This project would provide Koeberg with interim storage for about 30 to 40 years, depending on the fuel management strategy, load factors and outage duration.

Alongside this last re-racking project was the use of four casks for dry storage and transportation of spent fuel that aided the project by storing a total of 112 PWR spent fuel assemblies. At the end of the project, however, these assemblies were not returned to the re-racked pools and the casks have since been used as an initial step towards interim dry storage of spent fuel on site.

Despite all these interventions to cope with the spent fuel storage demand during the operating life of plant, Koeberg continues to face spent fuel storage capacity challenges. The recent storage challenge is due to a change in the fuel management strategy which accelerated the consumption of the storage space in the pools. The envisaged plant life extension by 20 years (from 2025) may further add to this challenge unless an alternative storage capacity is established. Over the 60-year operating lifetime of Koeberg due to this extension, a total of 5 200 PWR spent fuel assemblies generated from both reactors is projected. Of this total, about 2 000 assemblies will fully occupy the pools, and the balance of 3 200 assemblies would have to be stored dry storage casks either on the Koeberg site or on another site.

To address the immediate storage capacity shortage and, therefore, avoid the risk of premature shutdown of Koeberg, Eskom has planned to expand Koeberg's spent fuel storage capacity by building a TISF on the Koeberg site as a contingency measure until the CISF is built and operational on the Vaalputs site. The construction of the TISF on the Koeberg site was approved by the Minister of Energy in 2011 and has been communicated to the public at the public engagement forums during the TISF environmental impact assessment (EIA) process. Whereas, the CISF project received Ministerial authorisation in 2019. Thus, the linkage of the TISF to the CISF gives the public the assurance that the TISF is not permanent on the Koeberg site and that there are plans underway for storing spent fuel at an independent site. Furthermore, the availability of the CISF at the earliest date possible will limit unnecessary duplication of cost and storage capacity. For this reason, the TISF is designed to be constructed in a modular approach in order to terminate it upon the construction of the CISF.

1.4.2 Policy Perspective

According to the Policy, the storage of spent fuel on the reactor sites is finite and its practice unsustainable in the long term. The Policy, therefore, provides for the Government to ensure that investigations are conducted within set timeframes to consider the various options for safe management of spent fuel in South Africa. Included in the options for investigation is a "long-term aboveground storage on an off-site facility licensed for this purpose", which refers to the proposed CISF, with due caution that "storing above ground indefinitely may result in an undue burden on future generations." [5] As such, the Policy forms a basis for establishing the CISF for continued storage of spent fuel from the country's nuclear reactors.

1.4.3 International Obligation

South Africa is a contracting party to the International Atomic Energy Agency's (IAEA) Joint Convention on the Safety of Spent Nuclear Fuel Management and Safety of Radioactive Waste Management ("the Joint Convention") [6]. The Joint Convention is the first international instrument that deals with the safety of management and storage of spent fuel and radioactive waste in countries with and without nuclear programmes. It commits the signatory nations to report periodically to the IAEA their respective spent fuel and radioactive waste management policies, practices, strategies, facilities, inventories and other related data. The South African national third and fourth review reports of 2014 and 2017, respectively, on the compliance to obligations under the Joint Convention indicate that South Africa will establish a CISF by 2025.

1.5 Spent Fuel Storage Requirements

South Africa's spent nuclear fuel is generated from Eskom's only two 1 840 MWe nuclear power reactors at the Koeberg nuclear power plant and from Necsa's only one research reactor (SAFARI-1) at the Pelindaba nuclear research site.

Each Koeberg unit discharges a third of total spent fuel assemblies (SFAs) from its reactor core on a 16- to 18-month cycle. The discharged SFAs are temporarily stored in the reactor fuel pools for initial temperature cooling and radioactivity decay until they are safe enough to be handled. The storage pools have been re-racked to expand their storage capacity as it was envisaged that they would be full prior to 2000. During re-racking, four dry storage casks were obtained for transferring old SFAs from the wet storage facility and for subsequent use as additional storage capacity. At present, seven additional casks are being stored, together with the earlier four casks, in the cask storage building on the Koeberg site.

At the Pelindaba site, SFAs discharged from the SAFARI-1 reactor first stored in the spent fuel pools and then some of them transferred to the "pipe store", a licensed on-site dry storage facility, for continued storage. The operating license for the current pipe store will expire in 2035, which implies that the Safari SF must be transferred to an off-site licensed facility.

As spent fuel continues to be generated from their reactors, the waste generators, currently being Eskom and Necsa, will require additional storage capacity for continued operation of the reactors. The spent fuel storage facilities at the reactors were intended to serve for a limited period of time (a few years) as a place to keep spent fuel between unloading from the reactor and its subsequent reprocessing or disposal. However, despite the provision for spent fuel reprocessing in the Policy, a policy decision to reprocess has not been made, on the one hand. On the other hand, a national deep geological repository (DGR) for final disposal of spent fuel as an end-point for spent fuel management is still far from being developed in South Africa. Also, while the required additional storage capacity may be established at reactor sites, the Policy deems the continued storage of spent fuel at the sites to be unsustainable and thus provides for the establishment of an aboveground dry storage facility on an external independent site that is licensed for long-term storage of spent fuel as proposed for the CISF [5].

The CISF is required to provide storage for at least about 5 000 SFAs (2 500 MTHM equivalent) from Koeberg reactors (1 800 MWe) and about 1 200 SFAs from Necsa's SAFARI-1 research

reactor (20 MWe), assuming a 60-year operating lifetime of the reactors. Its design should provide for a phased modular construction of the facility, accommodate the use of dry storage technologies (casks, vaults, modules and/or silos) and provide for safe and secure storage of spent fuel for decades until the fuel is either reprocessed or disposed of as radioactive waste in the DGR. The CISF should be designed for an operating life of at least 70 years to allow each spent fuel assembly to be stored for at least 50 years, which is the minimum time required for the cooling of spent fuel before the fuel can be finally disposed of in the DGR.

1.6 Outline of the Study

Following the Introduction chapter, the study focuses on a set of chapters that constitute the Feasibility Study.

Chapter 2 provides a review of centralised interim storage of spent nuclear fuel, covering the storage framework and systems in various countries as well as technological options for centralised storage.

Chapter 3 focuses on site selection for a CISF, looking at the framework for siting (laws and regulations), site alternatives in site selection, Vaalputs site characterisation and justification and environmental impact assessment.

Chapter 4 identifies design alternatives for the CISF and established design criteria, requirements and characteristics; site structure and layout and storage facility and auxiliary structures; and cask operations methods and configurations.

Chapter 5 establishes cost estimates for the CISF based on the identified design alternatives and discusses estimating approach and reference for cost; basis of cost estimates; pre-operation, operation and decommissioning costs; and concludes with cost comparison and analysis.

In Chapter 6, financing and commercial aspects relating to the CISF establishment are considered. The discussion in this chapter covers methods for spent fuel storage financing; financial review of implementing organisation; financial requirements of spent fuel storage project; survey of financing sources; and commercial analysis of storage services.

Chapter 7 focuses on staffing and training requirements, including recruitment and qualification of personnel for the CISF, while Chapter 8 addresses project development and covers the seven FIDPM project stages; project development schedule; and contractual approach.

The last chapter of the study offers conclusions and recommendations as a way forward for the rest of the CISF project.

CHAPTER 2: REVIEW OF DRY STORAGE FACILITIES AND TECHNOLOGIES

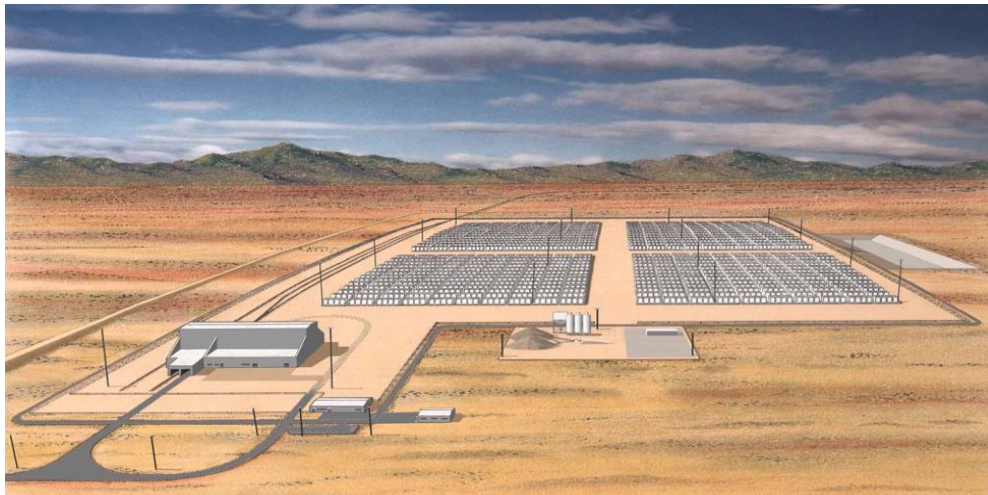
2.1 Centralised Interim Storage

Centralised interim storage of spent fuel at Vaalputs has been proposed as a medium-term solution for addressing issues associated with the accumulation of spent fuel at reactor sites. Under this proposal, spent fuel would be stored in dry storage systems, similar to the way in which dry storage works at nuclear power plants around the world.

Centralised interim storage involves storing spent fuel generated at different reactor sites at a large, central storage facility, independent of an operating nuclear reactor. A centralised interim storage facility (CISF) would resemble a large-scale dry cask storage installation, accompanied by necessary handling facilities and transportation infrastructure. Spent fuel destined for such a site would be loaded at its origin site into a transportation container, transported by rail or truck to the central site, then unloaded and placed in a dry cask or vault for storage.

There are varying degrees to which centralised storage can be applied. A smaller CISF may be used simply as an alternative destination for spent fuel leaving a spent fuel pool. Alternatively, a more extensive facility may be used to consolidate all existing inventories of spent fuel currently stored at reactor sites. A CISF would also need to be licensed as an independent spent fuel storage installation (ISFSI) by the National Nuclear Regulator (NNR), which is responsible for regulating, overseeing and licensing interim storage.

An artist's rendition of a CISF in a dry, desert environment like where the Vaalputs site is located is depicted in Figure 2.1.



Source: [7]

Figure 2.1: An Illustration of a Centralised Interim Storage Facility

Advocates for centralised interim storage cite a number of potential benefits that such a system could offer. These include reduced cost, enhanced security, increased storage flexibility and improved standardisation. Additionally, advocates suggest that a centralised site may prevent

early plant closures, as well as allow for earlier decommissioning of shutdown reactor sites still storing spent fuel. Operating reactors would be able to reduce the volume of spent fuel assemblies that are kept in pools and would no longer need to build dry-storage capacity on site. Opponents of centralising storage dispute these benefits, and point to concerns over transportation and storage risk, environmental impact, and site security. Opponents are also concerned that a centralised interim site may turn into a de-facto permanent site.

A CISF can also be seen as a means to assume responsibility for spent fuel prior to the opening of a permanent repository. This is in the interest of government because it would allow the government to avoid future liability to utilities for the cost of interim storage. Consolidating existing spent fuel inventories can also provide national security advantages and improve public confidence about the status of spent fuel. NRWDI's institutional mandate to take over and manage the storage and disposal of spent fuel would also increase utility confidence by removing the economic and legal uncertainties facing operators regarding continued at-reactor interim storage.

The potential benefits and risks related to a CISF cover almost all the aspects of the project: technical, economic, institutional and socio-political. Accordingly, there are some challenges and implications that must be addressed in analysing the development of the project, in order to evaluate properly the risks and benefits.

2.1.1 Benefits

2.1.1.1 Technical benefits

The techniques implemented to design, construct, operate and decommission a dry storage facility as proposed for the CISF are developed and tested worldwide, and are considered proven technologies. These may also be beneficial to other nuclear facilities in South Africa.

As nuclear power is envisaged to grow in South Africa, the limitation of the number of storage sites due to the existence of the CISF can lower national radiological risks as well as environmental impacts associated with long term storage of spent fuel at various reactors. Furthermore, storage at the CISF can enhance security against sabotage and terrorism by allowing more robust security measures at a central location when compared to several widely dispersed facilities. Also, in the event that certain nuclear power plants encounter difficulties in deploying storage capacity needed to avoid premature plant shutdown, the CISF could allow continued power plant operations.

2.1.1.2 Economic benefits

The establishment of a CISF is expected to bring economic benefits to both the host community and the spent fuel generators. However, a full understanding of economic situation and a reliable estimate of benefits of centralised storage cannot be obtained by either of the parties without also considering the costs associated with a final disposition solution.

The host community, that will bear the burden of storing the spent fuel, is expected to receive economic benefits in terms of receipt of funds from generators and/or profit on the operation of the facility. Important economic benefits to the local community that hosts the facility will be

obtained from employment opportunities, development of local infrastructure and any direct economic incentives that are provided.

The spent fuel generators will not have the burden of development, construction and operation of an expanded at-reactor storage facility. The balance of two options (at-reactor and centralised facility) could be favourable for the generators in terms of unit cost of spent fuel stored. However, it is possible that the driver for the generator to send spent fuel to a CISF may not be lower costs.

The economic benefits of the CISF can also be realised as the CISF allows nuclear power plants to continue operation, when otherwise they would be forced to shut down, and remain a source of revenue for the owner.

2.1.1.3 Socio-political benefits

The existence of the CISF increases transparency of the back end of the fuel cycle and limits the possibility for nuclear proliferation. It may also lead to increased safety and protection from sabotage and terrorism by virtue of international interest in the facility.

Relevant social benefits are foreseeable for the host communities, in terms of infrastructure and economic incentives, where the facility is located. It is possible that specific agreements could be established through negotiations among all parties involved to provide benefits to the host communities in the host region that are unrelated to direct development of the facility. These could include environmental or social programmes.

2.1.2 Risks

2.1.2.1 Technical risks

Technical risks associated with the establishment of the CISF are not unique as they are similar to those of at-reactor storage programmes. However, that the implementation of a CISF is likely to result in increased transportation that will take place over longer distances and through or near regions, municipalities or communities that may not otherwise be impacted.

As the CISF may involve a longer operational period than storage at the reactor site, depending upon the type of storage facility constructed and the length of time that the spent fuel is in storage, there may be a need to repackage the spent fuel during storage or before it is moved. However, this would be true of any storage facility if the storage period were extended.

2.1.2.2 Economic risks

Economic risks are borne by both the CISF operator and the spent fuel generator as the customer.

For the operator, the risk is that, if customers do not send spent fuel to the CISF as planned, the operation of the facility will lose profitability and public support. For the generator, the risk is that advance payments will not result in an operational CISF, thereby increasing the unit cost of further spent fuel handling.

There is an additional risk associated with the withdrawal or bankruptcy of the operating organisation subsequent to the start of operation (i.e., after the CISF has been established and spent fuel is located in the host community). It is also conceivable that costs could change after

the operation is underway, such that the project no longer remains economically viable. This could occur for variety of reasons such as: increased transportation fees from transit municipalities, increased operation costs at the facility, increased costs to purchase storage containers, licensing fee increase, etc.

These risks must be addressed in carefully negotiated binding agreements. Any devaluation of properties in a hosting community can be compensated by economic incentives.

2.1.2.3 Institutional risks

The life period of the CISF could be much longer than the life that many institutions have experienced so far. The time period for which the public must be protected from ionising radiation associated with spent fuel is longer than the existence of any government or institution. However, the progress made in recent decades in the direction of stable international treaties is encouraging and this progress can be considered as a reliable base on which future agreements can be built.

Another area that needs to be carefully considered is data management. It may be a challenge to maintain the required knowledge of spent fuel characteristics and burnup history that will be important to any future spent fuel handling or repackaging.

2.1.2.4 Socio-political risks

Public acceptance is crucially important and could be the weak point in the process of the CISF development. Sufficiently broad acceptance is a necessary condition to the success of the project, although it may not be sufficient. The consideration of public opinion, by means of political organisations, media and public debates, has to be maintained throughout all the phases of the facility life, with the goal of assuring people that the facility can be operated safely.

There could be a possibility after operations have begun that public support is lost as a result of an accident, whether directly associated with the project or not. In this case, it may be necessary for the operator and the generators to negotiate an equitable agreement regarding future operations.

Political continuity has to be considered in developing the CISF. The effectiveness of international treaties and conventions could be compromised by modifications in political relations among partners (operator, generators and third parties) as well as changes in national borders.

The remainder of this chapter reviews the types of dry storage of spent fuel and evaluates dry-storage concepts or alternatives which may be feasible for the CISF. It deliberately excludes the review of wet storage, which has already been eliminated in the prefeasibility stage.

2.2 Dry Storage Technologies/Systems

Dry storage of spent fuel differs from wet storage by making use of gas or air instead of water as the coolant (often an inert gas such as helium, or an only modestly reactive gas such as nitrogen, to limit oxidation of the fuel while in storage) and metal or concrete instead of water as the radiation barrier. Fuel must be stored in pools for several years before it becomes cool

enough for dry storage to be possible. As discussed below, dry storage is both safe and cost-effective: once the fuel has been placed in storage, there are few continuing operational costs or risks.

Reactor operators have a large range of choice of dry storage systems. For those seeking economies of scale in storing large quantities of spent fuel for a prolonged period, vaults and silos are attractive, while for those seeking the flexibility of a modular, piece-by-piece storage system, dry casks are preferred [8].

2.2.1 Dry Storage Vaults

A vault is a fixed, concrete building designed for dry storage of a large number of spent fuel assemblies. The building's exterior structure serves as the radiation barrier and its interior has large numbers of cavities suitable for spent fuel storage units. The fuel is typically stored in sealed metal storage tubes or storage cylinders, which may hold one or several fuel assemblies; these provide containment of the radioactive material in the spent fuel. Heat is removed in vault systems by either forced or natural air convection. In some vault systems, fuel is removed from the transport cask and moved without any container to its storage tube, while in others the fuel stays in the container in which it arrives, which is then placed in a transfer cask and moved by crane to its storage cylinder. Thus, vault systems typically also require cranes or fuel-handling machines.

While the up-front cost of establishing a vault is substantial, the marginal cost of building a larger vault to expand its capacity is small. Given this economy of scale, for storage of very large quantities of spent fuel at a single facility, the cost of vaults tends to be somewhat lower than the cost of other dry storage approaches.

The advantages and disadvantages of dry storage vaults are listed in Table 2.1.

Table 2.1: Advantages and Disadvantages of Dry Storage Vaults

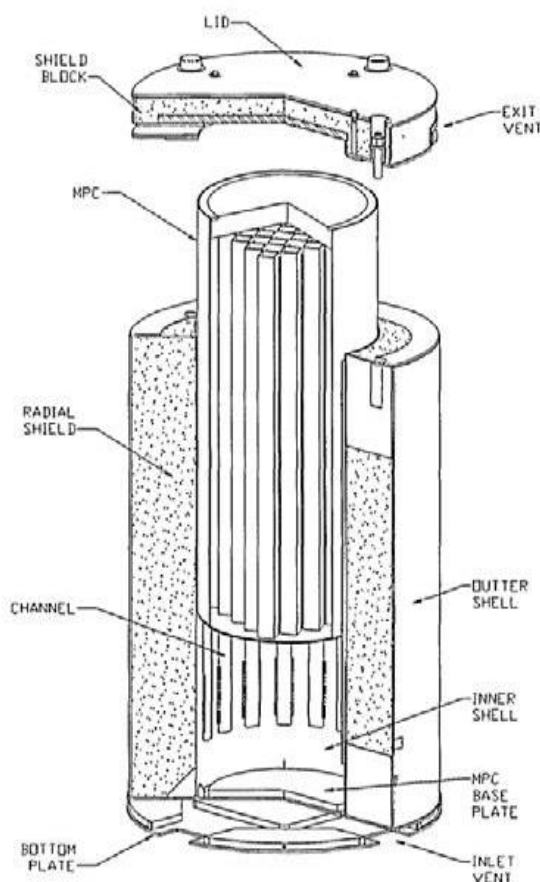
Advantages	Disadvantages
- Fuel cladding temperature is kept lower than in casks; - All equipment integrated in the same building; - Fuel can be withdrawn, if necessary, without return to pool; - Vault storage can be readily modified to accommodate storage of other radioactive materials which would be generated when a nuclear reactor is decommissioned. (This would not be as simple in the case of cask storage.)	- Use of safety related equipment; - Requires more maintenance than casks and concrete modules; - Long licensing period; - Building and almost all equipment must be completely built from the beginning, although expansion is possible; - Cask support is required for fuel loading and unloading; - Decommissioning is complicated; - Initial cost.

Vault storage has been used for over 40 years in the UK to store spent fuel from gas-cooled reactors and subsequently in the US to store spent fuel from water-cooled reactors. Example of this type of storage include the GEC-Alsthom modular vault dry storage (MVDS) system at the former experimental high-temperature gas reactor Fort St. Vrain in Colorado, USA, the Paks MVDS facility in Hungary, the Magnox Dry Storage Facility at the Wylfa reactor in the UK

- Cool the fuel to prevent heat-up to high temperatures from radioactive decay.
- Shield workers and the public from the radiation emitted by radioactive decay in the spent fuel and provide a barrier for any releases of radioactivity.
- Prevent criticality accidents.

The concrete provides the radiation shielding (as the building exterior does in the case of a vault) while the sealed inner metal liner or canister provides containment. Transfer casks are often used for loading of the fuel into the silos. Heat removal is by air convection. Silo and module systems are in use in the United States, Canada, the Republic of Korea, Argentina, and Armenia.

An example of a vertical concrete silo/module is shown in Figure 2.4 and that of a horizontal concrete module in Figure 2.5, within which the canister is placed.



Source: [11]

Figure 2.4: Typical HI-STORM 100 Vertical Storage Module

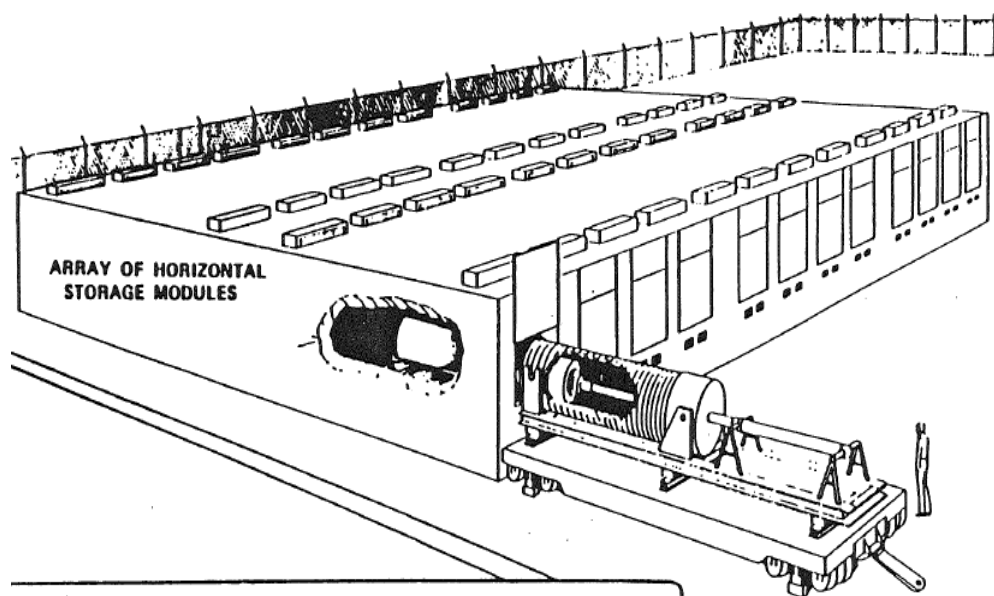
With these systems, all canister loading and storage preparation activities take place inside the plant. A transfer cask is required to take the loaded canister from the plant out to the ISFSI site, as it would be required for spent fuel transfer from Koeberg and Necsa to the proposed CISF. There, the loaded canister is transferred from the cask into a storage module or silo.

Maintenance and surveillance for these systems are similar to that required for metal casks.

The advantages and disadvantages of modular concrete storage are listed in Table 2.2.

Table 2.2: Advantages and Disadvantages of Modular Concrete Storage

Advantages	Disadvantages
• Materials easy to acquire; • Quick and easy fabrication; • Modular system.	• Complicated handling operations: - necessity of loading and intermediate cask; - difficult alignment to introduce canister in storage module. • Decommissioning process more complicated than for casks.



Source: [12]

Figure 2.5: Horizontal Concrete Storage Module

2.2.3 Dry Storage Casks

Dry storage casks are metal and concrete containers serving the same purpose of storing spent fuel as the vaults and silos. The storage of spent fuel in dry storage casks has the same three primary objectives as pool storage:

- Cool the fuel to prevent heat-up to high temperatures from radioactive decay.
- Shield workers and the public from the radiation emitted by radioactive decay in the spent fuel and provide a barrier for any releases of radioactivity.
- Prevent criticality accidents.

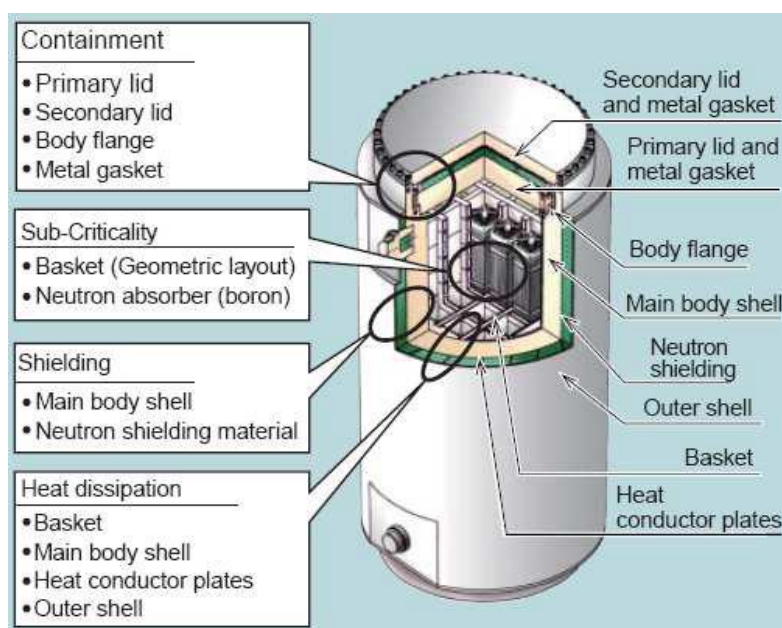
Dry storage casks are designed to achieve the first two of these objectives without the use of water or mechanical systems. Fuel cooling is passive: That is, it relies upon a combination of heat conduction through solid materials and natural convection / thermal radiation through air to move decay heat from the spent fuel into the ambient environment. Radiation shielding is provided by the cask materials: Typically, concrete, lead and steel are used to shield gamma radiation, and polyethylene, concrete and boron-impregnated metals or resins are used to shield neutrons. Criticality is provided by a lattice structure, referred to as a *basket*, which holds

the spent fuel assemblies within individual compartments in the cask. These maintain the fuel in a fixed geometry, and the basket may contain boron-doped metals to absorb neutrons.

2.2.3.1 Metal casks

Metal casks for dry storage of spent fuel are robust metal containers equipped with an internal fuel basket for holding the spent fuel elements. It is the most mature (in place since 1984 in USA) of all methods available for interim dry storage of light-water reactor (LWR) fuels. A further step in the development of metal casks has been the improvement of designs so that the same cask could serve for interim storage and for transport of spent fuel.

Originally, metal casks were designed only for storage (so-called “single-purpose” casks), but more recently, some cask designs have been licensed for both storage and transport (“dual-purpose”). A typical dry storage metal cask is illustrated in Figure 2.6, which indicates the relation between the cask structure and safety functions.



Source: [13]

Figure 2.6: Typical Metal Dry Storage Cask

Dry storage metal casks have been developed by several companies, including Transnuclear (TN) Inc., General Nuclear Systems, Inc. (GNSI), Nuclear Assurance Corporation (NAC) International, and Westinghouse. Metal cask designs offered by these vendors differ with respect to capacity, weight, handling features, and the materials used in fabricating the body and the internal basket which holds the assemblies. However, once a cask is loaded and sitting on a concrete pad there is very little difference between cask types. A metal storage cask would have to be designed to the same NNR criteria and requirements for use at the proposed CISF.

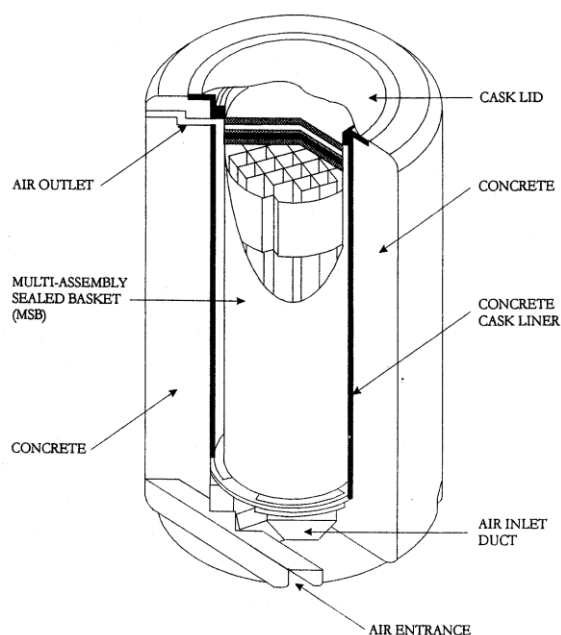
The advantages and disadvantages of dry storage metal casks are listed in Table 2.3.

Table 2.3: Advantages and Disadvantages of Dry Storage Metal Casks

Advantages	Disadvantages
- Highly modular designs – procurement can be adapted to the spent fuel discharges; - Easy operation, maintenance and decommissioning; - Simple control and installations; - Spent nuclear fuel loading in the pool performed by using the same cask that will be stored; - Spent fuel storage and transport carried out in the same cask – no need of further fuel handling for shipment after a storage period (dual-purpose casks); - Public perception; - Flexibility in responding to changes in the national nuclear energy and radioactive waste management policies.	- Cladding temperatures higher than in other systems; - Possibly long period required for licensing process; - Prices.

2.2.3.2 Concrete casks

A concrete cask storage system is similar to the metal storage casks, with the only difference being that the vessel of the cask is made of reinforced concrete lined with steel on the inside where an open or closed basket (canister) is placed. Basically, there are two major components – a metal dry storage canister and a concrete ventilated storage cask (VSC), as illustrated in Figure 2.7. These components perform the same functions as the dry storage canister and horizontal storage module, respectively. A transfer cask which encloses the storage canister is required to load the storage canister with spent fuel, and to transfer the storage canister from the pool to the concrete cask. The transfer cask fits onto the top of the concrete cask, and the storage cask is then loaded into the concrete storage cask.



Source: [8]

Figure 2.7: Ventilated Storage Concrete Cask

Placing a loaded storage canister into a concrete cask occurs inside the plant. The concrete cask is then moved from the plant to the storage site, and placed on a concrete storage pad.

Dry storage concrete casks have been developed by several companies including British Nuclear Fuel Limited (BNFL) Inc., NAC International, and Holtec International. Concrete cask designs offered by these vendors differ with respect to capacity, weight, handling features, and the materials used in fabricating the body and the internal basket which holds the assemblies.

The advantages and disadvantages of dry storage concrete casks are listed in Table 2.4.

Table 2.4: Advantages and Disadvantages of Dry Storage Concrete Casks

Advantages	Disadvantages
• Materials easy to acquire; • Quick and easy fabrication; • Modular system; • Lower prices than for metal casks.	• Direct loading is not possible – necessity of loading an intermediate cask (transfer cask); • Handling operations are more complicated than for metal casks.

2.3 Technical Issues

2.3.1 Fuel Behaviour

Extended storage periods entail potential challenges for the spent fuel integrity during storage, as well as during the subsequent transportation, and define the need for additional technical knowledge on spent fuel long-term behaviour under storage conditions. In addition, whatever the fuel cycle option adopted, the spent fuel will need to be transported after the extended period of storage. There is concern that the potential ageing and degradation processes during storage may change the condition of spent fuel, and can hence have an impact on the capability of the waste package to fulfil the transportation safety functions.

Some of the more relevant issues that may affect fuel integrity during storage are briefly described below [14].

2.3.1.1 Hydrogen effects

As the high-temperature reactor coolant water reacts with the cladding, zirconium based cladding materials undergo outer surface corrosion during in-reactor operation, producing a zirconium oxide layer. A number of factors, notably the alloy composition, influence the rate of oxide layer formation. The hydrogen released during this chemical reaction is partially absorbed by the cladding material (hydrogen pickup). When the concentration of hydrogen exceeds the solubility limit, zirconium hydrides form. Depending on the size, distribution, and orientation, these hydrides can embrittle the cladding and reduce ductility. Furthermore, the presence of hydrides can facilitate propagation of cracks if the hydrides are aligned radially, perpendicular to the tensile stress field.

Although comprehensive experimental and modelling programmes have been performed both with fresh (pre-hydrided) and irradiated cladding, the issue is far from being resolved. The results obtained in limiting conditions of cladding temperature and hoop stress indicate that hydride re-orientation to the radial direction and cladding embrittlement may still be an issue, but when more realistic conditions are examined, it appears that the associated risks may be

less than previously thought. As a result, more research work is necessary to close this knowledge gap.

Hydrides precipitate preferentially near the outer surface of cladding, which is at a lower temperature than the rest of the cladding material. The hydrogen precipitation near the surface can be enhanced if there is a thermal gradient created by oxide spallation. In this case, the spalled area becomes a cold spot in the cladding, enhancing hydrogen migration to that zone and hydride precipitation. In some instances, a hydride blister containing high concentration of hydrides can be created in the outer cladding surface.

These blisters are essentially brittle, and may jeopardise the capability of the cladding to withstand the loads associated to drying, storage and transportation.

2.3.1.2 Fuel drying

Once the cask is loaded and sealed in the spent fuel pool, the cask cavity needs to be drained and dried. Fuel drying is a key process for potential hydrogen induced fuel failures. Cladding hydrides are typically observed to be oriented in the circumferential direction but can reorient to the radial direction, depending on the stress condition of the cladding; when it is cooled from a higher temperature, such as will occur during storage following the drying process. Regulations in some countries (e.g., the US and Japan) limit the peak cladding temperature during the drying process to help reduce the potential for radial hydride formation causing embrittlement and loss of ductility.

In addition, the water remaining in the cask cavity after the drying process may lead to additional cladding oxidation during storage, and hence is also a key factor to avoid fuel degradation in long-term storage. Currently available information on this matter is reduced, and further research is needed to address the issue.

The availability of water in the cask cavity may lead to the generation of hydrogen by radiolysis. The potential for creating an explosive atmosphere inside the cask in the longer term needs to be clarified, and again deserves additional research work.

2.3.1.3 High-burnup fuel

Spent fuel is conventionally considered to be high-burnup fuel (HBF) if the assembly average burnup is higher than 45 GwD/MtU. High-burnup cladding is characterised by a thicker cladding corrosion layer, a dense hydride rim and a radiation-hardened zirconium-alloy matrix. The increased hydrogen contents in high-burnup spent fuel cladding may challenge its integrity.

HBF has also higher decay heat and higher rod internal pressure. Both factors together with higher hydrogen content make the cladding more susceptible to radial hydride formation. These potential differences in the behaviour of low and HBF have been reflected in the applicable regulations.

Furthermore, the fuel cooling over the storage period will promote hydride precipitation under stress, and if the peak temperature during drying and the cladding stress during cooling are high enough, hydride precipitation will occur in the radial direction. If the fuel cladding temperature during storage drops below a certain value, and if the total hydride content is high enough or sufficient radial hydrides have formed, the cladding behaviour will be brittle, and its capability to

withstand the mechanical loads associated to normal operation and postulated accidents after extended storage may be limited.

The limit temperature for which cladding embrittlement may occur due to radial hydrides is usually termed ductile to brittle transition temperature (DBTT), and depends on many factors. Determination of DBTT for the different cladding materials is hence a difficult process that requires an extended research effort. However, an issue of concern in this issue is that only Argonne National Laboratory (in the US) is performing experimental research on this phenomenon, and the knowledge of DBTT behaviour is scarce.

2.3.1.4 Transport implications

The mechanical properties of the irradiated cladding material after a long storage period are degraded by different mechanisms, mostly related to hydrogen effects, what could be particularly worse for HBF. It is important to note that even for brittle material, a large enough load must be applied to reach the failure.

The above-mentioned radial hydrides issue becomes more critical, and accurate determination of DBTT values for the different cladding materials is crucial to address this potential issue. The mechanical loads associated with normal transportation conditions (i.e., vibration and shock impacts); need to be precisely determined through tests and analysis, in order to verify the fuel integrity in those conditions. Research activities have been carried out in the past to determine the real loads on the cladding during normal conditions of transport, and new experimental projects are being launched.

The hypothetical accident conditions (regulatory cask drop accidents) are the most limiting scenarios for irradiated fuel from this perspective. An accurate representation of the spent fuel condition during transport, as well as the development of advanced analysis methodologies to model the dynamic spent fuel assembly and rod behaviour is needed to show compliance with the rod integrity requirements.

2.3.2 Facility Design and Monitoring

As required in the specific country regulations, the long-term interim storage facilities such as the proposed CISF are being designed based on existing industry codes and standards technically sound and widely accepted. However, the extended validity of this body of technical requirements and guidelines over hundreds of years can be questioned. In France, for instance, the validity of the industry codes and standards is considered to be limited to 50 years. As a result, monitoring and surveillance of the facilities and of the stored materials becomes a key issue, in order to assure a continued safe operation of the facility.

Leaving aside the necessary environmental surveillance of the facility during the storage period, the monitoring process should include both the facility and the materials stored. Monitoring of items such as concrete degradation, outer corrosion of storage canisters or casks, and cask seal integrity can readily be performed using standard techniques. However, monitoring of the stored material can only be performed if the stored packages can be accessed (linked to the retrievability safety function) and the means to carry the inspection of the material are available (i.e., adequate hot cell and other equipment). Given these conditions are fulfilled; a monitoring plan can be put in place to periodically retrieve selected packages for inspection of their

contents. The means to unload the storage packages and monitor the contents are not available in many cases.

Also, the process could be costly in terms of radiation doses to the operating personnel, as well as challenging in many different aspects. As a result, items like the status of the fuel matrix and cladding of spent fuel are not monitored in storage facilities. There is a need to develop techniques to monitor evolution of fuel in storage and to qualify fuel for subsequent activities. In order to minimise human intervention and waste generation, non-destructive monitoring methods should be developed.

2.3.3 Ageing of Facilities

Understanding the phenomena involved in ageing processes of the long-term interim storage facility structures, systems and components, as well as those affecting the stored packaged and their contents, is a key factor in long-term interim storage sustainability. Ageing processes are always present, and should be taken into account in the facility design to the extent possible.

Sufficient knowledge of the potential degradation phenomena is needed to reliably predict the behaviour of the long-term interim storage facility in the long term, what is essential in order to define acceptable criteria and safety margins during the storage lifetime. Predictions of ageing effects are also needed to substantiate the safety case presented in the PSR. Continued monitoring of the facility as described in Section 2.3.2 provides the necessary feedback for improvement of the predictions.

CHAPTER 3: SITE SELECTION AND JUSTIFICATION

3.1 Introduction

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

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

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

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

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

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

The SSR is required to address the following topics: description of site and environs, population growth and distribution, land use, adjacent sea usage (if applicable), nearby transportation, civil and industrial facilities, meteorology, oceanography and cooling water supply, impact of natural hazards, impact of external man-made hazards, hydrology, geology and seismology, fresh water supply, site control, emergency services, radioactive effluents, and ecology.

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

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

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

3.2 Laws and Regulations

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

3.2.1 National Nuclear Regulator Act, No 47 of 1999

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

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

3.2.1.1 Purpose and scope of regulations (No.2)

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

3.2.1.2 Lodging of applications (No.3)

- (1) Any person wishing to site a nuclear installation in terms of section 21(1) of the NNR Act must lodge an application for a nuclear installation site license with the Chief Executive Officer of NNR.
- (2) An application must: (a) be supported by a Site Safety Report containing such information as listed in regulation 5, and (b) be accompanied by the prescribed application fee, if any.

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

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

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

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

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

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

- (d) Population demographics;
- (e) Regional development
- (f) Projections of the above data commensurate with the design life of the nuclear installation(s).

3.2.2 National Environmental Management Act No.107 of 1998

The National Environmental Management Act No.107 of 1998 (NEMA), as amended, together with the EIA Regulations, 2014, does not contain any specific provisions regulating the siting of a nuclear installation such as the storage facility for spent nuclear fuel. However, it refers to the need for public participation in environmental matters (such as siting of facilities) by stating that “... the law should establish procedures and institutions to facilitate and promote public participation in environmental governance”. Compliance with this Act is controlled by the DEA, which is responsible for administering the EIAs to be submitted by implementing agencies. The EIA requires public participation (scoping) as part of the overall siting process.

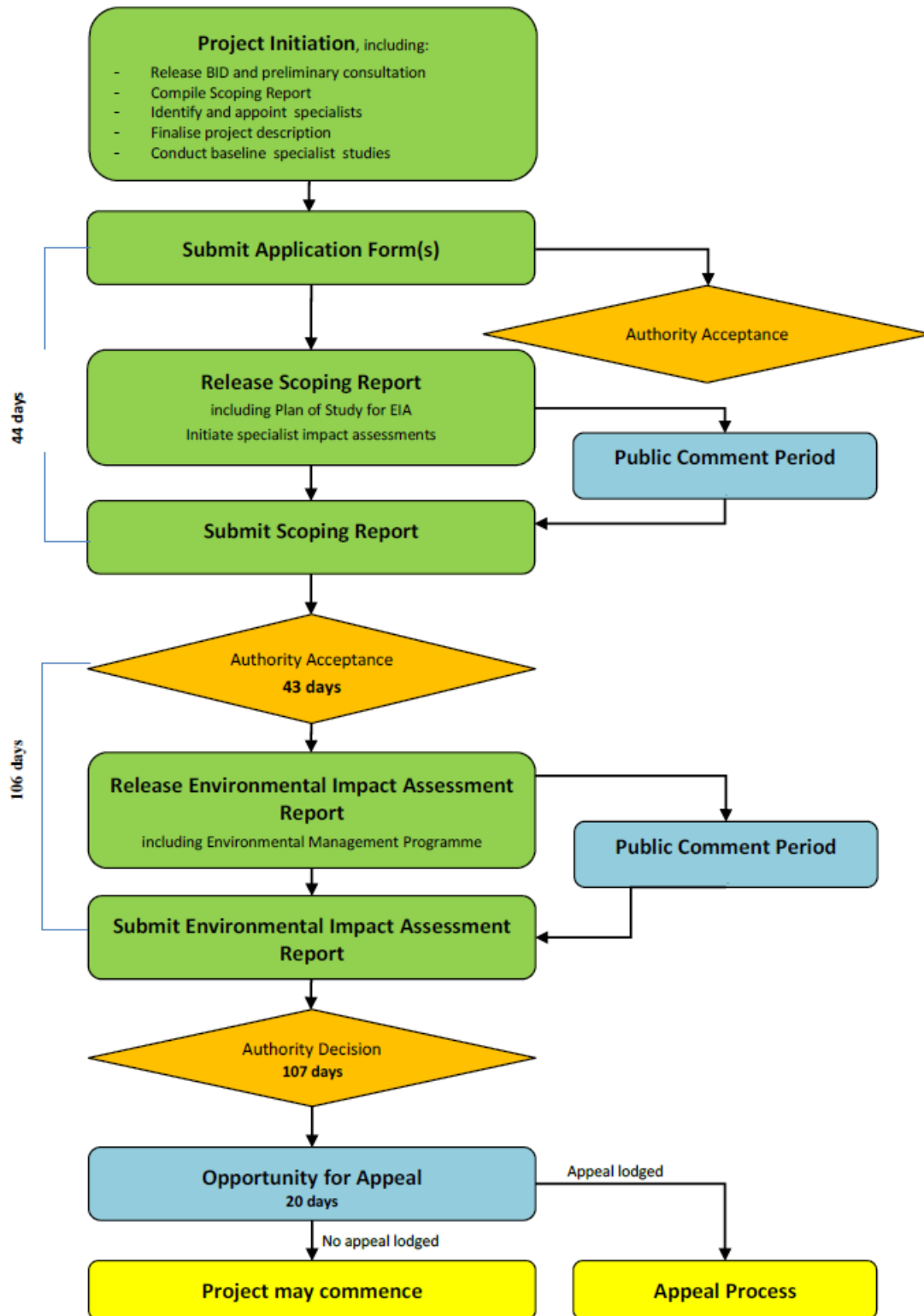
The scope of an EIA process within the framework of the NEMA EIA regulations depends on the extent of the proposed activity and whether the activity is listed in either GN R.544 or GN R.546, which would only require a Basic Assessment Process, or GN R.545, which would require a full EIA process respectively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

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

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

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

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



Source: [17]

Figure 3.1: Scoping and Environmental Impacting Report Process

3.3 Site Alternatives in Site Selection

3.3.1 General Consideration for Alternatives

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

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

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

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

3.3.2 General Site Selection Criteria

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

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

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

The IAEA [21] also emphasises confinement or containment of the fuel as a major selection criterion which refers to the protection against earthquakes, storms, tornadoes etc.

Determination of the site characteristics shall include geological and seismological investigations.

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

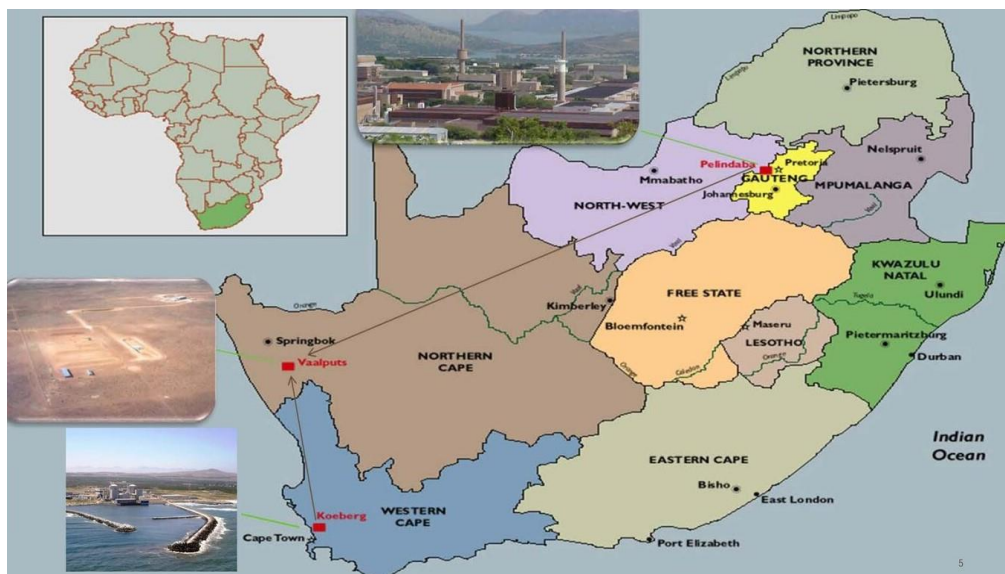
3.3.3 Site Alternatives Considered

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

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

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

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



Source: [22].

Figure 3.2: Locations of Vaalputs, Koeberg and Pelindaba Sites

Based on the available data of the three sites, the selection of the preferred site was made. Table 3.1 summarises the evaluation of the sites. The assessment of the considered sites indicates that the Vaalputs site carries more advantages and less challenges than any other

proposed site. The following section therefore focuses on the characterisation and justification of Vaalputs as the preferred site for the establishment of the proposed CISF.

Table 3.1: Siting Implications for Identified Sites

Site	Site Location/Description	Siting Implications	
		Attractiveness as a host site:	Challenges:
Koeberg (existing)	• Hosts the Koeberg nuclear power plant (KNPP). • Located on a sandy coastline of the West Coast, approximately 27 km north of the Cape Town and 1.5 km north of the residential area of Duynfontein. • The topography of the area is relatively flat with an active dune field extending north of KNPP. • The vegetation of the area consists of low coastal shrub (Cape Dune Strandveld and Atlantis Fynbos) up to 1.5 m high, typical of much of the West Coast.	• only on-site transfer and transport of spent fuel. • wealth of site data that will support both EIA and licensing processes is available. • 10 years for implementation (6 years for approvals; 4 years for construction).	• possible public opposition. • possible refusal of license by regulator
Pelindaba (existing)	• Situated south of the Hartebeespoort Dam and about 27 km west of Pretoria. • Stretches over 2 362 hectares in area. • Houses multiple chemical and nuclear facilities including the material test reactor, SAFARI-1. • Sits in the foothills of the Magaliesberg, one of the oldest ranges in Southern Africa (rocks are of Achaean age, more than 2600 Ma). • The region around the site is mostly rural and agricultural land.	• wealth of site data that will support both EIA and licensing processes is available. • 10 years for implementation (6 years for approvals; 4 years for construction).	• possible resistance from government. • possible public opposition. • distance between site and KNPP for transport of spent fuel.
Vaalputs (existing)	• Located in the Northern Cape Province, 90 km south-east of Springbok and 200 km from the Namibian border. • Situated in the District of Namaqualand on adjoining portions of the farm Vaalputs (portion 1, Geelpan and portion 2, Garing) and Bokseputs (portion 1, Stofkloof) and is about 10 000 ha in extent. • Hosts the national radioactive waste disposal facility. • Forms part of the area of about 2 500 km² which is topographically elevated above the surrounding plateau.	• opportunity for speedy and successful licensing of facility exists. • acceptance by the local population is possible and almost certain. • wealth of site data that will support both EIA and licensing processes is available. • co-location of CISF and DGR is possible. • 10 years for implementation (6 years for approvals; 4 years for construction).	• distance between site and KNPP for transport.
Greenfield (non-existing)	• A new site yet to be searched for. • Can be located anywhere in the country.	• co-location of CISF and DGR is possible. • 14 years for implementation (10 years for siting & approvals; 4 years for construction).	• requirement for new infrastructure and resources. • possible public opposition. • distance between site and KNPP for transport.

3.4 Vaalputs Site Characterisation and Justification

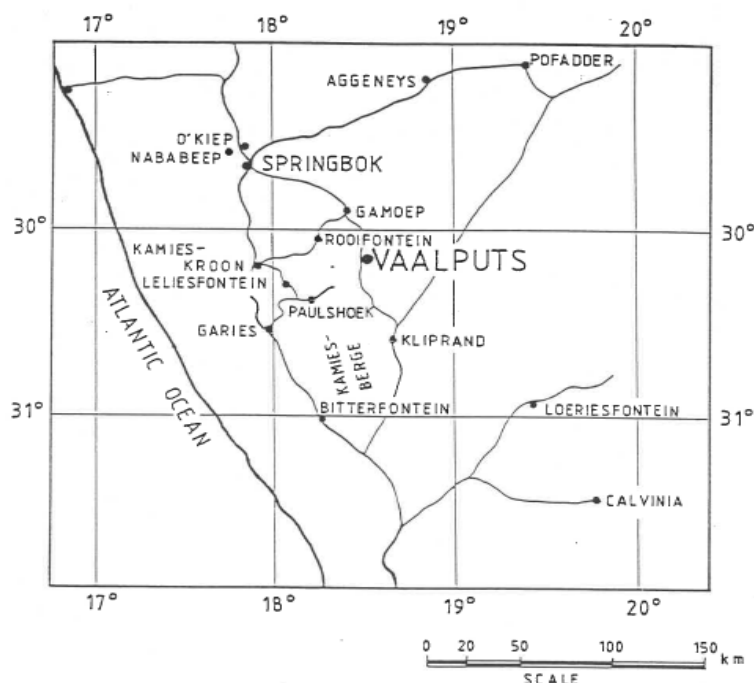
3.4.1 Site Location and Infrastructure

The Vaalputs site is located in the Northern Cape Province, 90 km south-east of Springbok and 200 km from the Namibian border. The site is situated in the District of Namaqualand on adjoining portions of the farm Vaalputs (portion 1, Geelpan and portion 2, Garing) and Bokseputs (portion 1, Stofkloof) and is approximately 10 000 ha in extent. The distances from neighbouring towns and settlements are given in Table 3.2. The locality of Vaalputs in relation to these neighbouring towns and settlements is shown in Figure 3.3, while its locality in Relation to neighbouring farms is shown in Figure 3.4.

Table 3.2: Distances to Vaalputs Neighbouring Points

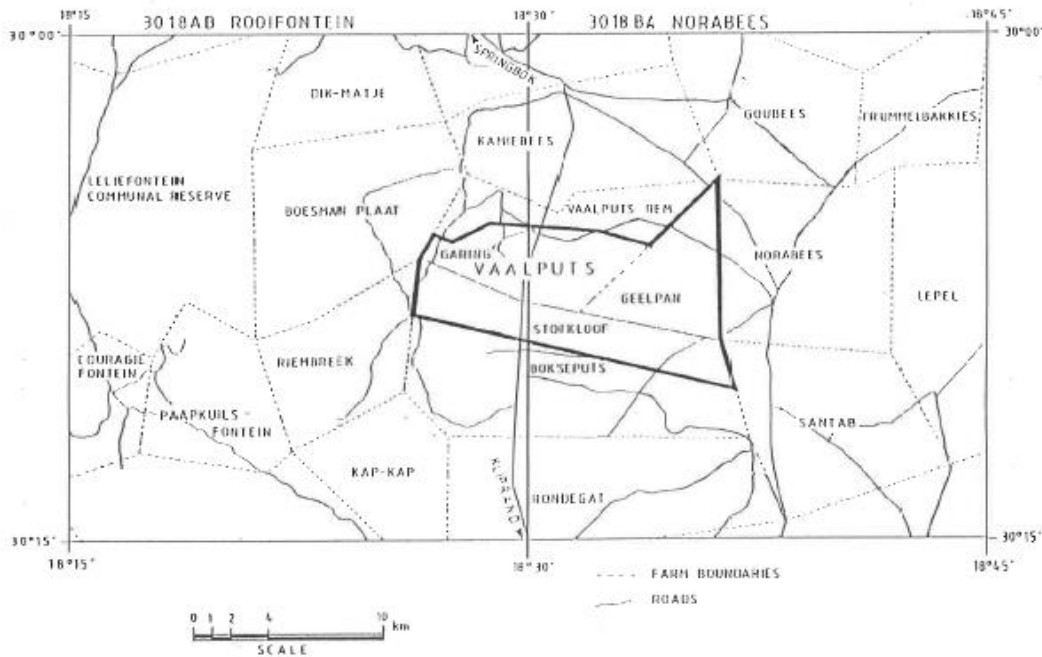
Town	km
Okiep	95
Springbok	90
Nabapeep	100
Kamieskroon	60
Garies	73
Rooifontein	25
Liliefontein	45
Paulshoek	35
Kliprand	55
Bitterfontein	105
Loeriesfontein	130

Source: [23]



Source: [23]

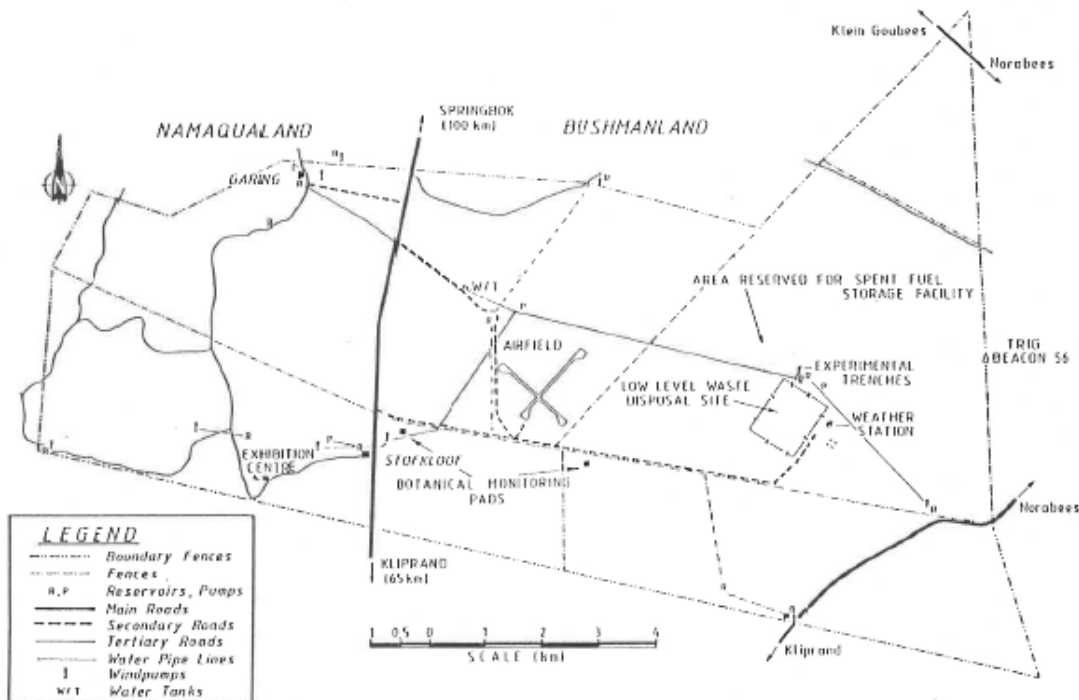
Figure 3.3: Locality of Vaalputs in Relation to Neighbouring Towns and Settlements



Source: [23]

Figure 3.4: Locality of Vaalputs in Relation to Neighbouring Farms

The infrastructure of Vaalputs is given in Figure 3.5.



Source: [23]

Figure 3.5: Infrastructure of Vaalputs

3.4.2 Site Description

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

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

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

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

3.4.3 Population Distribution

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

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

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

3.4.4 Uses of Adjacent Lands and Waters

The major agricultural activity in a 20 km radius around Vaalputs is sheep farming with 66% of the area supporting sheep [23]. A few farmers have goats, cows and chickens mainly for their own use. Although the water is brackish, certain farmers have managed to irrigate crops for their own use. The farms rearing sheep are located to the north, west and south-west of Vaalputs. Sheep are raised for mutton as well as for karakul pelts. Sheep generally graze off the natural vegetation which is supplemented with imported fodder. During the dry season. Farmers move sheep to wetter areas if they have such land available. Some time ago, the dry weather resulted in some farmers deserting their Bushmanland farms altogether.

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

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

3.4.5 Regional Meteorology

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

3.5 Vaalputs Geology

3.5.1 Stratigraphy and Lithology

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

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

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

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

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

Table 3.3: Stratigraphic Relationships of Vaalputs and Environment

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

Source: [23]

3.5.2 Structural Geology

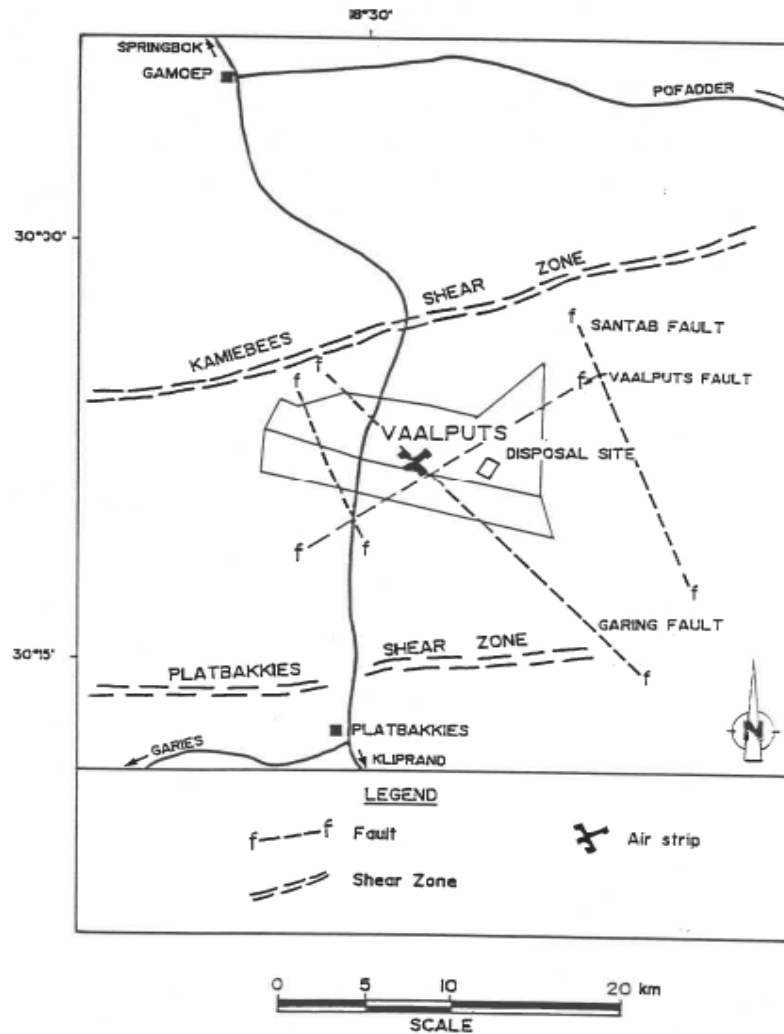
As illustrated in Figure 3.6, the major shear zones occur to the north and south of Vaalputs which are associated with the development of the Namaqualand Metamorphic Complex and subsequent faulting relating to rifting during the Mesozoic (230-65 Ma). The Garing and Vaalputs faults are the closest structural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

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

3.5.3 Neotectonics

In the Vaalputs area, structures of neotectonic origin, namely fractures and faults with slickensides, are extensively preserved in Late Cretaceous residual silcretes, in early Cenozoic alluvial deposits of the Dasdap Formation, and in the more recent siltstones of the Vaalputs

Form [29]. Activity of the faults outlasted however the deposition of the sediments as calcified, wind-blown Kalahari sand dunes appear truncated by NNW-trending faults in satellite images of the area. South of Vaalputs, fractures of Cenozoic age were recorded in the Vanrhynsdorp area. To the north, in Namibia, the NW-SE trending Kuiseb-Hebron fault downfaults by up to 65 m Cenozoic to Quaternary deposits [23].



Source: [23]

Figure 3.6: Major Faults and Shears in the Vaalputs Vicinity

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

3.5.4 Engineering Geology

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

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

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

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

3.6 Vaalputs Seismicity

3.6.1 Seismic History and Relationship to Geological Structure

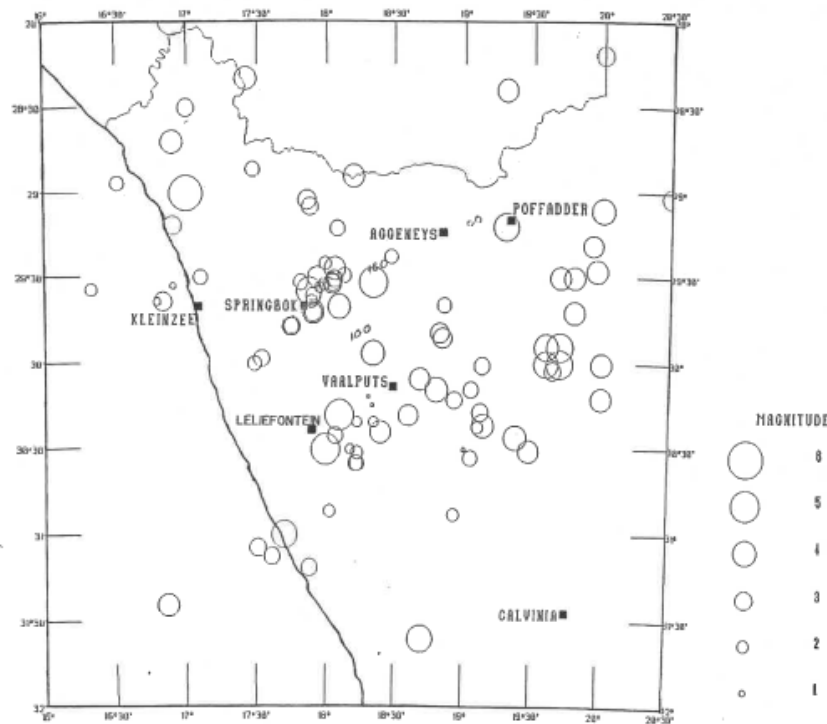
Seismic monitoring started at Vaalputs in mid and late 1989 when seismic recording systems were installed at Vaalputs and Kleinzee respectively. Up to June 1993, the two stations had recorded a total of 55 seismic events [34]. Although the earthquake activity did not appear rather diffused or scattered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

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

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

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

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



Source: [23]

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

3.6.2 Site Seismic Effects

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

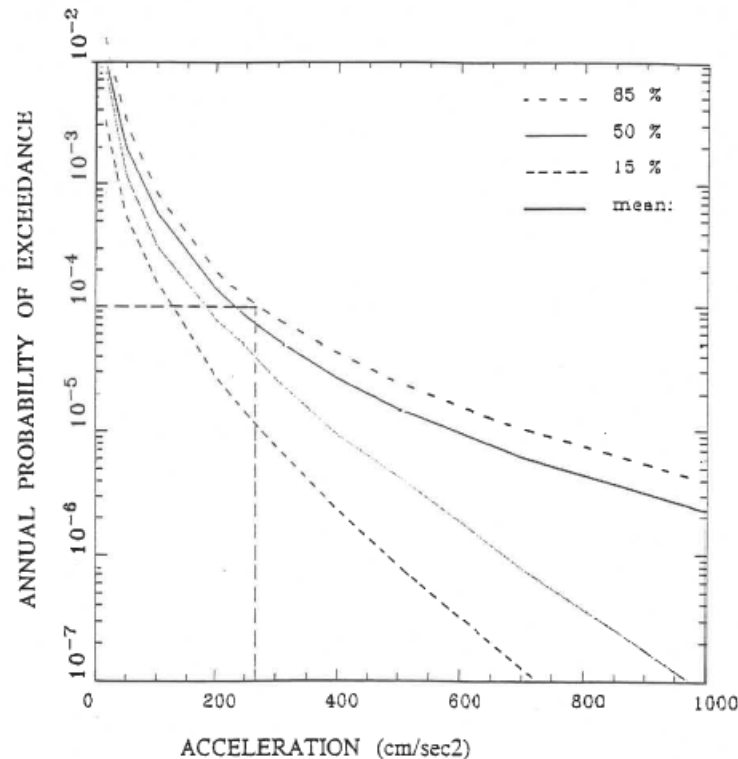
- The regional seismicity;
- The nature of the source mechanism;
- The travel path geology; and
- Local site conditions.

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

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

3.6.3 Influence of Ground Accelerations on Spent Fuel Storage Casks

Ground motion models for the Vaalputs terrain have been calculated for the evaluation of seismic hazard at the Vaalputs site, uncertainty of the seismic hazard and the major contributors to that uncertainty. The results are shown in Figure 3.8 for annual probabilities of exceedance between 10^{-2} and 10^{-7} from which an appropriate and realistic design level should be selected. A general consensus in the nuclear literature indicates that design levels at 10^{-4} annual probabilities of exceedance are both realistic in terms of current design capabilities and appropriate regarding the required safety [37].



Source: [23]

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

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

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

will have a lower centre of gravity than those in the upright position (about 1.4 m above ground level for the horizontal position) and will have the added advantages of the storage cradles keeping it in position.

It is therefore concluded that for the lower design accelerations at Vaalputs (compared to Koeberg) the casks in horizontal position or in upright position will remain intact during the expected maximum pga. Even in the highly unlikely event of the casks being toppled over or being lifted from its storage cradles they could only drop vertically for a distance of 0.7 m. Drop tests done on similar casks than the CASTOR X/28F have in any event indicated that the CASTOR X/28F cask could withstand a vertical drop of about 9 m without losing its containment or shielding integrity [39].

3.7 Vaalputs Geohydrology

3.7.1 Surface Water

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

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

3.7.2 Unsaturated Zone

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

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

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

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

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

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

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

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

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

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

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

Lithology	K _d Value			
	Element			
	U	Cs	Co	Sr
Loose red sand	2.5	485	1528	9.1
Calcretised sand	2.5	589	2295	8.4
Brown sandy gritty clay	6.8	341	1076	7.1
White clay	1.4	220	1524	8.3
Weathered granite	3.0	261	578	5.5

Source: [44]

3.7.3 Saturated Zone

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

3.7.4 Groundwater Monitoring

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

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

3.8 Environmental Impact Assessment

Steffen, Robertson and Kirsten Consulting Engineers were appointed by AEC as independent contractors to undertake the environmental impact assessment (EIA) for a potential spent fuel demonstration storage (demostore) [23]. The development of a demostore for spent fuel on the Vaalputs national radioactive waste disposal site is a relatively small structural development within an area that has already been disturbed for the low- and intermediate-level waste repository. The environmental impact of the demostore was evaluated according to the

Integrated Environmental Management (IEM) approach advocated by the Department of Environmental Affairs. This evaluation was instituted not due to the size of the project, as it will affect a limited area, but due to the hazardous nature of the material to be stored.

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

From this study, it was recommended that:

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

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

3.9 Vaalputs Suitability

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

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

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

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

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

CHAPTER 4: DESIGN ALTERNATIVES FOR A CENTRALISED INTERIM STORAGE FACILITY

4.1 Introduction

Construction of a spent fuel storage facility as for the proposed CISF starts with choice of a conceptual design and site selection and then followed by the preliminary design and presentation of the preliminary safety analysis report (PSAR) for licensing. Construction of the facility and preparation of the final safety analysis report (FSAR) follow the approval of PSAR. Final stage consists of testing and loading of the facility. The choice of the conceptual design mainly lies on the characterisation of spent fuel, review of various options for construction of additional spent fuel storage facility and the evaluation criteria for the suitability of a particular conceptual choice.

This chapter explores a number of generic design alternatives for dry storage of spent fuel that would constitute the proposed CISF. It provides NRWDI with a comparative basis to make decisions on which design alternative or combination of alternatives best address NRWDI's needs, which might depend in part on the site selected for the CISF. This would allow for collaboration with the host site on design options, considering community interests, the specific site characteristics, local infrastructure, and other factors that might impact optimum design.

4.2 Design Specifications, Requirements and Characteristics

A major consideration in the operation of a spent fuel storage facility is to achieve and maintain high standards of safety in terms of protecting operating staff, the environment and members of the public. Therefore, the purpose of the proposed CISF is to provide safe and secure storage of spent nuclear fuel from the country's reactors before it is either reprocessed or disposed of as a radioactive waste. This function will be accomplished with the aid of storage technologies.

Like other engineered systems, the safe operation and maintenance of the CISF will depend in part on adequate design and construction. The most important design features of the CISF will be those which provide the necessary assurances that spent fuel can be received, handled, stored and retrieved without undue risk to health and safety, or to the environment. To achieve these objectives, the design of the CISF will incorporate features to maintain fuel subcritical, to remove spent fuel residual heat, to provide for radiation protection, and to maintain containment over the anticipated facility lifetime as specified in the design specifications.

4.2.1 Design Specifications

The following principal user requirement specifications must guide the proposed solution:

- (1) The CISF must be equipped with a hot cell to provide for the transfer/reception of spent fuel and the possibility of spent fuel repackaging during the storage period;
- (2) The CISF must comply with the following four main requirements:
 - to maintain the sub criticality of the stored radioactive substances,
 - to allow the dispersion of the heat,
 - to keep the radiation rate dose below the regulated limits, and

- to assure the recoverability of the containers;
- (3) The CISF must provide necessary free capacities for removal and storage of the spent fuel assemblies (SFAs) from the reactors during operation and decommissioning;
- (4) The CISF must provide storage for at least about 5 000 SFAs (2 500 MTHM equivalent) from Koeberg reactors (1 800 MWe) and about 1 200 SFAs from Necsa's SAFARI-1 research reactor (20 MWe), assuming a 60-year operating lifetime of the reactors.
- (5) The CISF's design must provide for a phased modular construction of the facility, accommodate the use of dry storage technologies (casks, vaults, modules and/or silos) and provide for safe and secure storage of spent fuel until the fuel is either reprocessed or disposed of as radioactive waste.
- (6) The CISF must be designed for an operating life of at least 70 years to allow each SFA to be stored for at least 50 years, which is the minimum time required for the cooling of spent fuel before the fuel can be finally disposed of in a deep geological repository.
- (7) The CISF must allow future safe retrieval of the SFAs for their transport from the storage facility either to a disposal facility (repository) or to a reprocessing facility.
- (8) The CISF must incorporate a carefully selected storage system;
- (9) The selected storage system (e.g., casks) must be licensed for use and proven in applications to the extent possible;
- (10) The selected system has to be modular in concept – sufficiently modular to meet uncertain storage needs and financial conditions;
- (11) The selected system has to be capable of being designed to meet South African requirements and be constructed in not more than 30 months;
- (12) The selected system components have to be readily constructible in South Africa now or in the near future using available local materials and labour;
- (13) A proposed economic activity for the design, erection, installation, setting-to-work, commissioning, operation and decommissioning of the CISF must include all necessary spent fuel retrieval, packaging and transfer between reactor units and the CISF.

4.2.2 Design Requirements/Criteria

The structural design of the proposed CISF must satisfy the IAEA design requirements associated with the layout of spent fuel handling and storage systems [21]. These are outlined as follows:

- (a) Handling and storage areas for irradiated fuel shall be secured against unauthorised access or unauthorised removal of fuel.
- (b) The area used for storage shall not be part of an access route to other operating areas.
- (c) The transport routes for handling should be as direct and short as practical so as to avoid the need for complex or unnecessary moving and handling operations.
- (d) The layout shall minimise requirements for moving heavy objects above stored fuel and safety systems.
- (e) The layout shall reflect application of the ALARA ('as low as reasonably achievable') principle regarding all fuel handling operations, storage and required personnel access.
- (f) The layout shall provide for decontamination and appropriate maintenance of fuel handling equipment and shipping casks.

- (g) Space shall be provided, if necessary, to permit the inspection of fuel and fuel handling equipment.
- (h) Space shall be provided to allow the required movement of the fuel and storage containers and the transfer of these between different handling equipment.
- (i) Space shall be provided for the safe handling of a shipping cask. This can be achieved by using a separate cask unloading area or by including dedicated space within the facility.
- (j) Space should be provided for the storage and use of the tools and equipment necessary for the repair and testing of storage components. Space for the receipt of other radioactive parts may also be required.
- (k) Appropriate arrangements for containment measures and the safe storage of leaking or damaged fuel shall be provided.
- (l) The layout shall provide easy exit for personnel in an emergency.
- (m) The design shall permit access to all parts of the storage facility requiring periodic inspection and maintenance.
- (n) The design should ensure safe storage conditions following postulated external events, i.e., earthquakes, tornadoes, floods, etc.
- (o) Penetrations shall be designed to prevent the ingress of water (e.g., rain), inorganic solutions, organic materials, etc., which could reduce subcriticality margins, impair heat transfer or increase corrosion and degradation of the storage facilities in ways that might prevent inspection or repair.

4.2.3 Design Characteristics

The proposed CISF should possess the following general design characteristics [21]:

- Technology: Technology sophistication is kept at a minimum, and the only equipment selected is such that has proved to be fully operational for the intended purpose.
- Security: The facility has high physical security against theft of valuable materials and/or equipment through use of protective measures, including surveillances and security guards.
- Robustness: The facility is rugged, easy to operate without extensive training of operating staff, and has a high degree of accessibility.
- Engineering: The facility equipment is easy to maintain, and the interim storage part of the facility is easy to expand.
- Flexibility: Operational use of certain functional capabilities of the facility is likely to be infrequent. This pertains in particular to the handling of leaking fuel assemblies and to the handling of cask consignments that do not fully comply with the provision of the relevant transport regulations (e.g., due to damage in transit). The design incorporates features that provide the possibility of establishing temporary workplaces for these activities rather than permanent installations. This approach also applies to equipment maintenance work.
- Economy: The costs of constructing, operating and expanding the facility are kept as low as reasonably possible.
- Safety: Radiation protection and industrial safety aspects are appropriately considered for both the plant operation staff and for the general public off-site.
- Licensing: A generalised safety analysis report is developed (by NRWDI) to demonstrate compliance with the relevant IAEA Safety Standards and Safety Guides.

4.3 Storage System Design Alternatives

From the preceding chapter, two types of dry storage systems can be deduced for deployment at the proposed CISF: cask-based systems and canister-based systems. The canister-based systems are further broken into vertical configuration and horizontal configuration. Consideration of all these systems suggests that a number of CISF design alternatives or permutations for long-term interim storage of spent fuel is possible and can therefore be explored. In this study, only three major design alternatives are identified and evaluated. These are as follows:

- (1) An aboveground storage of spent fuel in vertical concrete casks and horizontal concrete modules and, for ease of reference, it is denoted by ACCM (Aboveground Concrete Casks and Modules);
- (2) An underground storage of spent fuel in underground vertical cylindrical concrete silos and, for ease of reference, it is denoted by UCMS (Underground Concrete Modular Silos); and
- (3) An enclosed storage of spent fuel in a surface modular vault dry storage system and, for ease of reference, it is denoted by ESMV (Enclosed Surface Modular Vaults).

For each of these design alternatives, the following elements form part of evaluation in order to arrive at a suitable choice of design:

- Identify and include the minimum design criteria for each alternative dry storage system evaluated.
- Identify items that are common, or generic, to all facilities regardless of site location and dry storage system concept.
- Consider and include (as appropriate) the facility design, fabrication, construction, testing, maintenance, and performance requirements for structure, system and components important to safety (e.g., consideration for seismic criteria).
- Develop the total estimated cost and annual operating and maintenance (O&M) costs.
- Develop a concept of operations, including assessments of the time and motion required for transferring the fuel from the transport casks to the storage configurations and the anticipated worker dose for each alternative dry storage system evaluated.
- Identify equipment maintenance requirements.
- Assess the licensability of each alternative storage system evaluated.
- Provide a schedule to the start of operations and staffing requirements.

Much of the analyses performed in this chapter are common or nearly identical for all three design alternatives. This is intentional, since a common baseline of assumptions will enable these analyses to highlight the differences in cost, licensing risk and other critical factors that are specific to each alternative. For example, each alternative will include nearly identical sets of buildings (cask handling building, concrete batch plant, administrative building, etc.). Each alternative will be evaluated with respect to nearly identical concepts for operation (similar staff organisational approach, similar assumptions regarding shift work/overtime, etc.).

4.3.1 Design Alternative 1 – ACCM (Aboveground Concrete Casks and Modules)

4.3.1.1 Description of alternative

Alternative 1 – an ACCM (Aboveground Concrete Casks and Modules) storage system – is an aboveground storage of spent fuel in vertical concrete casks and horizontal concrete modules. The alternative represents the current method of storage at most of the reactor-site independent spent fuel storage installations (ISFSIs) around the world. Dual-purpose casks are stored in a heavily reinforced vertical concrete overpack (large vertical cylindrical cask) or horizontal storage module (a rectangular prism) as shown in Figure 4.1.

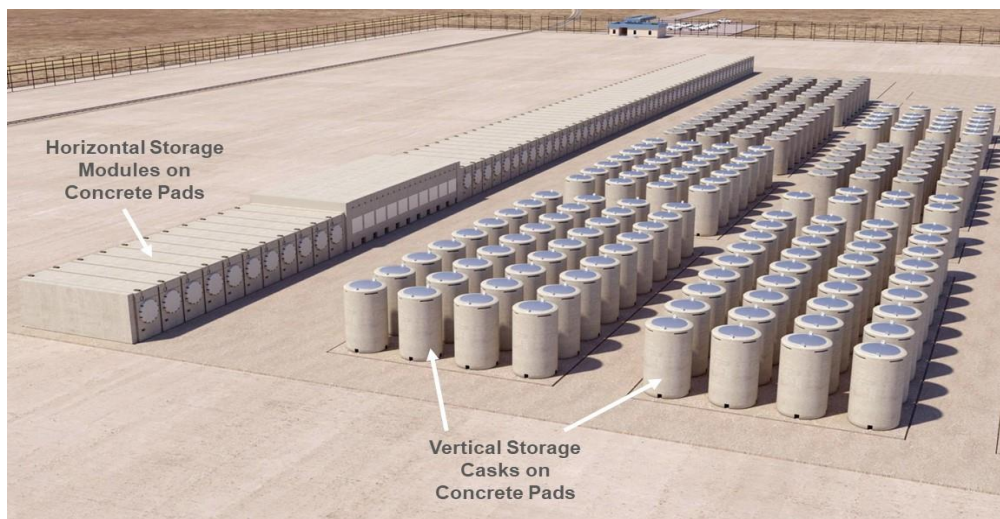
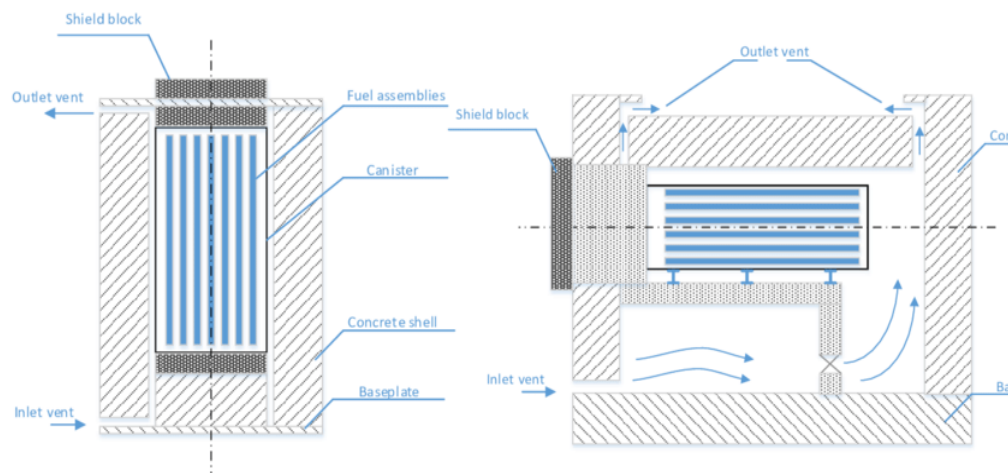


Figure 4.1: Conceptual Storage System Consisting of Concrete Casks and Modules

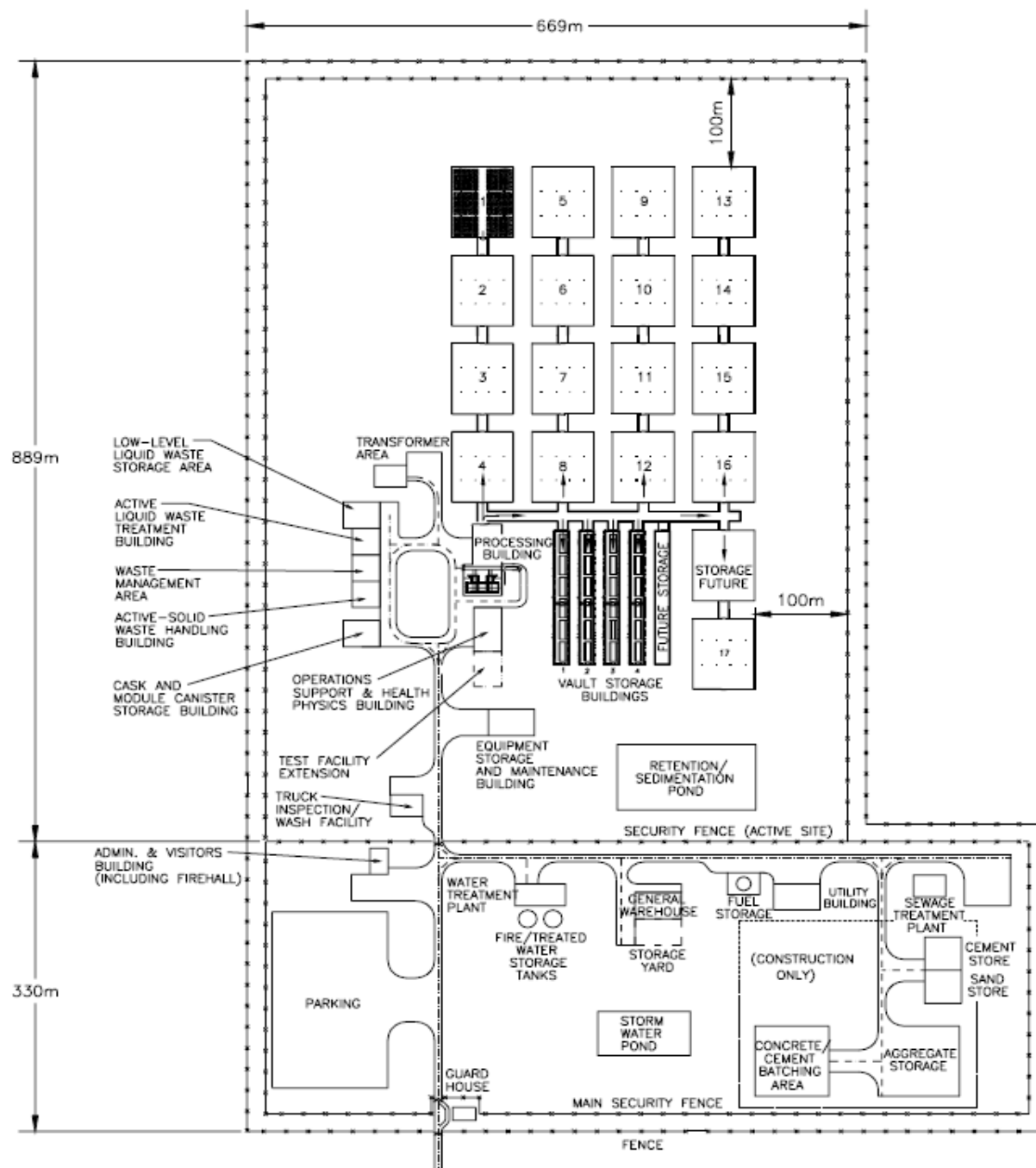
Both of these storage methods use a 45-cm to 90-cm thick reinforced concrete pad to provide a seismically stable platform for the overpacks or modules. The pads are designed to store multiple storage units. The conceptual plan for the proposed CISF is to use pads that can store up to 200 vertical overpacks and/or horizontal modules. Typical vertical and horizontal dry cask storage configurations are shown in Figure 4.2.



Source: [46]

Figure 4.2: Typical Vertical and Horizontal Dry Cask Storage Configurations

A typical site plan layout for the CISF based on the ACCM alternative is shown in Figure 4.3.



Source: [47]

Figure 4.3: Site Plan Layout for the CISF Based on the ACCM Alternative

4.3.1.2 Concept of operations

During the cask/canister handling operations, many supporting activities need to be performed by the CISF staff. The most directly related to the cask handling activities is the vertical storage overpack or horizontal storage overpack fabrication function. This is a full-time activity to

complete the fabrication of overpacks necessary to support cask/canister placement activities. The steel components of the storage systems are fabricated by the original vendor or contractors under the original vendor's control and shipped to the site. After receipt inspection to ensure that the components meet specifications, concrete is added to the steel components in accordance with the vendors' specifications to complete the overpack design. Since VCHM uses the original storage systems, the overpack fabrication crew needs to coordinate closely with the operations manager to ensure that the proper vertical storage overpack or horizontal storage overpacks are prepared far enough in advance of cask/canister placement to permit the concrete to cure properly. As a result, the overpack fabrication crew needs to be operating well ahead of the spent fuel acceptance process with a minimum of 30 days after the arrival of the steel components from the manufacturer until the overpack is ready to accept spent fuel.

The procurement activities necessary to support the overpack production must be well ahead of the delivery of the spent fuel because the lead time for overpack components, delivery and final fabrication is on the order of 24 months. Orders must be placed with the appropriate overpack vendors well ahead of the need in order to ensure that there is time to fabricate and deliver the necessary components. Ideally, the system should support just-in-time delivery of all necessary overpack components so that they can be used directly by the cask handling crews. However, as a practical matter, the system should allow for buffer storage of these components in order to assure that spent fuel shipments are not held up by the lack of availability of overpacks. This means that the supply chain management must identify the correct vendor, the correct model of cask and the schedule for delivery, in order to issue the purchase orders necessary to ensure the flow of material to the site. No shipment of spent fuel should be undertaken unless there is an appropriate overpack available on site.

The procurement activities necessary to support the overpack production must be well ahead of the delivery of the spent fuel because the lead time for overpack components, delivery and final fabrication is on the order of 24 months. Orders must be placed with the appropriate overpack vendors well ahead of the need in order to ensure that there is time to fabricate and deliver the necessary components. Ideally, the system should support just-in-time delivery of all necessary overpack components so that they can be used directly by the cask handling crews. However, as a practical matter, the system should allow for buffer storage of these components in order to assure that spent fuel shipments are not held up by the lack of availability of overpacks. This means that the supply chain management must identify the correct vendor, the correct model of cask and the schedule for delivery, in order to issue the purchase orders necessary to ensure the flow of material to the site. No shipment of spent fuel should be undertaken unless there is an appropriate overpack available on site.

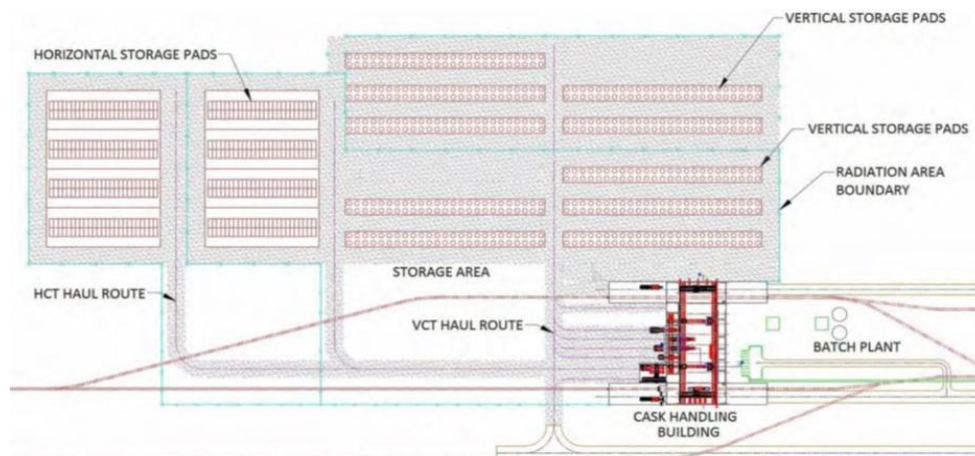
The cask handling operations staff is dedicated to the movement of spent fuel packages around the site. These operations are carried out by dedicated crews who focus on certain areas of the operation. This way, when multiple casks are processed each week, a crew learns specialised skills that will improve efficiency. The crews are: 1) the transport-bay crew, 2) the cask transfer crew and 3) the transporter crew.

The total CISF site organisation staff will consist of 200 workers to achieve the desired CISF throughput during the cask handling phase of the facility's life cycle. The ACCM system throughput with all of the assumptions will be 5 full-sized casks placed into storage each week.

The largest operations challenge for the ACCM storage system alternative is controlling the supply chain to ensure that the proper storage system is available to match the cask being received from the generator. The licensability of the final spent fuel package is based on the conformance of the storage system with the original licensed dry storage system. As described above, the preparation time for a storage system is at least a month after receipt of the hardware from the storage system vendor. The lead time for this shipment could be eighteen to twenty-four months. Therefore, up to two years ahead of the receipt of the spent fuel at the site, the supply chain manager needs to place an order for the necessary storage system components. This means that the CISF staff needs to know well in advance of delivery what vendor and what model of cask system is needed. The coordination of the supply chain for the overpack Fabrication and the spent fuel storage operations will be the largest management challenge for this design alternative.

4.3.1.3 CISF expansion

Each of the alternative storage methods is evaluated to determine if there are any additional pros or cons due to the expanded storage area. For ACCM storage, no additional pros or cons are noted for the expanded CISF. The number of pads and storage units increase proportionally with the number of casks and/or modules. Figure 4.4 shows the layout of the expanded CISF based on the ACCM storage system.



Source: [48]

Figure 4.4: CISF Layout Based on an ACCM Storage System

4.3.1.4 Summary of pros and cons for ACCM storage alternative

Pros

- The ACCM storage alternative is the quickest to implement with minimal effort. All of these storage systems are already designed and licensed either under a general license or a site-specific license for the location currently used. The CISF will use a site-specific license under NNR license regime. A site-specific license requires the initiation of a number of documents

associated with the development of a new site such as a license application, environmental report, safety analysis report (SAR), emergency plan, security plan and technical specifications. Preparation of all these documents plus the NNR review takes time. However, the material from existing storage system existing FSARs could be incorporated by reference into the CISF site-specific license which would greatly streamline the licensing process.

- These systems performance capabilities are well known. There are no unknowns that would need to be studied, designed for, or debated. The US-NRC has even determined that over several years, with proper maintenance, these storage methods are safe.
- The systems can be implemented over time, reducing their initial capital costs. Nuclear power plants generate spent fuel over a 40-to-60-year typical life span. As it is generated, the spent fuel can be shipped to the CISF where concrete storage pads and vertical overpacks or horizontal modules housing the casks/canisters can be installed over several years.

Cons

- Vertical systems require a more extensive cask/canister transfer process that could require a canister transfer facility. This facility is a large structure that increases the cost of the pad storage alternative dramatically. There are methods of canister transfer that can be performed without such a structure but they are more involved with increased manual steps that increases transfer time and personnel radiation dose. The horizontal storage system does not need the canister transfer facility because the transfer takes place at the storage module itself. However, innovated means of transfer on a daily basis will be necessary to reduce dose in the horizontal systems.
- There are 13 different systems that need to be accommodated. Currently, each system has been designed to use its own specific equipment. This could affect lifting yokes, canister transfer adapters, transporters, etc. (some of the transport casks are designed for multiple canisters which could cut down the number of transport casks required). Employing 13 sets of equipment to lift and offload a transport cask, transfer the canister from the transport cask to a storage overpack or module and move the canister by crane or transporter could be burdensome. The creation of equipment that could be used for multiple systems would eventually come to pass to relieve much of the burden but probably not initially.
- Storing multiple systems will also affect the analysis (or increase the number of analyses) of the storage pads which need to consider size, weight, tipping potential, direct radiation, etc. The pad design would likely not change.
- On-site fabrication is affected. Vertical overpacks are too large and heavy for standard shipping so they are manufactured in a vendor's plant in a lighter / smaller configuration so that the concrete can be applied at the site. Horizontal modules are typically manufactured in pieces that are shipped to the site and assembled there. The 13 storage systems require 7 different storage overpack or module designs. On-site fabrication of some sort will need to accommodate all 7 overpack designs.
- Although all of the storage systems are licensed, placing them at a specific location will require some licensing revisions and therefore, prolong the duration required to implement the CISF to some degree. These changes are most likely to result from seismic conditions and ambient temperature extremes. The probability that a system will not meet a specific site

condition is very small but the process to re-analyse the system for the site-specific conditions and the regulator review of those analyses will take time and money.

4.3.2 Design Alternative 2 – UCMS (Underground Concrete Modular Silos)

4.3.2.1 Description of alternative

Alternative 2 – an UCMS (Underground Concrete Modular Silos) storage system – is an underground vertical cylindrical concrete modular silo system of spent fuel storage. The method does away with pad storage altogether and places each cask/canister into an underground concrete silo. Currently there is only one company, Holtec International, that provides an underground storage system. The technology is known as HI-STORM UMAX (Holtec International Storage Module Underground MAXimum Safety) system (Holtec, 2015). It is an underground vertical ventilated module dry storage system engineered to be fully compatible with all presently US-NRC certified canisters. An artist's views of a CISF using an HI-STORM UMAX storage system are shown in Figure 4.5.

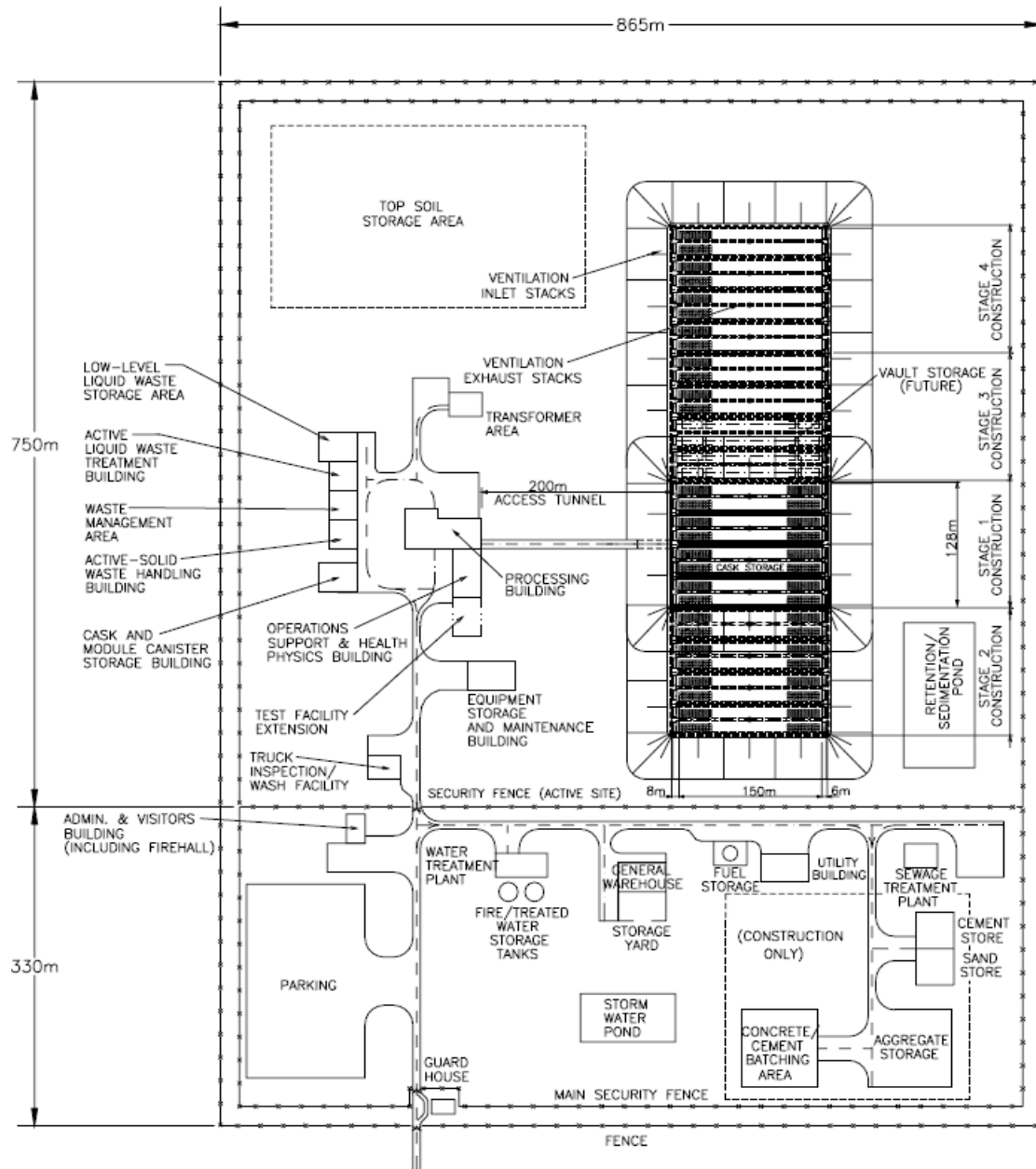


Source: [49]

Figure 4.5: An Artist's Rendering of the HI-STORE Interim Storage Facility

In 2017, Holtec submitted to the US-NRC an application for a license to build and operate a proposed HI-STORE consolidated interim storage facility for spent nuclear fuel and high-level radioactive waste in Lea County, New Mexico. The license application seeks US-NRC approval to store up to 8 680 metric tons of spent fuel for a 40-year license term. The US-NRC plans to complete its safety review of the proposed facility by January 2022. A final licensing decision on the facility will be made in conjunction with the release of the agency's final safety evaluation report [49], [50].

A typical site plan layout for the CISF based on the UCMS alternative is shown in Figure 4.6.



Source: [47]

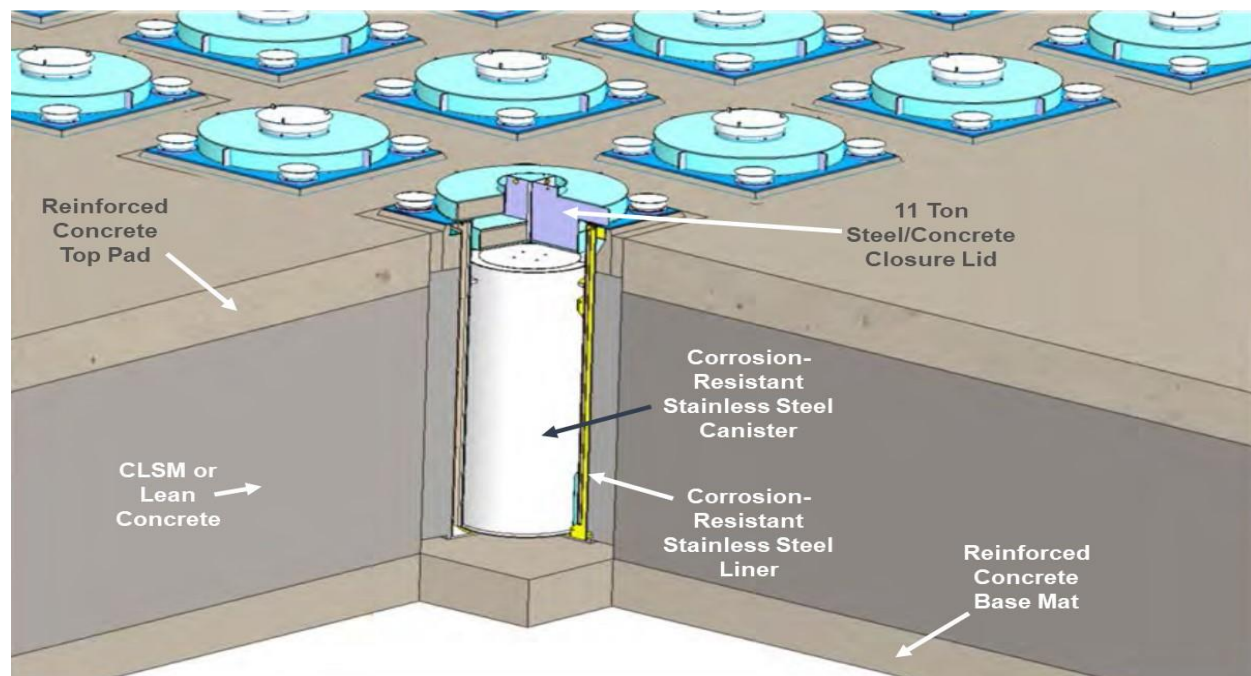
Figure 4.6: Site Plan Layout for the CISF Based on the UCMS Alternative

4.3.2.2 Concept of operations

The UCMS storage alternative is a straightforward application of the Holtec HI-STORM UMAX system for spent fuel storage. This is a new spent fuel storage technology but it has only been proposed for vertical storage canisters.

The HI-STORM system consists of interchangeable sealed metallic canisters which contain the spent fuel; a vertically ventilated storage overpack or underground vertical ventilated module, which contains the canister during storage; and an on-site transfer cask, HI-TRAC, which contains the canister during loading, unloading, and transfer operations. Each module provides

storage of the canister in the vertical configuration inside a cylindrical cavity located entirely below the top-of-grade of the ISFSI. The module, akin to the aboveground overpack, is comprised of the cavity enclosure container, the divider shell and the closure lid, as well as the interfacing structures, as illustrated in Figure 4.7.



Source: [51]

Figure 4.7: Holtec UMAX Storage System

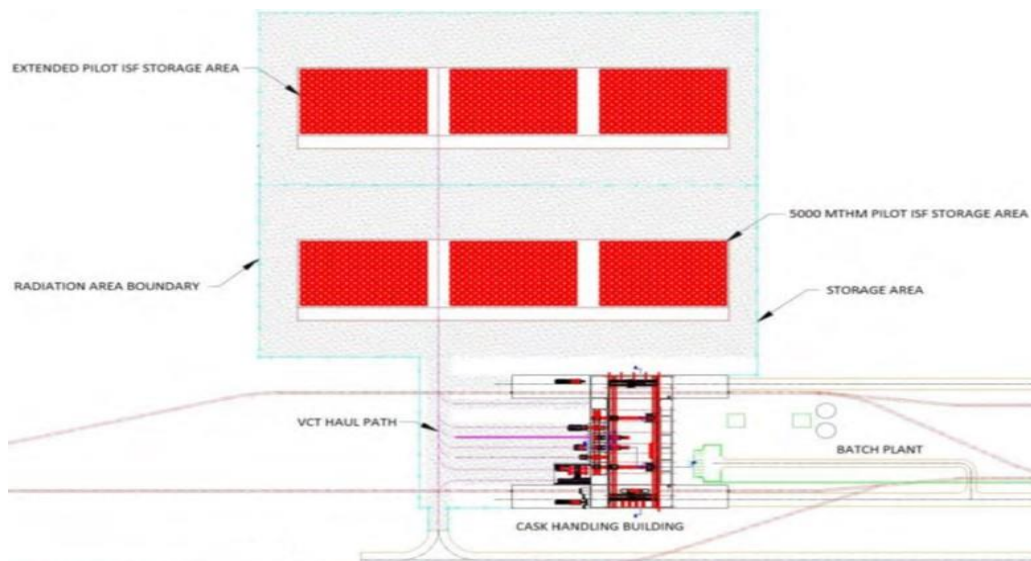
The canister is placed inside the divider shell that is concentric to the cavity enclosure container with air inlets at the bottom. The air inside the divider shell is warmed by the decay heat from the fuel inside the canister and rises and is released from the stack built into the closure lid. Cool air is drawn into the module via cool air inlets at the periphery of the closure lid and introduced into the inside of the divider shell via the penetrations at the bottom of the divider shell. The inlets and exhaust stacks on the closure lid have been designed to be able to function regardless of wind blowing across the storage site.

The UCMS storage alternative could broaden the applicability of this concept to accept both vertical and horizontal canisters. During the cask handling operations, various inserts and adaptors will be provided to enable the legacy canisters to fit properly in the cavity enclosure containers. Also, horizontal cask lifting frames for the legacy horizontal canisters cavity enclosure containers need to be produced in order to place horizontal canisters in the UCMS storage system. The inserts/adaptors/lifting frames will be designed by the legacy canister vendor to meet the design envelope of the UCMS modular silo.

A time and motion study performed by the US Department of Energy in 2014 [48] indicates that the total staffing requirements for the UCMS storage alternative will be a total CISF staff of 185, significantly better than the VCHM alternative. Time and motion studies also verified that the UCMS system throughput with all of the assumptions is 5 full-sized canisters placed into storage each week.

4.3.2.3 CISF expansion

Each of the alternative storage methods is evaluated to determine if there are any additional pros or cons due to the expanded storage area. For UCMS storage, no additional pros or cons are identified. The number of underground storage units increases proportionally with the number of canisters. Since the UMAX concept involves construction of a large number of cells – cavity enclosure containers (CECs) – at a time, the implementation of this concept would consider a phased approach, in which 450 UMAX CECs could be divided into three sections of 150 CECs each to enable faster phased deployment. If needed, the 450 CECs could be divided into six or nine sections to expedite deployment. The expanded CISF is shown in Figure 4.8.



Source: [48]

Figure 4.8: CISF Layout Based on the UCMS Storage System

4.3.2.4 Performance of structures, systems and components

Experience with the Callaway project [48], including the detailed design, licensing and construction effort, has reduced the potential issues with the UCMS storage alternative. As with the concept of operations discussion above, the new issues, primarily related to unanalysed licensing issues, are:

1. The vertical ventilated modules would need to be large enough to accommodate the largest of all of the canisters, requiring inserts/adaptors to ensure the protection of the confinement barrier and heat transfer capability of the original storage system.
2. Transferring horizontal canisters into vertical ventilated modules.

Unlike the manner in which these issues impact the risks with Alternative 1 (ACCM), this alternative benefits from the fact that the basic design has been developed, licensed and constructed. No fundamental problems in designing the spacers which smaller canisters would need for spent fuel placement in the modules are identified. These spacers would be designed by the canister manufacturers according to standard module interface specifications, eliminating any potential issues that canister manufacturers might raise relative to releasing design information to competitors.

Storing horizontal canisters in a vertical position could be somewhat problematic. This issue would require some analysis and licensing effort, but probably less than would be the case for the ACCM storage alternative. This is because of the better seismic and radiological performance of the UCMS design and the elimination of tip-over as an issue. A structural analysis would need to be performed to determine how a horizontal canister responds to an earthquake when stored in a vertical position. Thermal analysis would need to be performed to show adequate heat removal from the canister in the different orientation such that all the spent fuel and canister materials are below design limits.

4.3.2.5 Summary of pros and cons for UCMS storage alternative

Pros

- Removes the possibility of overpack tip over or sliding caused by an earthquake since the canister is locked into position within the ground.
- Greatly reduces direct radiation from the sides of the canister by using the earth as a shield. The distance to the owner-controlled area boundary could be reduced due to the reduction in direct and sky shine radiation.
- Minimises security concerns since the canisters are underground, and are more protected from design basis explosions or unauthorised intrusions. In addition, security staff can observe the entire storage area since the system lids protrude only a few inches above the ground.
- The storage system is visually obscured.
- The UMAX is licensed which will enable the SAR to be referenced into a site-specific license reducing the overall licensing duration.
- Depending on their size and layout, the underground storage blocks could be implemented over time, reducing their initial capital costs. Implementation would not be as flexible as ACCM but could be constructed in smaller blocks to suit the forecasted storage needs.

Cons

- This storage method needs to obtain a single license for systems owned by different vendors. Unlike Alternative 1 (ACCM) however, this is a patented design that does not allow each vendor to develop and license their own storage silo. Therefore, the use of this method may incur proprietary conflicts that will cost time and money to overcome legal issues.
- A canister transfer facility would be required to offload transport casks perform vertical canister transfer from the transport cask to a transfer cask and to re-package the horizontal canisters into a lifting cage. This large facility would increase the cost of the alternative.
- The underground storage system replaces ongoing overpack fabrication activities at the CISF (a good thing) with construction of large sections of the storage area at one time. But unlike pads that can be poured as the CISF grows, the large sections of the underground storage system must be constructed together. The system is designed with a large reinforced base pad, steel silos, soil or low strength concrete around each silo, an upper reinforced concrete pad and the silo lids.
- The underground storage method is also a one-size-fits-all system that would have to accommodate all the different canister sizes. The underground silo would need to be constructed for the largest canister. This would in turn necessitate design and fabrication

provisions for the smaller canisters such as shims or spacers to ensure they would not be battered around during an earthquake or ducting to insure adequate heat removal.

- Horizontal canisters cannot be lifted from the lid and would require some type of lifting cage to lift and place it into a vertical position. This is not a difficult task but it would add steps to the canister transfer process and the lifting cage would accrue additional costs.
- Placing horizontal canisters in a vertical position would require additional analyses. New thermal, structural and shielding analyses would need to be performed to show the horizontal canisters could be placed in the vertical position without adverse effects.

4.3.3 Design Alternative 3 – ESMV (Enclosed Surface Modular Vaults)

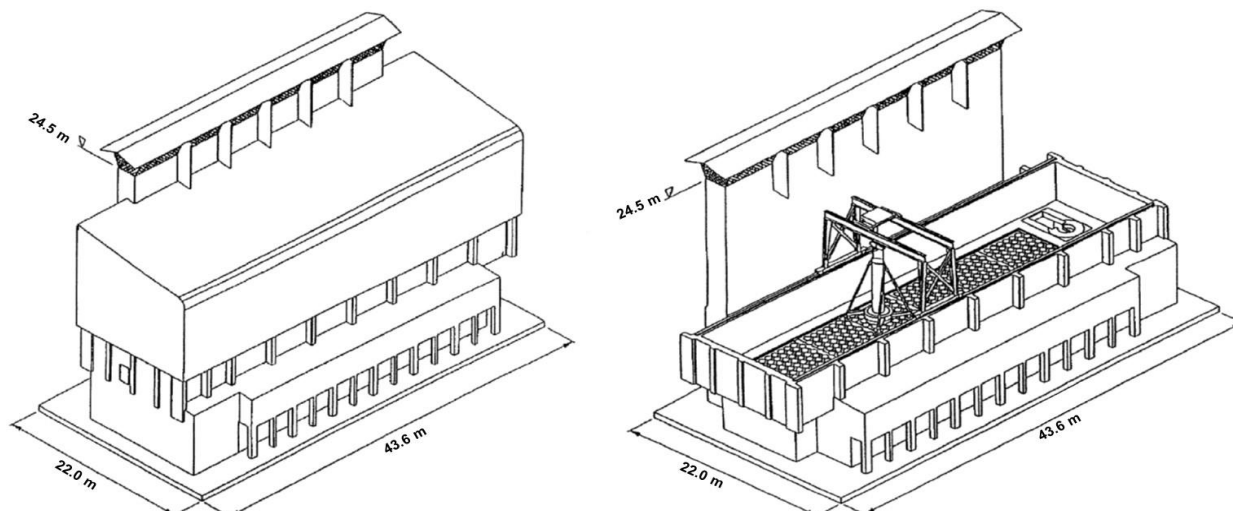
4.3.3.1 Description of storage alternative

Alternative 3 – an ESMV (Enclosed Surface Modular Vaults) storage system – is an enclosed storage of spent fuel in a modular vault dry storage (MVDS) system. The MVDS system is used for the interim storage of the high-temperature gas-cooled reactor (HTGR) fuel at Fort St. Vrain (FSV), which was permanently shut down in August 1989 [48], and is operated as a stand-alone facility on the FSV site. The system is designed to safely hold all types of irradiated fuel for intermediate storage periods. The design provides for the fuel elements, neutron source elements, and reflector elements to be stored in the canisters in an air environment that is compatible with the maximum predicted fuel temperatures and the properties of graphite.

The canisters are tubular, closed at the lower end and sealed at the top. They are vertically located and supported at their lower ends on the floor of the concrete vault module and supported at their upper ends by the charge face structure that also provides shielding for the charge hall. A shield plug is positioned in the charge face structure above each canister to provide shielding. Vertical storage in the vault module matrix is the same orientation for which the fuel was designed to operate in the reactor.

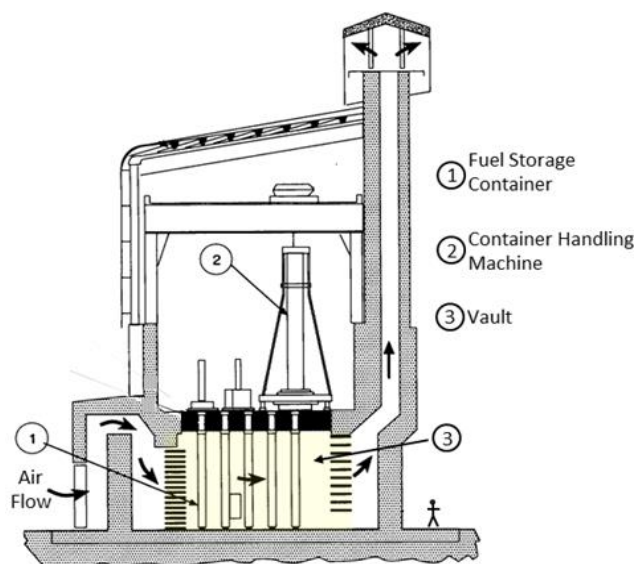
Canisters are positioned in an array of up to 45 to form a module surrounded by massive concrete shielding. The vault module unit is the basis of the modular construction of the MVDS.

In this concept, a large shielded structure is constructed that houses an array of storage locations into which canisters from legacy sites can be placed. It has a large service hall covered by an overhead traveling bridge crane. The floor of this hall is the shield structure covering the air-cooled vault. A shield plug is fitted into the floor over each storage location. Below this shield plug is a seismic restraint system that secures the canister in a way that prevents sliding and tipping in the event of a seismic event. The vault area beneath this shield floor is designed to encourage passive air flow around the canisters. Exhaust stacks on one side of the vault allow the air warmed by the canisters to escape while air inlets on the other side direct cool outside air into the vaults. This natural draft system provides bulk cooling to remove the decay heat from the spent fuel. Figure 4.9 is a schematic representation of the FSV MVDS storage facility, while Figure 4.10 shows major features of the system through a cross-section of one of six storage vaults.



Source: [52]

Figure 4.9: Fort St. Vrain MVDS Storage System (with and without Roof Structure)



Source: [53]

Figure 4.10: Major Features of Fort St. Vrain MVDS Storage System

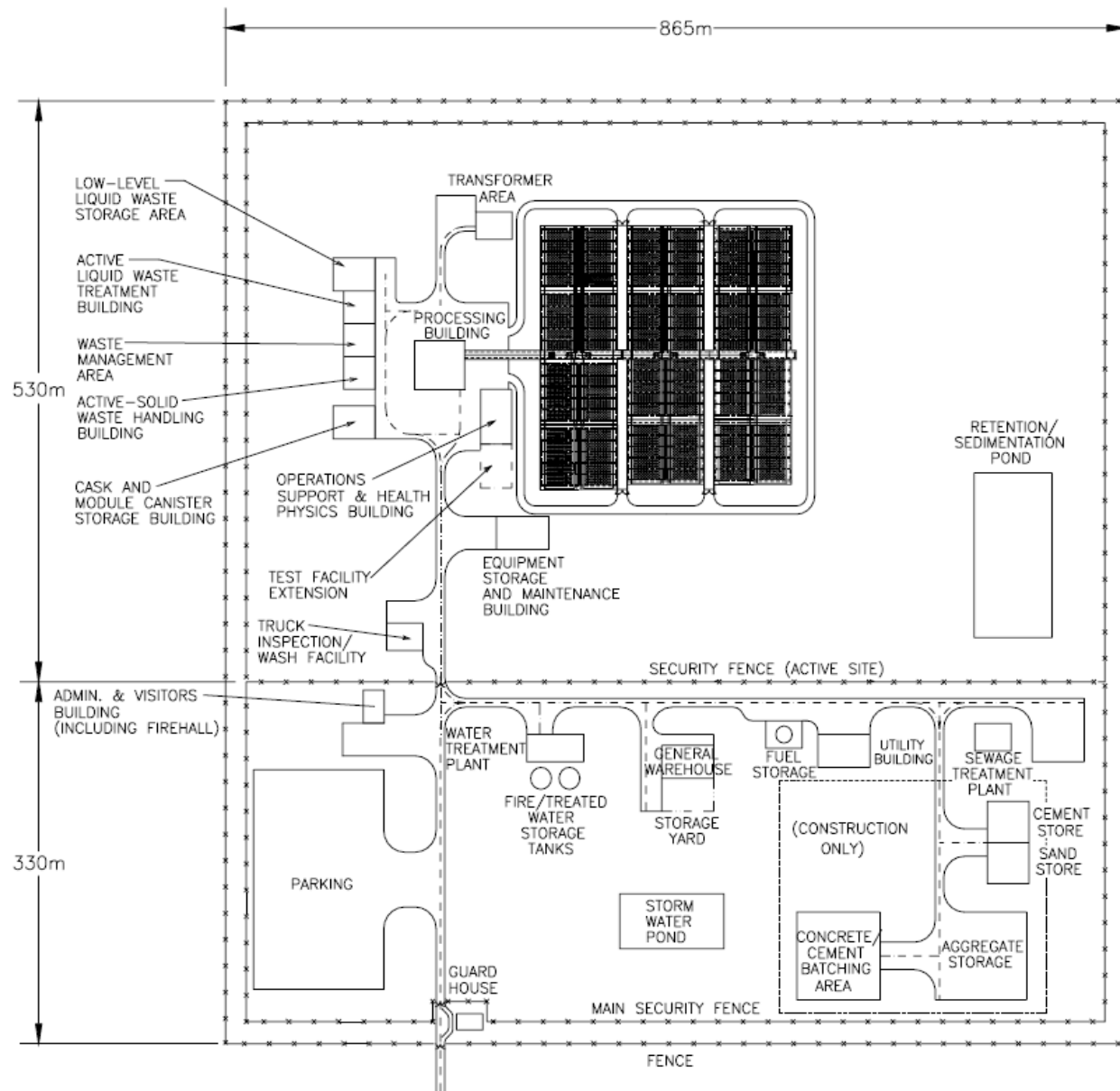
A typical site plan layout for the CISF based on the ESMV alternative is shown in Figure 4.11.

4.3.3.2 Concept of operations

The ESMV storage alternative has four variants with integral or standalone cask/canister handling buildings (CHBs) and with all vertical or vertical and horizontal storage. Figure 4.12 shows the ESMV overall site layout with the standalone CHB variant.

Fuel storage canisters are arranged up to 45 to each of the six vault modules. Each canister can store six fuel elements. There is an air environment in the sealed and loaded canisters. The decay heat is removed by the once-through buoyancy-driven ambient air flowing across the

exterior of the canisters. There is no contact between this cooling air and the fuel being stored. Long-term safety of the storage operation, therefore, is ensured by a totally passive system that is designed to withstand the most severe environmental conditions.



Source: [47]

Figure 411: Site Plan Layout for the CISF Based on the ESMV Alternative

To deal with anticipated potential faults (off-normal events) and to make provision for decommissioning of the ESMV, three storage wells are provided. These storage wells are built into the ESMV structure adjacent to the vault and can be accessed through the charge face by the cask handling machine.

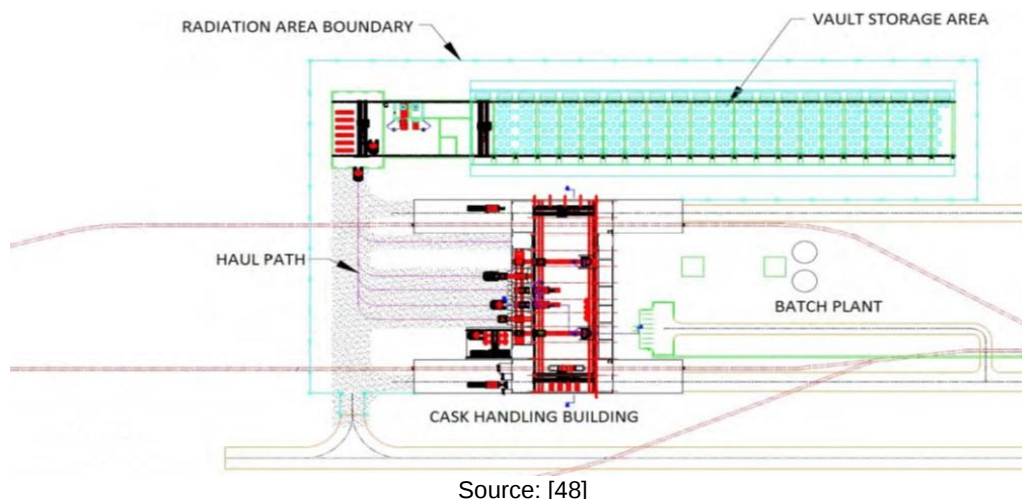


Figure 4.12: CISF Layout Based on the ESMV Storage System

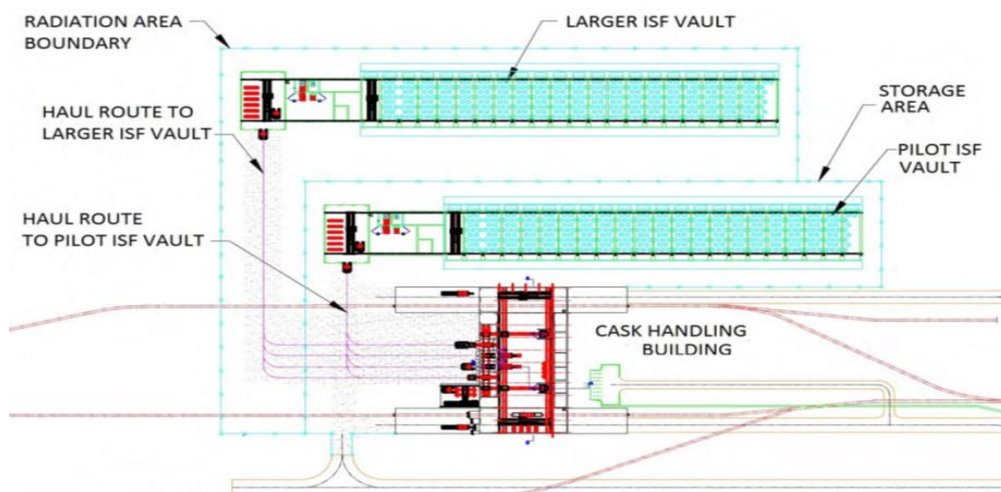
Utility services required at the ISFSI facility are limited to the electrical requirements for the electric radiant space heaters, security system, security facility, administration building, fuel handling equipment during the handling operations, as well as telephone for the security facility and administration building and domestic water requirements for the administration building.

4.3.3.3 CISF expansion

Each of the Alternative storage methods is evaluated to determine if there are any additional pros or cons due to the expanded storage area. For ESMV, additional storage at vaults creates some difficulties. Vaults nearly a 300-m long are not likely to be lengthened in order to provide more storage. Therefore, additional vaults would be required. The initial vault contains the equipment and necessary provisions to offload the transport cask and perform canister transfer operations. A second vault could also incorporate these functions providing the rail line could be added to the second vault. However, this would seem to be more difficult as subsequent vaults are added. Perhaps a better method would be to employ the offload and canister transfer capabilities into the first vault and then use wheeled or tracked transporters to move the canisters from the first vault to the second vault, and so on. This would maximise the use of the equipment and provide cost reductions for additional vaults. Figure 4.13 shows the vault storage layout with a standalone CHB for the expanded CISF.

4.3.3.4 Performance of structures, systems and components

There are significant licensing challenges with Alternative 3. Design and licensing tasks would be extensive and involve significantly more time than the other storage methods. The US-NRC has never licensed a vault system for storing large commercial canisters. The performance characteristics of a vault would need to be licensed as part of the CISF Specific License which would require considerable development in the CISF SAR, costing more regulator review time. This vault storage method would involve obtaining a single license for systems owned by different spent fuel storage system vendors. Therefore, the use of this method could incur proprietary conflicts that could be difficult to resolve, possibly involving legal issues.



Source: [48]

Figure 4.13: Expanded CISF Layout based on ESMV Storage System

Vault storage for large commercial casks/canisters is still conceptual, unlike other storage methods. In order to store 450 canisters, a vault 30 m in width would need to be about 245 m long, increasing the complexity of the structure. The canisters (fuel storage containers) at FSV are much smaller (only 50 cm in diameter), and have a much lower heat release rate than LWR fuel canisters, so FSV experience is not entirely transferable.

The horizontal canisters cannot be lifted by the lid and would require some type of lifting cage to lift and place into a vertical position. The lifting cage for handling horizontal canisters in a vertical orientation would need to be addressed in the licensing documentation (i.e., CISF SAR).

4.3.3.5 Summary of pros and cons for MVDS storage alternative

Pros

- Since the canister storage is effectively indoors, the vault alternative may provide a more controlled environment than other alternatives. The canisters are stored within the building largely away from the effects of weather (although there is some effect since the cooling air is drawn into the building past the canisters. The canisters would likely feel humidity changes during wetter weather and temperature changes between summer and winter).
- All operations such as cask offload, canister transfer from the transport cask to the vault and storage are maintained within the structure with an integral CHB. Once the railcar enters the facility there are no outdoor operations unless a separate CHB concept is used.
- A vault shields canisters from view, easing security concerns. Also, since the canisters are stored within a secured building, they are more protected from design basis explosions or unauthorised intrusions. In addition, security staff can observe the entire storage area since the system is all internal to the MVDS building.
- The vault positions the canisters so that direct radiation from the sides of canisters is shielded by the ground.
- Removes the possibility of canister tip over caused by an earthquake or other postulated accident since the canisters are locked into position within the vault.

- Vaults with integral CHBs have inherently lower throughputs than vaults with standalone CHBs, but accomplish this at a significant reduction in capital and operating costs during the cask handling phase of the project. If the throughput is acceptable based on the ability to deliver canisters to the site, and if expansion of the CISF is not desired, these designs offer a lower cost approach to storing spent fuel in vaults. If, on the other hand, it is determined that expansion of the CISF is appropriate, the follow-on concepts are not forced to follow the same design. In other words, a vault with standalone CHB can be added to the site at a later date to increase throughput or to expand the capacity of the site.

Cons

- Unlike other storage methods, vault storage for large commercial canisters is still conceptual. Canisters stored in existing vaults do not have the increased performance issues such as weight and thermal loading characteristic of commercial canisters. Since the performance capability of a vault is unknown, rigorous analyses will need to be performed to show that the vault could perform as desired.
- A vault is a large nuclear structure impacted by potential seismic, construction, cost overrun issues typically associated with large nuclear projects. In order to store 450 canisters, a vault 30 m in width would need to be about 245 m long increasing the complexity of the structure.
- Design time and licensing would be extensive and involve much more time than the other storage methods. The FSV vault is a site-specific license and cannot be referenced under a General License nor has the US-NRC licensed a vault system for large commercial canisters. The performance characteristics of a vault would need to be licensed as part of the CISF Site-Specific License which would require considerable development in the CISF SAR costing more regulator reviewing time.
- Most canisters in existing dry fuel storage systems are much hotter than the FSV canisters. Heat removal using stack effect in a vault is limited to thermal outputs much less than the licensed limits in existing storage methods. Some newer canisters with hotter spent fuel may not be able to be adequately cooled in a vault which would require longer pool cooling prior to storage.
- Like UCMS, this storage method needs to obtain a single license for systems owned by different vendors. Therefore, the use of this method may incur proprietary conflicts that will cost time and money to overcome legal issues.
- The vault is a one-size-fits-all system that would have to accommodate all the different canister sizes. Each floor opening would likely be the same diameter which would require some means to keep smaller canisters secure. This would necessitate design and fabrication provisions for the smaller canisters such as shims or spacers to ensure they would not be battered around during an earthquake.
- The horizontal canisters cannot be lifted from the lid and would require some type of lifting cage to lift and place into a vertical position. This is not a difficult task but it would add steps to the canister transfer process and the lifting cage would accrue additional costs.
- Placing horizontal canisters in a vertical position would require additional analyses. New thermal, structural and shielding analyses would need to be performed to show the horizontal canisters could be placed in the vertical position without adverse effects.

4.3.4 Schedule

The time to design, license and construct the CISF is significantly impacted by the alternative selected. Licensing is expected to have significant impacts on schedule. Overall project schedules can become protracted when a site-specific ISFSI license is reviewed and subject to the regulator hearings which invite public review and potential contentions. In addition, the schedule is impacted when the regulator is asked to review and approve new technology, or to review design or operational approaches that lack a track record or operating experience. Some options will require extensive design and licensing work. Other, less onerous issues that could cause additional licensing time include storing fuel contained in horizontal canisters in a vertical configuration and storing vertical canisters in a horizontal configuration.

There are a number of approaches that could impact schedule, including considerations outside the scope of this report (e.g., government project rules vs. commercial projects that can start site preparation and early construction activities “at risk” while licensing efforts are in progress).

Figure 4.14 shows a schedule for each storage option and the estimated time frame until CISF operation can begin. It should be noted that time zero cannot start until the site is selected, environmentally investigated, approved and given a ‘Decision to Proceed’ recommendation.

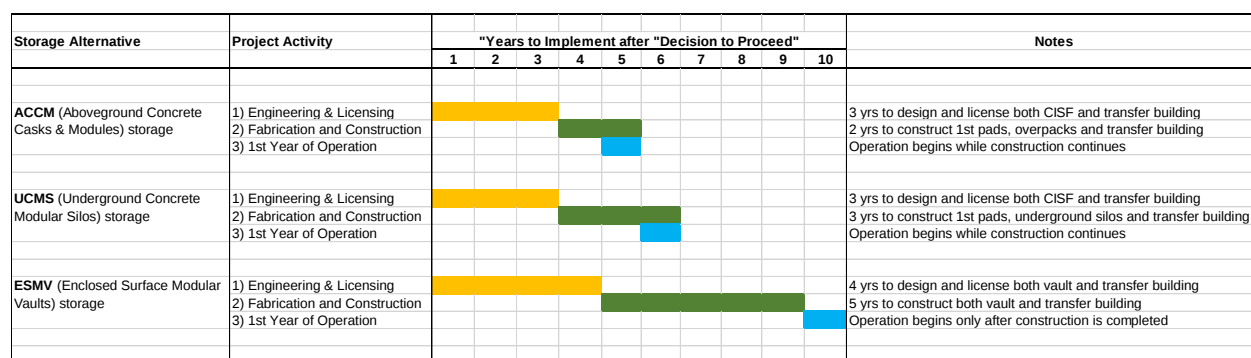


Figure 4.14: Estimated Schedule Duration for the Start of the CISF Operations

4.4 Alternative Comparison and Conclusions

This chapter has covered three generic design alternatives for dry storage of spent fuel that would constitute the proposed CISF and provided a comparative basis for making decisions on which design alternative or combination of alternatives best address NRWDI's needs, which might depend in part on the site selected for the CISF. Significant variations in design approach among the alternatives have been observed and a number of metrics, except cost, which will be addressed in the next chapter, are used to evaluate the alternatives. Central to the conclusions that might be drawn from these metrics are issues that impact schedule as discussed in Section 4.3.4 above. Table 4.1 summarises the pros and cons of each design alternative.

Table 4.1: Summary of Pros and Cons for Design Alternatives

Alternative	Pros	Cons
ACCM (Aboveground Concrete Casks & Modules) storage	• Quickest and easiest to implement – already licensed • Performance capabilities are known • Can be constructed in phases allowing earlier operations	• Multiple overpack designs to fabricate, maintain and monitor • Canister transfer facility may be required for a high throughput operation • Overpacks may need to be bolted to pad to mitigate a hypothetical tip-over at high seismic sites • Some licensing revisions may be required • Equipment is needed to accommodate 13 storage systems • Multiple systems complicate pad analysis
UCMS (Underground Concrete Modular Silos) storage	• No tip over due to an earthquake • Ground provides radiation shielding • Ground shields canisters from view • Already licensed for a limited number of licensed canisters • Reduces security staffing • Can be constructed in phases allowing earlier operations	• Obtaining single storage license difficult with multiple vendor proprietary designs • Canister transfer facility may be required for high throughput operation • Large sections of storage area construction required up front • One size fits all requires design and installation of shims • Horizontal canisters require lifting cage to place in vertical position • Possible horizontal to vertical canister fuel orientation concerns
ESMV (Enclosed Surface Modular Vaults) storage	• Controlled storage environment (indoors) compared to outdoor storage • All operations are maintained within structure • Shields canisters from view easing security concerns • Provides good radiation shielding using the earth • Removes a seismic tip over event since canisters are locked in place • Lower building / crane height	• Storage concept with commercial canisters unproven • Large nuclear structure increases engineering and initial capital costs • Requires long design and licensing time • Thermal performance capability limited to the design of current transport casks • Obtaining single storage license difficult with multiple vendor proprietary designs • One size fits all requires design and installation of shims • Horizontal canisters require lifting cage for vertical position • Entire vault needs to be constructed to be operational

As discussed above, this chapter is focused on generic design alternatives for storing spent fuel at a CISF, with maximum flexibility to accommodate an expanded CISF. Design specifications, requirements and criteria; conceptual plot plans, layouts and drawings; performance of structures, systems and components; schedules; and radiation dose analyses developed in this report provide information that can assist decision makers in selecting options for the CISF.

The cost estimations and analyses for each of the three design alternatives are addressed in the following chapter, and a comprehensive multi-criteria analysis for selecting a preferred alternative is carried out in Chapter 8.

CHAPTER 5: COST ESTIMATION FOR A CENTRALISED INTERIM STORAGE FACILITY

5.1 Introduction

This chapter presents the cost estimates for the centralised interim storage facility (CISF) design alternatives which can accept spent nuclear fuel from the country's nuclear reactors, including the two reactors at the Koeberg nuclear power plant and the SAFARI-1 reactor operating at the Pelindaba site. The estimates are based on the conceptual designs for the three facility alternatives considered in the previous chapter.

The three alternatives are:

- (4) An aboveground storage of spent fuel in vertical concrete casks and horizontal concrete modules, i.e., ACCM (Aboveground Concrete Casks and Modules);
- (5) An underground storage of spent fuel in underground vertical cylindrical concrete silos, i.e., UCMS (Underground Concrete Modular Silos); and
- (6) An enclosed storage of spent fuel in a surface modular vault dry storage system, i.e., ESMV (Enclosed Surface Modular Vaults).

The cost estimates include the cost of siting, design, construction, operation and decommissioning of the CISF. The cost estimates are for a stand-alone and self-sufficient storage facility, with a capacity to store 7 000 spent fuel assemblies (SFAs). The cost estimate excludes the cost of spent fuel retrieval from the spent fuel owners' storage locations, preparation of the spent fuel for transport and transportation of the spent fuel to the CISF location. These costs are the responsibility of the spent fuel owners or generators. The cost estimates assume a 70-year period of operation of the facility and include the replacement or refurbishment of the storage complexes and the repackaging of the SFAs into replacement fuel containers when they have reached their end of operating life within this period.

5.2 Work Breakdown Structure

This section provides a high-level description of the work that would be carried out in a work programme, irrespective of the CISF alternative selected. The following section describes the work scope of each work element at Level 2 of a typical Work Breakdown Structure (WBS). All the work elements at the lowest level of the WBS and the costs associated with each work element will also be addressed. There are nine Level 2 work elements, which cover all the aspects of a programme to site, develop and operate a CISF. A generic WBS with the work elements at Level 2 of the programme WBS is shown in Figure 5.1.

5.2.1 100-10 Siting

Siting includes all activities related to planning and implementing of a siting programme for the CISF. Planning activities include development of a siting strategy, development of a siting process, development of siting criteria and public consultation. Implementation activities include site screening, environmental studies and site investigation at candidate sites and at the preferred site. It should be noted here that, as indicated in Chapter 3 of this study, that siting will

be performed within the boundaries of the Vaalputs site. Several candidate areas will be identified and investigated, and a preferred area for CISF installation will be selected.

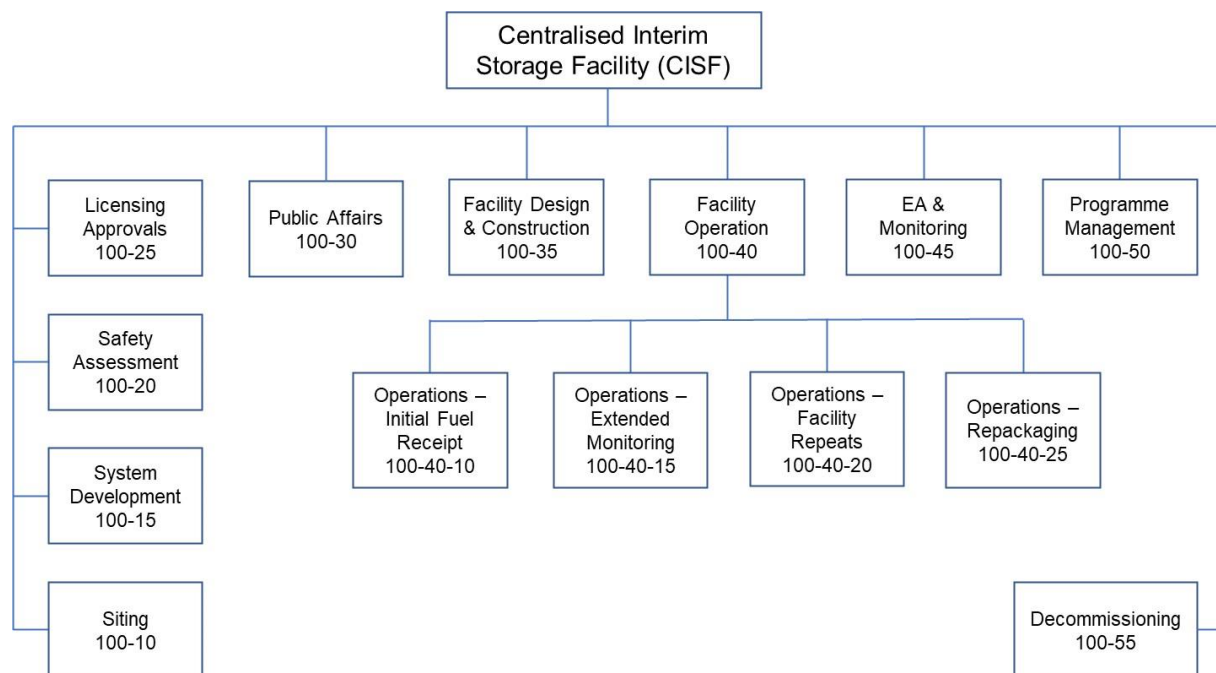


Figure 5.1: Level 2 Work Breakdown Structure and Coding for CISF Cost Estimate

5.2.2 100-15 System Development

System development includes all activities related to the optimisation of the conceptual design, and the development of the preliminary designs of the CISF. The work activities include the preparation of drawings, descriptions, lists of materials, work force requirements, equipment requirements and associated calculations, and the output of these activities will get progressively more detailed as the facility design evolves. It provides design information necessary to support environmental assessments and site licence applications.

Specifically, system development includes (where appropriate):

- Container system development work;
- Preparation of geo-technical design and specifications;
- Preparation of site-dependant designs during the siting process;
- System applications including assessment of constructability, development and demonstrations of systems;
- Development of performance specifications;
- Security and safeguards.

System development excludes final design for the CISF. It also excludes engineering support during the construction and operation phases of the facility.

5.2.3 100-20 Safety Assessment

Safety Assessment includes all activities related to predicting the safety of CISF and its potential impact. Safety assessments would be carried out through all phases of the

development and operation of the CISF. Safety assessments would have to be completed in support of licence applications.

5.2.4 100-25 Licensing and Approvals

Licensing and Approvals includes interactions with all provincial and national regulators, preparation and submission of licence applications for siting, construction and operation.

5.2.5 100-30 Public Affairs

Public Affairs work includes the development of a public affairs strategy to support the development and implementation of the public affairs strategy. The public affairs programme is implemented through all phases of development and operation of the facility. A public affairs programme provides information to key-decision makers, stakeholders, potential host communities, media and the general public.

The scope of the public affairs programme would include the following:

- Public involvement programme
- Volunteer/host community programme
- Impact management programme
- Community information programme
- Socio-economic impact assessment programme
- Government relations programme
- Interest group programme
- Employee programme

5.2.6 100-35 Facility Design and Construction

Facility Design and Construction includes all activities that are required to prepare the detailed final design drawings of the CISF. The scope of work includes the provision of facilities necessary to receive and store SFAs, but excludes the on-going construction of storage capacity constructed during facility operations.

5.2.7 100-40 Facility Operation

Facility Operations comprises four activities:

- 100-40-10 Operations – Initial Fuel Receipt
- 100-40-15 Operations – Extended Monitoring
- 100-40-20 Operations – Facility Repeats
- 100-40-25 Operations – Repackaging

Initial fuel receipt covers the activities necessary to receive, condition and store fuel at the CISF.

Extended monitoring covers the long-term management of the stored fuel inventory.

Facility repeats covers the refurbishment or renewal of the storage complex facilities, which periodically reach the end of their service lives. SFAs will be transferred from one storage structure to another, and the time-served storage structure demolished (or refurbished) and replacement structures constructed, within the overall 'footprint' of storage complex.

Repackaging covers the periodic removal of SFAs from existing storage containers which have reached the end of their service life. Spent fuel containers are transferred from the storage complex to a repackaging facility, where SFAs are transferred from an existing storage container to another.

5.2.8 100-45 Environmental Assessment and Monitoring

This includes the preparation of environmental assessment (EA) documents to support application for a construction license and updates to the EA documents in advance of major refurbishment and repackaging events. Work includes compilation of data, preparation of documents, document printing and attendance at a hearing.

Environmental monitoring provides the tools and processes for monitoring the environmental performance of the CISF. The monitoring programme would be directed by the CISF's environmental management system (EMS) and the EMS would ensure that the implementing organisation's environmental policy is managed, implemented, checked and periodically reviewed within the overall context of continual improvement. It would provide both the process, and assurance, to ensure that the policy is improving the environmental performance of the facility, while also demonstrating management's due diligence with respect to managing the environmental impacts.

For the purpose of the CISF cost estimate, it shall be assumed that the EMS is based on ISO 14001. ISO 14001 describes a system based on continual improvement in the following five key areas: environmental policy; planning; implementation and operation; checking and corrective actions; and management review.

The EMS would require monitoring and continually improving environmental performance. The EMS would encompass all environmental aspects of the CISF including monitoring of radiological and non-radiological emissions to: air; surface water and groundwater; soil; flora and fauna; and produce.

The programme would also include on-going monitoring of human health of the population in the vicinity of the CISF.

It is assumed that the implementing organisation's staff will manage and co-ordinate the overall EMS programme. However, a specialised consultant will prepare the EMS plan. Specialised consultants will also carry out the collection, analyses and reporting of all data.

The scope of environmental monitoring is restricted to monitoring the potential environmental impacts due to the day-to-day operations of the CISF. The scope of this work element excludes monitoring of the storage container and storage structure performance (included in 100-40).

5.2.9 100-50 Programme Management

Programme Management includes senior-level staff direction to the programme as well as project management, financial and business support for the programme. Programme management will be provided by NRWDI as the implementation organisation. Corporate overheads, insurance costs, human resource services throughout the programme are also included. Project management for the facility design and construction will be provided through the Architect Engineer.

5.2.10 100-55 Decommissioning

As the final step in its lifecycle, the decommissioning of the CISF is considered for cost estimation. Decommissioning involves activities from shutdown and removal of nuclear material to the environmental restoration of the site. It includes activities such as planning, physical and radiological characterisation, facility and site decontamination, dismantling, and materials management. Decommissioning is a normal part of a nuclear facility's lifetime and needs to be considered at the earliest stages of its development. The whole process is complex and typically takes 20 to 30 years to complete.

5.3 Schedule Estimates

5.3.1 Overview

The cost estimates for the three CISF alternatives are phased in accordance with the generic schedule developed for the alternatives as shown in Figure 5.2, which is applicable to each facility alternative. For the purposes of comparison, the schedule is developed over 70 years. This represents the cumulative time for the establishment of the site, the receipt of fuel and the timeframe for the extended storage and monitoring of the longest-lived fuel containers employed by the alternative. Given the lesser service lives of some fuel container types, the schedule identifies time periods when repackaging events (for storage casks) are scheduled, within the extended monitoring timeframe.

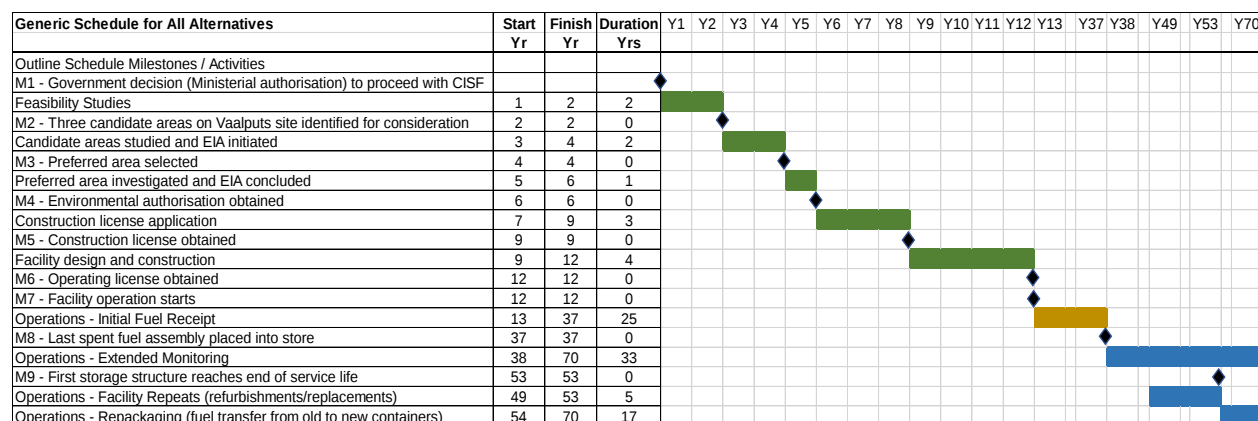


Figure 5.2: Generic Schedule for CISF Alternatives

5.3.1.1 ACCM alternative

For the ACCM alternative, the schedule would include intermediate facility repeat and repackaging events, when storage canisters will be removed from time-served storage structures (casks or modules). Fuel in module format will be transferred from old to new storage module canisters and in turn the canisters will be transferred to new modules. Similarly, fuel in cask format will be transferred from old to new casks. The operating lifetime of these storage systems is assumed to be 40 years and replacements should occur soon thereafter.

5.3.1.2 UCMS alternative

For the ACMS alternative, the schedule would include intermediate facility repeat and repackaging events, when module canisters will be removed from time-served modular silos. Fuel will be transferred from old to new module canisters. Similarly, module canisters will be transferred from old to new modular silos. The operating lifetime of these storage systems is assumed to be 40 years and replacements should occur soon thereafter.

5.3.1.3 ESMV alternative

For the ESMV alternative, the schedule would include intermediate facility repeat and repackaging events, when canisters will be removed from time-served vaults. Fuel will be transferred from old to new vault canisters. Similarly, canisters will be transferred from old to new vaults. The operating lifetime of these storage systems is assumed to be 40 years and replacements should occur soon thereafter.

5.3.2 Siting Phase

The Siting Phase covers the time period in which a suitable location for a CISF is being sought. The Siting Phase begins after a formal decision is made to begin the process of finding a suitable site and would end when regulatory approval is received to construct the facility (i.e., assumed to be Y1 to Y9). Activities carried out in the Siting Phase include development of a siting process and site screening criteria, site screening, site evaluations (surface-based and underground-based), preparation of safety assessment and environmental impact assessment (EIA) documents, participation in public hearings and preparation of licence applications.

The approach involves the use of “desk-top” technical feasibility studies during the early stages of siting Y1 to Y2. Then surface-based characterisation work, including subsurface exploration by borehole drilling, is carried out on three candidate sites or areas on the Vaalputs site Y3 to Y4 and a preferred candidate site is selected Y4. It is assumed that the preferred candidate site will be acceptable for storage and there are no significant delays.

The EA and construction licensing approvals process is assumed to proceed without any significant delays from Y5 to Y8 and that a construction licence will be granted at the start of Y9.

5.3.3 Construction Phase

The Construction Phase is the period (Y9 to Y12) in the life cycle of the CISF when the functional surface and underground facilities (if required by the alternative under consideration), and infrastructure are created for the purpose of spent fuel storage. This phase begins with the receipt of regulatory approval to begin construction and ends when the “cold” and “hot” commissioning of the facilities are completed prior to receiving the first formal shipment of spent fuel for storage operations. Note that construction, as an activity, will continue during the subsequent Operations Phase of the facility. Construction includes clearing of land, surface and/or underground excavation, construction of processing building and ancillary facilities, and construction of the first stage of the storage complex.

5.3.4 Operation Phase

The Operation Phase is when the spent fuel is placed into the CISF and the facility is monitored in perpetuity. Initial fuel receipts are assumed to occur over the 25-year period, Y13 to Y37. Following spent fuel receipts, the facility enters into an indefinite period of extended monitoring until all spent fuel is either reprocessed or disposed of in a DGR. Activities during this period include routine monitoring of fuel, and intermittent periods of increased activity, when fuel storage facilities will be replaced or refurbished, and fuel storage containers are repackaged.

5.3.4.1 Operations - initial fuel receipt

The initial fuel receipt is the period (Y13 to Y37) in the life cycle of the CISF when fuel is received onto the CISF site, and conveyed to the storage complex. Fuel will arrive in existing storage casks, or be conveyed in transportation casks containing modules or baskets. Depending on the CISF alternative under consideration, some fuel will require conversion in a processing building into a format appropriate for long-term storage. During the initial fuel receipt phase, additional fuel storage capacity will be constructed, expanding the storage complex capacity in a staged manner.

5.3.4.2 Operations – extended monitoring

Extended monitoring is the period in the life cycle of the CISF when spent fuel and storage structures are monitored on a regular basis. The extended monitoring period effectively commences at the end of initial fuel receipts and continues indefinitely. During this period there will be facility repeats and repackaging events until all spent fuel is either reprocessed or disposed of.

5.3.4.3 Operations – facility repeats

The facility repeat events occur periodically given that the storage facilities and principal containment structures have a finite life span. Thus, it will be necessary to move fuel baskets, module canisters and storage casks from an ageing storage complex to new facilities. Depending on the alternative under consideration, this may be achieved by the staged building of additional storage capacity on the site, permitting the transfer of fuel containers from one storage location to another. Once the spent fuel has been transferred and the storage unit has been emptied, the redundant building will be demolished, and a replacement unit constructed. The facility repeat event for each alternative is assumed to comprise a 5-year duration.

5.3.4.4 Operations – repackaging

Depending on the requirements of the alternative, the spent fuel repackaging facility will perform functions relevant to the specific alternative under consideration. It is assumed that the repackaging facility will comprise a shielded cell complex, housed within a large building, configured to perform the activities required by the repackaging event.

Over the 70-year operating period of the CISF, there will be one repackaging event which requires consideration. This event, based on an assumed 40-year service life of the storage casks, modules, silos and canisters (applicable to ACCM, UCMS, and ESMV alternatives), requires the removal of fuel from these systems and repackaging in fresh systems. For the ESMV alternative, the shielded cell complex has the capability to open module canisters,

withdraw the existing modules, transfer fuel to ‘fresh’ modules and encase these modules in a new welded canister. The repackaging event for each alternative is assumed to comprise a 17-year duration over the 70-year operating life of the CISF.

5.3.5 Decommissioning Phase

At the end of its operating life, the CISF will need to be decommissioned, cleaned up and demolished so that the site is made available for other uses. This includes all clean-up of radioactivity and progressive dismantling of the facility.

The main activities involved in the Decommissioning Phase include: the decontamination of the facility and the buildings, as well as their segmentation into smaller units suitable for subsequent handling; the treatment and packaging of waste material; and the demolition of the storage overpacks, casks and modules and the remaining buildings. Decommissioning should lead to the complete or partial removal of the regulatory control that was in place during the facility’s operation. It is therefore an essential step in ensuring that the legacy of the activities from which this generation has benefitted are not passed on to future generations.

5.4 Cost Estimate

5.4.1 Basis of Estimate

The cost estimates are based on the processes and activities considered necessary to establish and operate a CISF on the Vaalputs site. Each of the three conceptual designs is required to store spent fuel from all the country’s reactors, and must be capable of accommodating and storing fuel delivered in different formats. A separate cost estimate is therefore established for each CISF alternative (ACCM, UCMS and ESMV).

Each cost estimate assumes that the storage inventory of 6 200 SFAs are accumulated over a 60-year period. Spent fuel is to be stored at the CISF for 70 years. To allow comparisons to be made between the facility alternatives, the estimates are formulated over an extended period of time to capture costs associated with facility repeats and repackaging events. Beyond the initial fuel receipt period (25 years), each estimate covers the activities considered necessary to maintain the facility over a 70-year cycle, including a number of facility repeats and repackaging events as necessary. This 70-year cycle is defined by the service life of the fuel containers, such as casks, baskets and module canisters.

Recognising that continued operation and periodic renewal will be required to maintain the integrity of the CISF, a source of funding needs to be established. It is assumed that a Radioactive Waste Management Fund will be established, which, through annual growth and contributions from spent fuel generators/owners, will generate sufficient funds to bankroll all activities necessary to manage the facility. It should be noted that yearly expenditure at the CISF is unlikely to be uniform, being strongly influenced by the site activities in progress. Periods of extended monitoring, for example, will require a smaller workforce than that required during initial fuel receipt, and periodic increases in the workforce will also be required during facility repeats and repackaging events. Such events will also require expenditure on replacement fuel containers and storage structures.

5.4.2 Methodology

The structure for the cost estimates has been prepared by the development of the Work Breakdown Structures (WBS) for each alternative cost estimate (refer to Fig.5.1 for typical WBS). Each element on the WBS is broken down to the most appropriate level, to describe activities with sufficient accuracy for cost estimating purposes. The developed cost estimate work elements are also phased to years, to represent the timing within the cost estimate cycle, when these activities are scheduled.

The cost data for the alternatives, together with estimating information for the processing of storage casks, construction of surface storage buildings and the management of casks and vaults, is taken from and guided by the following international studies:

- Cost Estimates for Four Centralized Extended Storage Facility Alternatives for Used Nuclear Fuel, by CTECH [47].
- Cost Estimates for Reactor-site Extended Storage Facility Alternatives for Used Nuclear Fuel: Alternatives for Pickering, Bruce and Darlington Reactor Sites, by CTECH [54].
- Cost Estimate for an Away-From-Reactor Generic Interim Storage Facility (GISF) for Spent Nuclear Fuel, by EPRI [55].
- Generic Design Alternatives for Dry Storage of Spent Nuclear Fuel, by US-DOE [48].

The cost estimates obtained from these studies are adjusted to the conditions of the current CISF study in terms of programme scale (size) and base date, by using relevant conversion factors, escalation rates and exchange rates. Hence, the cost estimates are prepared and presented in South African rands (ZAR) with the base date of December 2021.

5.4.3 Estimating Assumptions

To estimate future costs for the programme of siting, designing, constructing and operating the CISF for spent fuel storage, the following assumptions are made:

5.4.3.1 Siting phase

- All CISF technical development work will be completed by the time a construction licence is obtained from the National Nuclear Regulator (NNR).
- The estimate considers costs relating to the implementation of a stand-alone CISF located on the Vaalputs site.
- The estimate assumes the programme will be continuous with no hold points and periods of inactivity whilst awaiting say, funding approvals, management reviews or licensing decisions.

5.4.3.2 Construction phase

- Detailed final design and the preparation of working drawings for the facility will commence immediately following EA approval and the acquisition of a construction licence.
- The CISF will be located sufficiently close to centres of population such that a purpose-built townsite, local to the facility for construction labour will not be required.

5.4.3.3 Operation phase

- The CISF operations will commence following the construction of the process building, ancillary facilities, initial storage complex capacity. Further stages of capacity will be constructed during the operations phase.
- The design throughput of the CISF will be a nominal 250 SFAs per year. Spent fuel will be received over a 25-year period.
- All SFAs will arrive at the CISF in transportation casks and/or storage casks. The cost of transportation to the CISF is excluded.
- The CISF will have all necessary staff and equipment to unload a transportation cask or storage cask from the transport vehicle, conduct radiological surveys, unload nuclear fuel waste from the transportation cask and to prepare the empty transportation cask for the return journey. The cost of these facilities and activities is included in the CISF estimate.
- During operations all labour will be deemed indigenous and will not receive any allowance for housing.
- The storage containers (casks, canisters or baskets) will be fabricated at an unspecified off-site location(s) and then shipped to the CISF site.
- The concrete overpacks, modules and silos will be manufactured on the CISF site.
- Security is required during facility operations. The level of required security would depend on security risk during the various periods of operation; i.e., fuel packaging or repackaging events versus extended monitoring.

5.4.3.4 Decommissioning phase

- The CISF decommissioning will commence soon after shutdown of the facility and will last for a duration of 20 years.
- In estimating the decommissioning costs, it is assumed that decommissioning costs would be 15% of the CISF design and construction costs.

5.4.3.5 General

- The estimate is based on CISF designs that only receive Koeberg and SAFARI-1 SFAs, with the design capacity of the CISF being 7 000 SFAs.
- The scope of this cost study excludes consideration of non-standard fuels.
- The estimate is prepared and budgeted in South African rands (ZAR), base December 2021.

5.4.4 Level of Cost Estimation

The CISF designs and other elements of the programme are defined at a conceptual level of detail. Therefore, the CISF cost estimates are based on incomplete design information, information about technology that is in the early stages of development, and many assumptions about the programme and how it will be executed. As a result, there is uncertainty associated with various elements of the CISF cost estimates. However, as the CISF programme would develop so the uncertainty in future estimates would be reduced and the accuracy of the estimates increased.

The purpose of contingency is to improve accuracy of a cost estimate by compensating for the inherent inaccuracies due to uncertainties in a programme of this size, complexity and duration.

The contingency should be large enough to compensate for the maximum range of uncertainty associated with an estimate. Therefore, each CISF cost estimate will be equal to the sum of all work element estimates and their associated contingencies.

5.4.5 Auxiliary Surface Facilities

All three CISF design alternatives considered in the previous chapter are subjected to cost estimation in this chapter. Also included in the cost estimation are key surface facilities, which are required, irrespective of the CISF alternative under consideration. These are:

- Administration and visitors building
- Operations support, health physics/radiation protection and test facility building
- Equipment storage and maintenance building
- Storage cask/module canister store (tailored to alternative under consideration)
- Active-solid waste handling building
- Active-solid waste storage building
- Active-liquid waste treatment building
- Active-liquid waste storage building
- General warehouse
- Guardhouse and perimeter security system
- Truck inspection/wash facility
- Utility building

In addition, a number of systems, features and areas are provided to support site activities:

- Fire protection systems
- Security and communication systems
- Electrical and emergency power
- Sanitary sewer system
- Potable water system
- Retention/sedimentation pond
- Storm water pond
- Batch plant and construction materials storage area
- Site materials storage area
- Access roads and vehicle compounds.

The costs for the establishment and maintenance of these facilities are included in the detailed cost estimates.

5.4.6 Cost Estimate for the ACCM Alternative

This section presents the cost estimate for the ACCM alternative of the CISF by major work elements and development phases. Table 5.1 provides all estimates for pre-operation work elements, namely, Siting, System Development, Safety Assessment, Licensing and Approvals, Public Affairs, Facility Design and Construction, and Programme Management. Table 5.2 provides estimates for Operation and Decommissioning phases.

Table 5.1: Pre-Operation Cost Estimates for the CISF ACCM Alternative

WBS	WBS TITLE	2021 ZAR '000
100-10	Siting	21 431
100-10-10	Siting management	6 897
100-10-15	Feasibility studies (3 sites)	6 051
100-10-20	Candidate sites (3 sites) (on Vaalputs)	5 822
100-10-25	Preferred site	2 662
100-15	System Development	47 275
100-15-10	System development management	5 984
100-15-15	System optimisation	3 275
100-15-20	Process system engineering (packaging, repackaging, decontamination)	28 875
100-15-25	Storage system engineering	7 700
100-15-30	Security & safeguard engineering	1 440
100-20	Safety Assessment	27 654
100-20-10	safety assessment management	6 303
100-20-15	SA - Siting	6 375
100-20-20	SA - Operating license	1 911
100-20-25	SA - Facility operations	10 210
100-20-30	SA - Decommissioning (processing facilities)	2 855
100-25	Licensing & Approvals	11 211
100-25-10	Liaison with regulator	574
100-25-15	Construction license	8 579
100-25-20	Other govt approvals	808
100-25-25	Operating licence (initial application)	1 250
100-30	Public Affairs	38 183
100-30-10	Public affairs - Feasibility studies	6 919
100-30-15	Public affairs - Candidate sites	10 379
100-30-20	Public affairs - Preferred site	4 058
100-30-25	Public affairs - Public review & EA approval	6 699
100-30-30	Public affairs - Design & construction	3 704
100-30-35	Public affairs - Programme management	4 118
100-30-40	Community offsets and benefits	2 306
100-35	Facility Design and Construction	1 699 553
100-35-10	Site & improvements	119 815
100-35-15	Processing building	1 501 700
100-35-20	Common ancillary facilities	47 304

100-35-25	Storage construction (stage 1)	30 016
100-35-30	Commissioning management	204
100-35-35	Equipment, spares and consumables	243
100-35-40	Energy consumption	272
100-50	Programme Management (Y1 to Y12)	95 086
100-50-10	Programme management (Y1 to Y12)	95 086
	TOTAL	1 940 393

Table 5.2: Operation and Decommissioning Cost Estimates for the CISF ACCM Alternative

ACCM WBS	WBS TITLE	2021 ZAR '000
100-40	Facility Operation - over 70 years	3 460 627
100-40-10	Operations - Initial fuel receipt	994 570
100-40-15	Operations - Extended monitoring	804 403
100-40-20	Operations - Facility repeats (40-year replacement)	242 554
100-40-25	Operations - Repackaging	1 419 100
100-45	EA & Monitoring - over 70 years	393 498
100-45-10	EA & monitoring programme management	71 161
100-45-15	EA & construction licence	9 077
100-45-20	Groundwater monitoring	44 221
100-45-25	Radiological biosphere monitoring	209 375
100-45-30	Non-rad biosphere monitoring	53 987
100-45-35	Human health monitoring	5 677
100-55	Decommissioning	254 733
100-55-10	Decommissioning (15% of design & construction cost)	254 933

5.4.7 Cost Estimate for the UCMS Alternative

This section presents the cost estimate for the UCMS alternative of the CISF by major work elements and development phases. Table 5.3 provides all estimates for pre-operation work elements, namely, Siting, System Development, Safety Assessment, Licensing and Approvals, Public Affairs, Facility Design and Construction, and Programme Management. Table 5.4 provides estimates for Operation and Decommissioning phases.

Table 5.3: Pre-Operation Cost Estimates for the CISF UCMS Alternative

UCMS WBS	WBS TITLE	2021 ZAR '000
100-10	Siting	21 431
100-10-10	Siting management	6 897
100-10-15	Feasibility studies (3 sites)	6 051
100-10-20	Candidate sites (3 sites) (on Vaalputs)	5 822
100-10-25	Preferred site	2 662
100-15	System Development	58 763
100-15-10	System development management	5 984
100-15-15	System optimisation	3 275
100-15-20	Process system engineering (packaging, repackaging, decontamination)	37 309
100-15-25	Storage system engineering	10 755
100-15-30	Security & safeguard engineering	1 440
100-20	Safety Assessment	27 654
100-20-10	safety assessment management	6 303
100-20-15	SA - Siting	6 375
100-20-20	SA - Operating license	1 911
100-20-25	SA - Facility operations	10 210
100-20-30	SA - Decommissioning (processing facilities)	2 855
100-25	Licensing & Approvals	12 573
100-25-10	Liaison with regulator	574
100-25-15	Construction license	9 673
100-25-20	Other govt approvals	808
100-25-25	Operating licence (initial application)	1 519
100-30	Public Affairs	38 183
100-30-10	Public affairs - Feasibility studies	6 919
100-30-15	Public affairs - Candidate sites	10 379
100-30-20	Public affairs - Preferred site	4 058
100-30-25	Public affairs - Public review & EA approval	6 699
100-30-30	Public affairs - Design & construction	3 704
100-30-35	Public affairs - Programme management	4 118
100-30-40	Community offsets and benefits	2 306
100-35	Facility Design and Construction	1 869 182
100-35-10	Site & improvements	119 815
100-35-15	Processing building	1 501 700
100-35-20	Common ancillary facilities	47 684

100-35-25	Storage construction (stage 1)	199 265
100-35-30	Commissioning management	204
100-35-35	Equipment, spares and consumables	243
100-35-40	Energy consumption	272
100-50	Programme Management (Y1 to Y12)	106 192
100-50-10	Programme management (Y1 to Y12)	106 192
	TOTAL	2 133 978

Table 5.4: Operation and Decommissioning Cost Estimates for the CISF UCMS Alternative

UCMS WBS	WBS TITLE	2021 ZAR '000
100-40	Facility Operation - over 70 years	4 409 129
100-40-10	Operations - Initial fuel receipt	1 426 070
100-40-15	Operations - Extended monitoring	1 051 245
100-40-20	Operations - Facility repeats (40-year replacement)	129 873
100-40-25	Operations - Repackaging	1 801 941
100-45	EA & Monitoring - over 70 years	393 498
100-45-10	EA & monitoring programme management	71 161
100-45-15	EA & construction licence	9 077
100-45-20	Groundwater monitoring	44 221
100-45-25	Radiological biosphere monitoring	209 375
100-45-30	Non-rad biosphere monitoring	53 987
100-45-35	Human health monitoring	5 677
100-55	Decommissioning	280 377
100-55-10	Decommissioning (15% of design & construction cost)	280 377

5.4.8 Cost Estimate for the ESMV Alternative

This section presents the cost estimate for the ESMV alternative of the CISF by major work elements and development phases. Table 5.5 provides all estimates for pre-operation work elements, namely, Siting, System Development, Safety Assessment, Licensing and Approvals, Public Affairs, Facility Design and Construction, and Programme Management. Table 5.6 provides estimates for Operation and Decommissioning phases.

Table 5.5: Pre-Operation Cost Estimates for the CISF ESMV Alternative

ESMV WBS	WBS TITLE	2021 ZAR '000
100-10	Siting	21 431
100-10-10	Siting management	6 897
100-10-15	Feasibility studies (3 sites)	6 051
100-10-20	Candidate sites (3 sites) (on Vaalputs)	5 822
100-10-25	Preferred site	2 662
100-15	System Development	69 933
100-15-10	System development management	6 941
100-15-15	System optimisation	4 922
100-15-20	Process system engineering (packaging, repackaging, decontamination)	39 885
100-15-25	Storage system engineering	16 745
100-15-30	Security & safeguard engineering	1 440
100-20	Safety Assessment	27 654
100-20-10	safety assessment management	6 303
100-20-15	SA - Siting	6 375
100-20-20	SA - Operating license	1 911
100-20-25	SA - Facility operations	10 210
100-20-30	SA - Decommissioning (processing facilities)	2 855
100-25	Licensing & Approvals	12 573
100-25-10	Liaison with regulator	574
100-25-15	Construction license	9 673
100-25-20	Other govt approvals	808
100-25-25	Operating licence (initial application)	1 519
100-30	Public Affairs	38 183
100-30-10	Public affairs - Feasibility studies	6 919
100-30-15	Public affairs - Candidate sites	10 379
100-30-20	Public affairs - Preferred site	4 058
100-30-25	Public affairs - Public review & EA approval	6 699
100-30-30	Public affairs - Design & construction	3 704
100-30-35	Public affairs - Programme management	4 118
100-30-40	Community offsets and benefits	2 306
100-35	Facility Design and Construction	1 688 655
100-35-10	Site & improvements	119 815
100-35-15	Processing building	1 354 047
100-35-20	Common ancillary facilities	47 666

100-35-25	Storage construction (stage 1)	166 458
100-35-30	Commissioning management	191
100-35-35	Equipment, spares and consumables	206
100-35-40	Energy consumption	272
100-50	Programme Management (Y1 to Y12)	109 359
100-50-10	Programme management (Y1 to Y12)	109 359
	TOTAL	1 967 789

Table 5.6: Operation and Decommissioning Cost Estimates for the CISF ESMV Alternative

ESMV WBS	WBS TITLE	2021 ZAR '000
100-40	Facility Operation - over 70 years	4 855 039
100-40-10	Operations - Initial fuel receipt	1 728 365
100-40-15	Operations - Extended monitoring	1 005 934
100-40-20	Operations - Facility repeats (40-year replacement)	1 053 552
100-40-25	Operations - Repackaging	1 067 188
100-45	EA & Monitoring - over 70 years	393 498
100-45-10	EA & monitoring programme management	71 161
100-45-15	EA & construction licence	9 077
100-45-20	Groundwater monitoring	44 221
100-45-25	Radiological biosphere monitoring	209 375
100-45-30	Non-rad biosphere monitoring	53 987
100-45-35	Human health monitoring	5 677
100-55	Decommissioning	253 298
100-55-10	Decommissioning (15% of design & construction cost)	253 298

5.4.9 Summary of Cost Estimates

A summary of all three CISF design alternatives under consideration in this chapter is shown Table 5.7.

Table 5.7: Summary of Cost Estimates for the CISF Alternatives

Phase	WBS Element	Cost Estimates (2021 ZAR '000)		
		ACCM	UCMS	ESMV
Pre-Operation	Siting	21 431	21 431	21 431
	System Development	47 275	58 763	69 933
	Safety Assessment	27 654	27 654	27 654
	Licensing & Approvals	11 211	12 573	12 573
	Public Affairs	38 183	38 183	38 183
	Facility Design & Construction	1 699 553	1 869 182	1 688 655
	Programme Management	95 086	106 192	109 359
	Total	1 940 393	2 133 978	1 967 789
Operation	Facility Operation – Over 70 Years	3 460 627	4 409 129	4 855 039
	EA & Monitoring – Over 70 years	393 498	393 498	393 498
	Total	3 854 125	4 802 627	5 248 537
Decommissioning	Decommissioning – Over 20 Years	254 933	280 377	253 298
	Total	254 933	280 377	253 298

5.5 Analysis and Conclusion

This chapter has established cost estimates for the three CISF design alternatives under consideration (ACCM, UCMS and ESMV). The estimates are based on cost data from international studies cited in the chapter. Although the assumption is that the CISF will be established on the Vaalputs site, site specific geological conditions, location of the preferred area on the site and specific site features will influence the actual costs and may result in higher or lower costs for construction of the facility.

The cost estimates as presented indicate that the ACCM alternative is comparable with, though slightly lower than, the ESMV alternative in terms of pre-operational (siting and capital) costs. The UCMS alternative is the most expensive of the three options in this regard. In terms of operating costs, the ACCM alternative is the cheapest of the three options, followed by the UCMS, while the ESMV alternative bears the highest costs.

A comprehensive multi-criteria analysis for selecting a preferred alternative is carried out in Chapter 8.

CHAPTER 6: FINANCING AND COMMERCIAL CONSIDERATIONS

6.1 Introduction

Generation of electricity from nuclear power leads to two main types of deferred costs: the cost of dismantling the power plant and returning the site to non-nuclear use, and the cost of managing spent nuclear fuel. These costs will be incurred years or even decades after the production of electricity. There are numerous issues of public concern about these costs, including the scale of costs, ensuring that operators make appropriate provision for future costs and that there will not ultimately be a call on public finances to meet them. An appropriate financing structure for these long-term liabilities can make an important contribution to the public acceptability of nuclear power. This is particularly important at a time when there is a real prospect of a very large increase in nuclear power because of its role in reducing carbon dioxide emissions and increasing energy security of supply.

Many countries have signed the Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management [6] and have adopted basic financing principles aimed at avoiding burdens for future generations and ensuring that adequate funds are available for the proper discharge of all nuclear liabilities. Hence, an important consideration in the development and operation, as well as closure of a CISF for long-term interim storage of spent fuel is the estimation of life cycle costs of the facility. Financial considerations play an important role in the decision-making process for a CISF development project and therefore the provision of adequate cost estimates is essential.

Other important issues associated with the financial considerations for a CISF development project include the various financing sources and mechanisms that are potentially available for the project. These schemes need to be identified and established before a CISF development project is undertaken. Many countries with nuclear power programmes have adopted a range of approaches to establishing financing mechanisms for development of such facilities and to funding the decommissioning of nuclear installations.

Chapter 5 identified the cost elements associated with CISF development. It indicated three main phases: pre-operational, operational, and decommissioning. This Chapter considers how each of these phases and their major cost elements could be financed. The main objective in deriving an appropriate financing scheme for a particular facility is to ensure that the money is available as and when required throughout the life cycle of the facility, that costs are allocated fairly and that value-for-money is optimised.

6.2 Legal Basis and Basic Principles of Financing Schemes

6.2.1 Requirements of the Joint Convention

The Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management ('the Joint Convention'), which is the first legal instrument to address the issue of spent fuel and radioactive waste management safety on a global scale, is a binding international treaty [6]. It came into force on 18 June 2001. Most Member States of the

International Atomic Energy Agency (IAEA) with nuclear power wastes are signatories to the Convention.

Article 3 of the Convention includes a requirement on Contracting Parties *‘to aim to avoid imposing undue burdens on future generations.’* In addition, Article 22 requires Contracting Parties to take appropriate steps to ensure that:

- *‘adequate financial resources are available to support the safety of facilities for spent fuel management and radioactive waste management during their operating lifetime and for decommissioning’; and*
- *‘financial provision is made which will enable the appropriate institutional controls and monitoring arrangements to be continued for the period deemed necessary following the closure of a facility’.*

Article 19 (1) requires Contracting Parties to *‘establish and maintain a legislative and regulatory framework to govern the safety of spent fuel and radioactive waste management’.*

The legislative and regulatory framework should provide for *‘a clear allocation of responsibilities of the bodies involved in the different steps of spent fuel and of radioactive waste management’* (Article 19 (2)).

Taken together, these articles establish a requirement on Contracting Parties to the Convention to ensure that sufficient funds are made available, in a way that they cannot be diverted to other uses, to cover the costs associated with long-term management of all existing radioactive wastes, including their disposal. In some Member States, particularly those with nuclear power programmes, segregated funds have been established with the aim of providing sufficient financial means to address all expected management costs of fuel cycle wastes. Additional guarantees may be required to ensure that financing is available when needed.

6.2.2 Principles Governing the Financing

The ‘polluter pays’ principle is widely accepted as a governing principle for the establishment of mechanisms for financing radioactive waste management. This principle is reflected in the environmental protection legislation of many Member States, as well as in international agreements, such as the European Community Treaty [56]. In this case, the principle is included in Article 174 (2):

- *‘Community policy on the environment shall aim at a high level of protection taking into account the diversity of situations in the various regions of the Community. It shall be based on the precautionary principle and on the principles that preventative action should be taken, that environmental damage should as a priority be rectified at source and that the polluter should pay.’*

The establishment of financing schemes should normally also aim to achieve the following objectives [57]:

- to ensure the long-term adequacy of funds;
- to allocate the costs fairly; and
- to optimise value for money.

These objectives may not to be mutually achievable, e.g., a special levy on the price of electricity produced from nuclear power plants may help to ensure the long-term adequacy of funds for managing nuclear fuel cycle wastes, but may not mean that waste producers pay the costs exactly in proportion to their specific waste producing activity.

The type of financing scheme used will influence the behaviour of waste producers through the price signals it creates. It is a requirement of the Joint Convention that Contracting Parties should take appropriate steps *‘to ensure that the generation of radioactive waste is kept to the minimum practicable’* (Article 11). Financing schemes that incorporate charging mechanisms that are related to the volume of waste produced are likely therefore to result in smaller volumes of waste being produced. Financing schemes are explored further in Section 6.4 below.

6.3 Responsible Organisations

In many countries, including South Africa, there are typically four main types of organisations involved in radioactive waste management [58]:

- the waste generators (e.g., nuclear power plant, institutional waste generator, others);
- the regulatory / licensing authorities;
- the waste management organisation (WMO) which may be State owned, utility owned or a private company;
- the government.

This institutional arrangement is often referred to as the ‘classical triangle’. Generally, the three organisations have different assignments and are independent. In some cases, there are strong organisational linkages between them, such as where the WMO is owned by the waste generator(s). The roles and responsibilities of each are briefly described below.

6.3.1.1 Waste generators

The use of radioactive material in nuclear power production, other industry, medical applications, research and other areas generates radioactive waste which requires safe long-term management. Any organisation which owns radioactive materials which no longer have a use is considered to be a waste generator. The responsibility of the waste generators is to provide the financial resources necessary for the safe long-term management of the waste they generate under the ‘polluter pays’ principle. In cases of unknown waste ownership, or where the owner no longer exists, this responsibility falls to the State.

6.3.1.2 Regulatory body

In most countries one or more Regulatory Bodies supervise the waste generators and WMO consistent with their legal requirements and policies. According to the definition in the IAEA Glossary the Regulatory Body is defined as follows: *‘A regulatory body is an authority or a system of authorities designated by the government of a State as having legal authority for conducting the regulatory process, including issuing authorisations and thereby for regulating the siting, design, construction, commissioning, operation, closure, decommissioning and, if required, subsequent institutional control of the nuclear facilities (e.g. near surface facilities) or specific aspects thereof. This authority could be a body (existing or to be established) in the*

field of nuclear related health and safety, mining safety or environmental protection vested and empowered with such legal authority' [59].

6.3.1.3 Waste management organisation

Many countries have founded a national WMO or entrusted this function to an existing institution. Some are government owned and others are owned by the major waste generators. In some countries, for example the USA, private companies have been established and operate on a commercial basis. The range of tasks undertaken by WMOs varies between countries. In most cases the WMO is responsible for the development of disposal facilities - where these are envisaged - including research and development, siting, construction, operation, repository closure and post-closure monitoring. In some countries, a national WMO may also have broader pre-disposal management responsibilities, particularly for institutional wastes. This may include providing facilities for treatment, conditioning, storage and transportation. Examples also exist where the WMO is responsible for the decommissioning of nuclear facilities.

It is normally also the responsibility of national WMOs to develop cost estimates for the long-term management of radioactive wastes, including the costs associated with each life cycle phase of the repository. These estimates provide the basis for determining appropriate financing mechanisms, as discussed in Section 6.4 below. In some countries, the WMO is also responsible for administration of the funds collected, with appropriate oversight arrangements.

Responsibility for long-term waste management in countries with radioactive wastes resulting only from medical and research applications is generally undertaken directly by an agency within a government department. In some countries the safe management of orphan or historic waste is entrusted to the WMO.

Table 6.1 shows the WMOs for some countries, their legal status and responsibility for the waste, and the types of funding mechanism in place.

Table 6.1: National Arrangements for Waste Management Funding

Country	Institution Responsible for RWM	Type*	Type of Funding Provision	Waste Ownership*
Argentina	CNEA	Gov	Segregated Fund	State
Australia	DEST (Commonwealth waste)	Gov	State Budget, Fees	State
Austria	Nuclear Engineering Seibersdorf	Gov	State Budget, Fees	State
Belgium	NIRAS/ONDRAF	Gov	Segregated Fund	WMO
Bulgaria	SE RAW – NPP waste	Gov	Segregated Fund	State
	INRNE – institutional waste	Gov	Governmental Provisions	State
Canada	LLRWMO - AECL	Gov	Fees	Generator
Czech Republic	RAWRA	Gov	Segregated Fund	State
Denmark	Riso Research Centre	Gov	Commercial Contracts	State
Finland	POSIVA Oy	Ind	Segregated Fund	State
Germany	BfS (DBE – contracted operator)	Gov	Advanced Payment Ordinance	State (after closure)
Hungary	PURAM	Gov	Segregated Fund	WMO
India	NPPs, BARC	Ind	Financial Provisions	Generator

I. R. of Iran	AEOI – WMD	Gov	Budget, Fees	State
Japan	JNFL (NPP LILW)	Ind	Financial Provisions	Generator
Lithuania	RATA	Gov	Segregated Fund	WMO
Netherlands	COVRA	Gov	Segregated Fund	WMO
Norway	IFE Kjeller	Gov	Financial provisions	State
Poland	RWMP Swierk	Gov	Financial Provisions	WMO
Romania	ANDRAD	Gov	Financial Provisions	WMO
Russia	RADON	Gov	Financial Provisions	State
Slovakia	VYZ	Ind	Segregated Fund	WMO
Slovenia	ARAO	Gov	Segregated Fund	State
South Korea	KHNP	Ind	Segregated Fund	Generator
Spain	ENRESA	Ind	Segregated Fund	WMO
Sweden	SKB	Ind	Segregated Fund	WMO
Switzerland	NAGRA	Ind	Segregated Fund	WMO
UK	NDA	Gov	Financial Provisions	WMO
USA	Multiple private companies	Priv	Segregated Funds	State Government
	Federal Government facilities	Gov	Budget	Federal Government

Organisation type: Gov – owned by the government; Ind – owned by utilities; Priv – private commercial company; WMO – waste management organisation. Source: [60].

6.3.1.4 Government

It is generally accepted that the State must have the ultimate responsibility for disposal of radioactive waste, especially should the organisations responsible for creating it no longer exist. The government is also responsible for making laws and policies for radioactive waste management and for defining the responsibilities of the different organisations involved.

6.4 Financing Mechanisms

6.4.1 Financing Mechanisms for the CISF Development Phases

A study on radioactive waste management financing schemes in industrialised IAEA Member States, published in 1999 by the European Union [57], concluded that there was no ideal scheme, and therefore extreme caution should be exercised in attempting to transpose a model from one country to another. A particular scheme or mechanism adopted must be tailored to particular circumstances. Thus, this Chapter does not attempt to recommend an ideal system, but rather to present the attributes of a number of mechanisms which could be used.

This Chapter pays specific attention to the requirements of NRWDI as the implementing organisation for the CISF project) which generally has the task of producing the programme plan, monitoring it as time goes on, and spending the money from whichever source(s) of funding is made available. This plan may be subject to regulatory approval or other oversight mechanisms established by the Member State.

This section identifies individual financing mechanisms which may be appropriate for a particular phase or element of CISF development, and the following section describes these mechanisms in more detail. The fundamental assumption which underpins the approach is that the ‘polluter pays’ principle should apply wherever possible, although it is recognised that this may not always be practical or fully adopted as national policy. It further discusses the attributes of the mechanism and compares them against several criteria discussed in [57]; being that financing mechanisms should be:

- financeable – they should ensure that sufficient money is available when it is needed and that an undue burden is not transferred to future generations;
- fair – they should ensure that waste producers pay in proportion to the contribution which their wastes make to costs.
- understandable – it should be as straightforward as possible for all stakeholders to understand and agree the basis on which charges are determined; and
- efficient – they should ensure that unit costs are minimised by giving appropriate economic signals, e.g., for better control of waste streams, reduction of high-cost drivers.

Table 6.2 shows possible financing mechanisms for each major sub-phase of CISF development as described in Chapter 5.

Table 6.2: Financing Sources and Mechanisms

Phase	Sub-Phase	Financing Sources and Mechanisms
Pre-Operational	Project planning and design	• State budget • State guarantee • Advance payments from waste generators • Endowment • WMO resources • Waste management fund
	Siting	• As above, plus: • Loan
	Construction	
Operational	All sub-phases	• Fund • WMO resources • Income from charging for services
Decommissioning	All sub-phases	• Fund • WMO resources

Source: [60].

6.4.2 Description of Financing Mechanisms

6.4.2.1 State budget and state guarantees

(1) State budget

The State budget may be the only practicable financial resource available at the early stages of developing waste management systems and infrastructure, especially in the case where no dedicated resources for waste management exist. Such a situation may emerge in a country like South Africa with non-existing CISF and no financing scheme for long term interim spent fuel storage and final disposal. In these circumstances, the full cost of the pre-operational phase, including CISF planning, site selection and characterisation as well as CISF construction may need to be financed by the State budget.

(2) State guarantees

Instead of the direct use of State budget resources, the provision of State guarantees may allow NRWDI to obtain financial resources through bank loans or through other financial instruments. These are generally more applicable in the early stages of CISF implementation (e.g., in pre-operational stage) but they may also be used for particular activities in later stages. Their use

may also be convenient when NRWDI does not have sufficient commitments from the waste generators to provide its own security for a bank loan. It may also be advantageous for the State budget since it does not directly drain State resources. From NRWDI's point of view, the main disadvantage is the fact that the State guarantee might not be given at the time it is needed or at the level required. However, it is an understandable and efficient mechanism.

6.4.2.2 Endowments

In some cases, the initial capital to start waste management activities by the waste management organisation (WMO) or implementation organisation like NRWDI, is provided by the State in the form of an endowment. This is a lump-sum, one-off payment provided for a clearly specified purpose and without the need for reimbursement. Endowments can be considered to be appropriate for financing the early phases of CISF development, particularly the pre-operational stage. It is more applicable to countries without adequate financial provision or lacking other financial mechanisms for waste management. This financing mechanism may be particularly appropriate for providing the resources for developing a waste management infrastructure.

Initial endowments may also be provided by the Government, waste generator or others to help establish a waste management (or reactor decommissioning) fund in the case where a CISF is already in its operational phase and is not generating enough income from waste generators to finance the decommissioning phase.

6.4.2.3 Waste management fund

(1) General

The basic function of a fund is to collect and invest contributions and revenues from nuclear utilities, other major waste producers, and possibly from the State Budget. In this way, money is made available for satisfying cash flow needs throughout the life cycle of the CISF. In principle, the fund takes advantage of the time value of money, by earning interest from medium- or long-term investment in financial instruments. Figure 6.1 shows a fund model in which contributions are made at a level rate throughout the life cycle of the facility; in practice the rate of contributions may vary according to factors such as the income stream from the waste generating activity. Funds build up over time from contributions and from investment returns and then decreases as costs are incurred. For the given set of assumptions any particular time the size of the fund is assumed to shrink to zero as the last costs are incurred; in practice the financing needs will continually change as these assumptions are overtaken by real outcomes.

(2) Fund management and risk considerations

Financial risks need to be taken into consideration before establishing a fund to manage financial resources. The two main types of risk return risk and liquidity risk. These risks imply constraints on the way the available cash can be invested for medium- to long-term periods:

- Return risk reflects the choice of investment portfolio. This risk can be managed by carefully defining an investment strategy. Some countries have limited the acceptable investment classes to bonds with high ratings, sometimes only governmental bonds with relatively low credit risks;

- Liquidity risk is usually a more serious risk and may be present even when the only investment is in corporate or government bonds. This is because the exact dates of the life cycle of the CISF are not known, and thus the date when cash will be needed will also be uncertain. This risk could prevent the use of the money at a time when important cash withdrawals are required on a short-term basis, such as the pre-operational phase of the CISF.

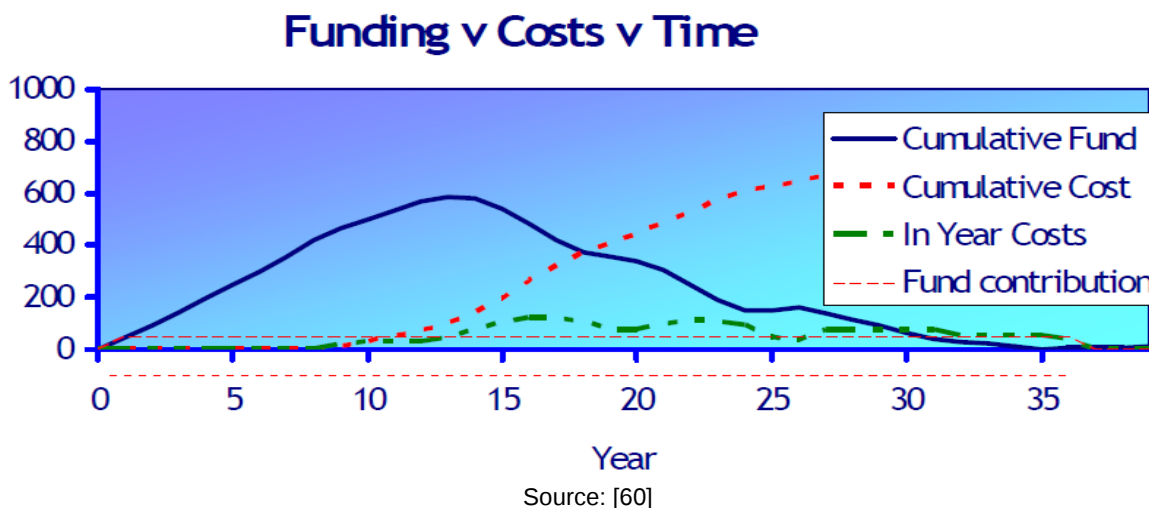


Figure 6.1: Illustrative Time Projection of Funding Costs

However, investment strategy in a particular country may be based on specific approaches. As an example, the strategy that the Swedish Nuclear Waste Fund [61] has adopted consists of setting a target for investment returns and in defining a strategy for managing financial risks. In order to limit the financial risks, the administration of the Fund should be conducted within an established framework. The framework may consider the number of issues, such as:

- interest rate risks;
- credit risks;
- liquidity risks;
- currency risks;
- long-term distribution between investments with nominal and real returns to reduce the inflation risk;
- maturities;
- administrative risks;
- follow-up activities.

The use of a waste management fund is generally most appropriate in phases of the life cycle which are distant in time, such as the decommissioning phase for the CISF.

An additional institutional risk for the fund is that the usage of the available assets could be diverted for other purposes than financing the CISF life cycle. Ideally the fund should be legally protected or segregated for its sole purpose ('ring fenced') and managed by an independent body under the supervision of an experienced audit committee.

6.4.2.4 Waste management organisation resources

(1) Accumulated profits

In some countries, the WMO is allowed to make profits and as a result it may accumulate financial resources. Those resources could be utilised to finance certain activities in the CISF life cycle. They may be generally used at an early phase of the life cycle such as planning, identification of requirements, preliminary costing. The advantage of such a mechanism is that it allows the WMO to act proactively and independently from the regulator, the waste generators and the State allowing for example development of alternative storage options. The financial risk lies with the WMO and to be sustainable, this cash outflow from has to be balanced in the future through prospective profits.

(2) Accumulated reserves

A further possibility for WMO financing is directly to charge the waste generators for services rendered, as described below. One option for WMO financing is to charge the waste generators a 'once and for all' charge at the time of delivery or collection of spent fuel, covering all past, present and future services associated with the storage of their spent fuel.

If no CISF exists at the time of payment, a large portion of the fee is reserved on the WMO's accounts and financial balance sheet. In the case of an existing CISF, part of the fee could be reserved for future decommissioning costs.

Reserves accumulated by the WMO from direct payments are a source of financing. The advantage of financing through accumulated provisions is the greater certainty that the resource would be available at time it is needed. One drawback is that this approach relies on an early prospective cost estimate. Should the requirement for resources be increased with time as the project develops, there may be no possibility for the WMO to recover additional costs from the waste generator, unless this is specifically covered by contract, i.e., the financial risk is taken by the WMO and not the waste generator.

6.4.2.5 Bank loan

This source of financing might be used when CISF planning is at an advanced stage and where cost requirements are known with some degree of confidence. A loan could be used at the construction stage, to implement equipment replacement, or at the decommissioning of the facility. At the decommissioning stage, it may be the WMO that takes financial responsibility and not the waste generator. In that specific case may be afforded the opportunity to realise a profit in return for accepting risk.

The advantage of this source of financing is that funds are readily available, when needed, should the WMO offer a reasonable guarantee to the bank. To be fully sustainable this source of financing needs to be associated with firm contractual commitments from the waste generators to make payments to the WMO covering the interest and capital associated with the loan. It might be in the WMO's interest to link this payment to the bank's requirements and not to the time at which waste is delivered to the facility.

The drawback of this method of financing is that it assumes that the waste generators will have adequate resources to cover the initial WMO commitment during the duration of the loan.

6.4.2.6 Advance payment

This method of financing applies mainly at the early phase of CISF implementation (planning, construction, siting) or to finance larger capital investments such as the component replacement at the facility repeat stage 40 years into the operational phase.

The required amount of finance is distributed among the waste generators in proportion to their forecast future use of the capacity with payments being made through regular instalments, as agreed with the WMO. In return for the advance payment for construction, the waste generators are normally guaranteed access to reserved capacity in the CISF for their particular spent fuel.

This method of financing respects the ‘polluter pays’ principle. Should the project fail or should the reserved capacity not be used, the WMO would have no obligation to pay back the waste generator. The financial risk here lies with the waste generator.

The main advantages of this method of financing are that funds are available to the WMO when needed, and the expenses are shared in an equitable manner between the waste generators. The efficiency of this system is guaranteed through the contractual agreements. A drawback of this method is that the waste generators may need to be encouraged to provide advance payments, possibly through interventions by the Regulator or other authority. There may also be disagreement between the WMO and the waste generators over the amounts required.

6.4.2.7 Income from charging for storage services

Apart from the limited cases of nuclear power countries which apply an electricity levy to finance the spent fuel management programme, additional revenue streams are generated from payments associated with storage operations during the operational phase of the CISF. Such an income stream may utilise a pricing system for selling storage space to the waste generators. The pricing may thus include:

- Proportional costs per unit volume related to the handling and storage of the spent fuel;
- The amortisation of prior financing commitments, mainly the capital costs of infrastructures and other pre-operational costs, which have been the object of loans contracted by the WMO with banks, or other pre-financing mechanisms described in other sections of this chapter;
- Contributions to funding the decommissioning phase of the CISF.

6.5 Commercial Consideration

5.1.1 Profit from Commercial Service

In most countries, a utility is legally responsible for generating sufficient revenues to fund the interim management of the spent fuel. The funds must be conservatively invested and the owner is not entitled to profit from this dedicated pool of money. The utility may ‘profit’, however, to the extent it can sell its electricity in the market at prices that exceed all costs including the spent fuel management cost. Thus, the owner has an incentive to keep the cost of spent fuel management low, which is a part of the cost base. In some countries, a public body is established with the mission to “take title” of the spent fuel and for downstream management, including final disposal or reprocessing. In this case, the overall responsibility of spent fuel storage is not subjected to commercial conditions, although the facilities and equipment provided by commercial vendors may be.

5.1.2 Financial Analysis for Storage Business

It has not yet been customary, in any of the existing institutional arrangements, to see the 'ownership' of spent fuel transferred to a private business. But the possibility of privatising the business of spent fuel storage for the interim term (until turnover to the end point) is feasible. For example, storage of spent fuel in existing reprocessing facilities has already been offered by some reprocessing companies. Normally, this is offered in conjunction with subsequent intent to reprocess the spent fuel, but in principle, it could be returned without reprocessing at an agreed service charge. Similarly, an independent central storage facility could be set up for this purpose. Should the opportunity open to industry for spent fuel storage as normal business, the key economic factor will be profitability for the interested entrepreneurs. For such business, financial analysis tools such as COMFAR would provide the results of profitability analysis.

6.6 Conclusions and Recommendations

This chapter presents information on alternative financing mechanisms for establishment of a CISF for long-term interim storage of spent nuclear fuel. It addresses the financing requirements in the life cycle of the CISF from pre-operation phase (planning, siting, design, development and construction), through operation phase, to decommissioning phase. This information is intended to contribute to timely, systematic and comprehensive consideration of the financial aspects of CISF planning and development beginning at an early stage in this process.

The approach discussed in this chapter incorporates the complete life cycle of the CISF, consistent with current international requirements, principles, standards and guidance. The main focus of the chapter is on potential financing mechanisms. IAEA publications and other relevant publications are referenced to provide details on pertinent technical and non-technical cost factors relating to CISF development, operation and decommissioning.

It is recognised that while national policy and legal frameworks for storage facilities are broadly similar in many countries, specific circumstances directly relevant to comprehensive cost estimation and evaluation of available financing schemes may be very different. These differences include the responsibilities and obligations of the waste generators, the waste management organisation and the regulators. Other important considerations impacting on costs are the CISF design, its storage capacity and planned operating life time. Important factors bearing on the choice of an appropriate financing scheme include the available sources of financing; charging arrangements and application of the 'polluter pays' principle for CISF and for related spent fuel management tasks; payment timing; fund management responsibilities and investment policy; and methodologies for estimating costs and considering uncertainties over the full CISF life cycle.

No single approach or set of approaches to financing are recommended for application by NRWDI, but it is recommended that the information presented be utilised in full consideration of the national policy, strategy and legal framework because it considered to be a valuable contribution to the CISF planning and development process.

CHAPTER 7: STAFFING AND TRAINING REQUIREMENTS

7.1 Introduction

The economics of running a future nuclear facility are influenced significantly by the component of labour costs. These costs, from facility staff, corporate support and purchased services will affect the overall facility economics.

The most significant component of operation and maintenance (O&M) cost in the proposed Centralised Interim Storage Facility (CISF) will be the direct and indirect cost of personnel; it would therefore be essential for the operator of the CISF to address the efficiency and effectiveness of its organisational structure and staffing in order to maintain the economic viability of the facility. The designer of the CISF would have to strive to improve the maintainability and operational characteristics in order to achieve the more effective use of staff and improve overall facility economics and performance.

In this Chapter, the requirements for the staffing of the CISF as well as for the training and development of the human resource (HR) are discussed. These requirements are discussed in terms of two distinct phases in the development of the CISF programme: (1) preparatory work for the contracting and construction of the CISF, and (2) activities to implement the CISF. This approach is adapted from two International Atomic Energy Agency (IAEA) publications on human resource management (HRM) for new nuclear programmes [62], [63], [64].

7.2 Human Resource Management in the Nuclear Energy Field

Prior to addressing the staffing and training requirements for the establishment of the proposed CISF, it is important to first explore and understand the HRM strategy and its elements in the nuclear energy field.

7.2.1 Elements of a Human Resource Management Strategy

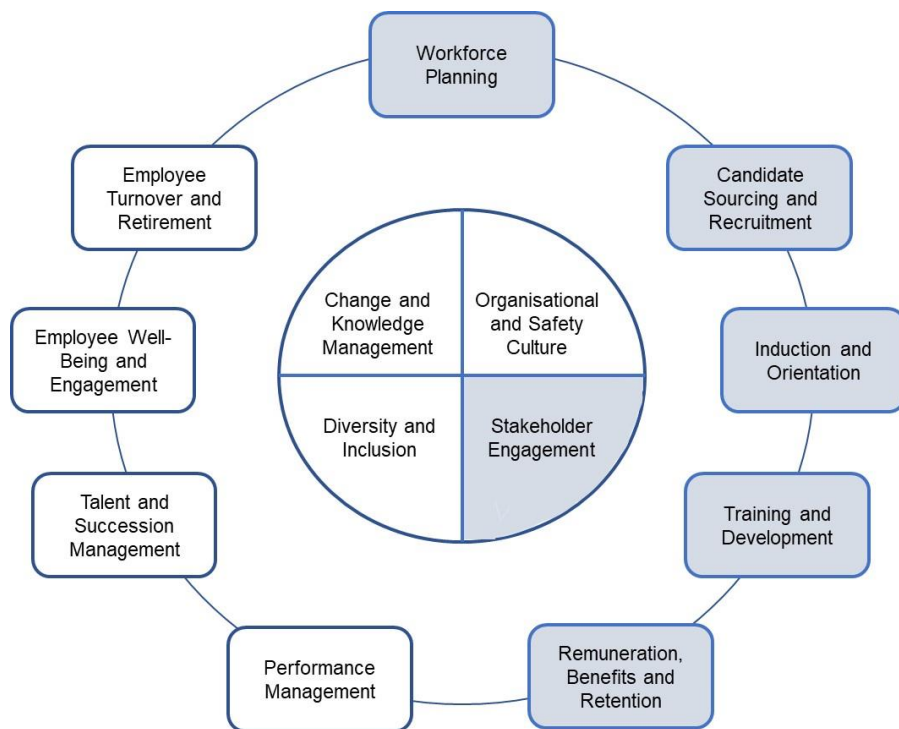
The different components of an integrated HRM strategy in the field of nuclear energy are identified in this section and indicated in Figure 7.1. Those items that are shaded on the diagram will be the key inputs into the development of the initial HRM strategy, while the other aspects of HRM strategy will also need to be introduced at the appropriate time.

The key components defined below represent the majority of the effort that will be required in the area of HRM throughout the two programme phases:

- *Workforce planning* is the systematic analysis of what an organisation is going to need as a function of time, in terms of the size, type and quality of workforce to achieve its objectives. It identifies what mix of experience and competencies are expected to be needed and helps ensure that the programme has the right number of people with the right skills, in the right place at the right time. Further, the term workforce is intended to refer to all personnel, including contractors, involved in the activities.

Workforce planning needs to be seen as an integral part of an organisation's overall HRM strategy and needs to be aligned and integrated with other HR activities and processes. For

example, workforce planning will identify who needs to be recruited and when and will identify the need for and nature of training and experience required.



Source: [62]

Figure 7.1: Elements of Human Resource Management Strategy

- *Recruitment* includes the preparation of job specifications, including any job specific education and experience requirements, identification of sources of candidates, shortlisting, interviewing and finally selection of staff for particular roles. Following recruitment, induction and onboarding takes place, including medical and security clearances.
- *Education, training and development* includes those activities in both the national education system and organisation specific systems required to develop an individual's competence for a specific role or task. This area will cover both professional/graduate education programmes and vocational/technical training programmes. (Professional/graduate indicates that the individual obtained a university degree, whereas vocational/technical indicates that the individual has obtained a skill-based qualification.)
- *Remuneration and retention* include both the direct financial reward (pay and bonuses) and other non-financial rewards intended to attract and retain staff such as subsidised housing, transport, education, and medical cover for staff and their families.
- *Stakeholder engagement* is the process of involving and engaging a wide range of interested parties in the decision-making on nuclear programmes to enhance public awareness, understanding and confidence. While this issue is very important to countries embarking on new nuclear programmes, it is covered in other IAEA publications and will not be discussed in detail [65].

As the programme develops, the HRM strategy and associated workforce plans need to be reviewed and developed in more detail. As part of the HRM strategy, it is important to correctly identify the total HR investment required for the programme. This may include, among others:

- New education programmes;
- Training facilities and courses;
- International recruitment of staff and/or advisors;
- International training;
- Secondment of national staff abroad;
- Language training.

It is essential that decisions on all these investments are driven by the demands of the programme, both in terms of numbers and timing. It needs to be recognised that investment in some of these areas will be necessary prior to the selection of a particular design.

7.2.2 Human Resource Requirements

The specific characteristics of a nuclear programme present challenges related to recruiting, hiring, training and sustaining a suitably qualified and experienced workforce. These are addressed in the following subsections.

7.2.2.1 Safety, security and safeguards

The unique aspects of a nuclear programme related to safety, security and safeguards necessitate an organisational culture and individual attitudes that ensure these issues are given the highest priority. The organisation that coordinates the nuclear programme is responsible for promoting this culture at the outset of the programme. However, developing this culture takes considerable time and effort for all the key organisations of the programme, particularly the owner/operator and regulator. The staffing and development efforts needed in this regard need to be incorporated in the HRM strategy.

As the programme develops, the owner/operator and the regulator may be supported by organisations from other countries, each with its own language and organisational culture. These diverse backgrounds may create challenges in establishing an organisational culture that gives the highest priority to safety, security and safeguards, and may require a dedicated effort and supporting programmes.

7.2.2.2 Competence requirements

A nuclear programme requires a higher level of education, training and experience compared to other energy sources. The job-specific training and experience for some positions can add years to the competence development process. The options for obtaining experienced national staff are: to recruit nationals who have been working abroad; to second staff abroad to develop experience; or, to recruit experienced staff from abroad and use them to train national staff through mentoring or shadowing programmes. Suitable national staff may also be sourced from any existing nuclear research facilities, such as research reactors. The above issues need to be considered in the recruitment and retention policies of the organisation to ensure that the right staff are attracted to, and retained in, the organisation.

The time from recruiting an individual with suitable education for a position to when that individual is fully qualified to work independently in the nuclear sector, is longer than for many other fields. This lead-time for certain positions in the owner/operator can be five to ten years (e.g., license engineer, operational planning, shift supervisor, emergency planning engineer, plant manager). Therefore, the workforce plan needs to identify when these individuals need to be recruited, taking into account these training lead times, and when they are needed to perform their job function.

Outreach and engagement programmes with educational institutions – from primary schools to universities – will help to attract suitable candidates and will also foster greater public understanding regarding nuclear technologies. These programmes need to be included in the national stakeholder involvement and public communication plans [65].

7.2.2.3 Security and medical screening and fitness for duty

The term ‘fitness for duty’ is used to cover a broad range of requirements in nuclear operating organisations but has three main elements:

- Initial screening of candidates, including a thorough review and verification of qualifications and experience, as well as criminal records and financial reviews and background/security checks. Also, there may be legal constraints around security clearances, beyond the control of the recruiting organisation, which will impact the recruitment of foreign workers;
- Medical testing and questionnaires, including drug and alcohol testing, is also necessary to ensure general fitness for duty for the organisation's requirements;
- Psychometric testing based on job-specific requirements (e.g., control room operators) may also be required. These tests are designed to confirm aspects such as an employee's suitability to work on shift, effectiveness in stressful situations, approach to safety, ability to work in teams, etc.

Medical and psychometric testing are typically used as part of the initial recruitment process and at regular intervals (e.g., 1-3 years), as part of any job change requirements (promotion, job rotation) and after any extended absence from work, especially if for a medical reason.

This screening and testing can both reduce the pool of potential workers and also lead to higher and unplanned turnover rates, which need to be considered in the HRM strategy [66].

7.2.2.4 Staff retention

The long lead times and specific competencies required make the unplanned loss of personnel in the nuclear industry particularly costly, both in monetary terms as well as maintaining the programme schedule. Therefore, a retention strategy and succession plan are needed to mitigate the risks. For example, when staff receive training overseas, they may be attracted by opportunities in the host country. Incentives or formal agreements may be useful to ensure that staff return following the completion of the training.

7.2.2.5 Knowledge management

Nuclear facilities have at least a 100-year lifetime from planning, construction, commissioning and operation, through to decommissioning. This timescale means that the workforce of a nuclear facility will span several generations. Therefore, the establishment of a knowledge management programme will ensure that specific knowledge and skills are archived and shared throughout the lifecycle of the facility. This will include the initial planning, design, licensing and construction information. It will also include archiving the knowledge of people when they move internally to new positions or leave the organisation [67].

These processes are also needed to ensure that knowledge is transferred from external experts to the staff in the organisation that will be responsible for the continued sustainability of the nuclear programme. In particular, it will be important for the owner/operator to establish processes to transfer knowledge from the vendor to its organisation. It is important that knowledge related to the design, construction, commissioning, operation and maintenance of the first unit(s) is archived and transferred from the vendor [68].

In addition to normal turnover, the organisation should anticipate situations that may lead to higher rates of separations. For example, the organisation might have age demographics that may result in higher-than-normal numbers of retirements. Knowledge management processes need to be configured to anticipate and prepare for such situations.

7.2.2.6 Management of contractors

A nuclear programme requires the management of experienced and specialist contractors. These contractors are typically used to perform tasks that are of a specialised or temporary nature, such as siting studies. They may also be used to supplement the staff of the owner/operator or regulator and provide training and mentoring to future staff of an organisation. Different numbers and types of contractors will be used throughout the duration of the programme.

There are two key aspects to consider related to the use of contractors. First, the customer (owner/operator) needs to be capable of specifying the work required, overseeing the work carried out and understanding the implications of the results or conclusions. Second, the customer needs to ensure that work carried out by contractors is conducted by personnel who are competent for that purpose and suitably qualified and experienced to perform their duties.

The use of contractors will have a direct impact on the workforce planning of the organisation. For example, using contractors to perform specialised or temporary tasks will generally reduce the total number of permanent staff. Alternatively, when contractors are used to supplement the staff, the total headcount and cost may temporarily increase.

7.2.2.7 Global workforce

The global workforce is becoming increasingly mobile due to technological advances and the attitudes and behaviours of the current generation. This mobility, combined with the global nature of the nuclear industry, creates a competitive environment for recruiting and retaining a competent workforce. The implication of this environment is that recently trained and qualified personnel may leave an organisation to work in other countries. This mobility, however, may

also present an opportunity for an organisation to recruit experienced staff. These issues need to be addressed by the organisation's recruitment, remuneration and retention policies. The global nature of the industry may ultimately lead to a diverse workforce, and the HRM strategy should consider the need to ensure that policies and procedures are understood and consistently implemented by all staff to ensure a coherent workforce.

7.2.3 Experience with Human Resource Management Aspects

Assessment of staffing levels has to be based on certain productivity of staff and their development of attributes identified as "responsibility", "quality" and "competence". To achieve this goal, the HRM needs to ensure:

- quality of planning;
- quality of training;
- quality of follow-up.

7.2.3.1 Quality of planning

Good planning needs three inputs:

- a) frozen staff strengths and entry level qualifications;
- b) time of placement of identified staff and;
- c) method of recruitment.

The reasons why external, open-market recruitment might not be successful for the staffing of the CISF are as follows:

- 1) demand of high quality leading to higher standards of recruitment;
- 2) remoteness of the CISF site as compared to conventional industries located in cities or near cities;
- 3) long nuclear training programmes with contractual obligations; fear of over-specialisation in the nuclear field with reduced chances for change of job in outside market;
- 4) housing shortages due to presence of large construction workers at peak of their activities.

A decision, therefore, would be to build a nuclear training centre and to start in-house induction, training and qualification of O&M personnel out of fresh candidates from colleges. Recruitment planning would have to be co-ordinated with training planning as per capacity available.

7.2.3.2 Quality of training

Nuclear facilities need staff with high degree of "responsibility", "quality" and "competence". At any phase or point of time, collectively nuclear facility personnel must have all the skills needed to attain the nuclear facility goals. The human resource development policies are established with a view that future performance will largely be achieved with today's people.

The staffing requirements are greatly influenced by the quality of training imparted. Increased emphasis on on-job training, re-training, human factors training and managerial skills development would be possible only if:

- initial training, on-the-job training and retraining are planned so as not to overload training centres with clear policies on what need to be in centralised training and;
- training resources of simulators, mock ups, manuals and trainer development are planned in advance.

Policies and special training services would be provided by the corporate training group including homegrown systematic approach to training methodology.

7.2.3.3 Quality of follow-up

Quality of follow-up aims at retention of trained facility personnel and at maintaining the human resource profile despite changes of separations, ageing and re-deployment of human resources.

(a) Career planning

For retention, certain career policies link individual aspirations to facility needs:

- Continuous, non-vacancy based but appraisal focussed promotion to higher pay scales for same facility jobs within a cluster of jobs;
- Additional salary for acquiring licensing-based qualifications and career;
- Opportunity to tradesmen and technicians to acquire professional qualifications in engineering and then to obtain higher positions;
- Assistance on science fundamentals to experienced technicians to acquire licensing-based qualifications at engineer level;
- Opportunity to engineers to take senior positions in another new facility or in headquarters.

The idea is not to lose experienced and skilled staff. However, the above do create additional inputs to human resource planning as the profile gets changed by induction from lower levels by promotions as well as by transfer of experienced staff.

(b) Replacement planning

Experience with existing nuclear power plants shows that delays in commissioning of some of the projects, leads to loss of young trained professionals. It is then hard to replace them, as it takes about four years to get qualified to the first position. Additionally, the tradition of taking large batch of fresh trainees also now create a new problem – of large-scale retirement too at one time. This (retirement) being an age dependent event, it happens to both engineers as well as technicians. So, some measures adopted are: (1) train and qualify about 10% extra i.e., over and above vacancies among engineers; and (2) continuously fill vacancies of technicians and train – with no extra staffing though.

(c) Retention and make-up needs

However, extra staffing does not always lead to required competence, as training and on-job experience opportunities get divided among larger number of trainees. The only way to make human resource planning effective is to make unplanned separations as low as possible so that make-up needs are either small or predictable so as to avoid negative effects of separations.

7.2.4 Standard Recruitment Planning

One year, before scheduled commissioning of the facility, all technical staffing must be in position.

- *Source of manpower:* Seventy percent of the total strength are recruited as fresh trainees and trained in operation & maintenance (O&M), construction and commissioning activities. Rest 30% positions are manned by transfer of experienced personnel from other nuclear facilities for senior positions as well as from the local construction group.
- *Lead time of recruitment:* Recruitment of trainees must start four years before commissioning, at 25% per year. They need to go through intensive induction nuclear training ranging from one year to two years before undertaking on-job training for licensing/qualification programmes.
- *Training capacity:* A certain number of trainees, engineers, supervisors and tradesmen at one time, must be put on training in different O&M disciplines at a nuclear training centre. This will then not overload the theoretical, practical and field training programmes. Installed training capacity, therefore, limits the recruitment size and backlogs are avoided by co-ordinating recruitment with training centres.
- *Educational qualifications:* The new recruit must have entry level standard education such that they can secure the highest level of facility qualification in their category. For example, an engineer trainee needs to reach up to shift charge engineer / senior maintenance engineer / senior management positions and must, therefore, have a bachelor of engineering university degree.
- *Regulatory requirements:* Appointments to management positions, shift charge engineers, assistant shift charge engineers, control engineers both in main plant as well as refuelling operations are done under direct surveillance of the regulator. For all other positions, the regulator audits the training and qualifications programme for ensuring the competency needs for safe operation.

7.3 CISF Staffing Requirements

7.3.1 Staffing Requirements and Throughput

To allocate for CISF staffing requirements and throughput, it is assumed on the basis of experience that the CISF operates 24-hour, 7-days a week basis, but cask/canister handling operations are limited to a single 8-hour shift, 40-hour work week. This is done because deliveries of transport casks to the site do not warrant around-the-clock cask handling operations. It also provides the ability to accommodate surges of work that might be necessary by adding additional cask handling crew shifts.

There are two phases to CISF operations: cask handling operations and storage facility surveillance and maintenance operations. The cask handling operations are the activities necessary to accept transport casks from nuclear plants and to place the canisters in them into interim storage on site. In addition, there are other supporting activities such as storage overpack fabrication, procurement to support the overpack production, maintenance of equipment, planning and scheduling, engineering, record keeping, physical security of the site and management.

A time and motion study performed by the US Department of Energy [48] identified all of the steps necessary to be performed in sequence in order to move the canisters from the transport bay to the pad. In addition to the sequencing and timing, the staff required for each step was

developed from the experience with operating ISFSI operations. In the study, the number of people and the time required for each step was used to determine the throughput and the total staffing requirement. The design basis throughput for the CISF, which is based on the anticipated spent fuel inventory of about 3 100 MTHM from the current reactors to be received over 25 years, is 125 MTHM/yr (250 SFAs/yr).

Table 7.1 shows a summary of the number of workers that are required for each storage alternative and also shows the maximum throughput of the alternatives. A minimum throughput of 2.5 MTHM processed a week is required to obtain 125 MTHM per year. The table further shows the processing structures or equipment that is required to achieve 125 MTHM per year throughput.

Table 7.1: Summary of ISF Staff and Throughput

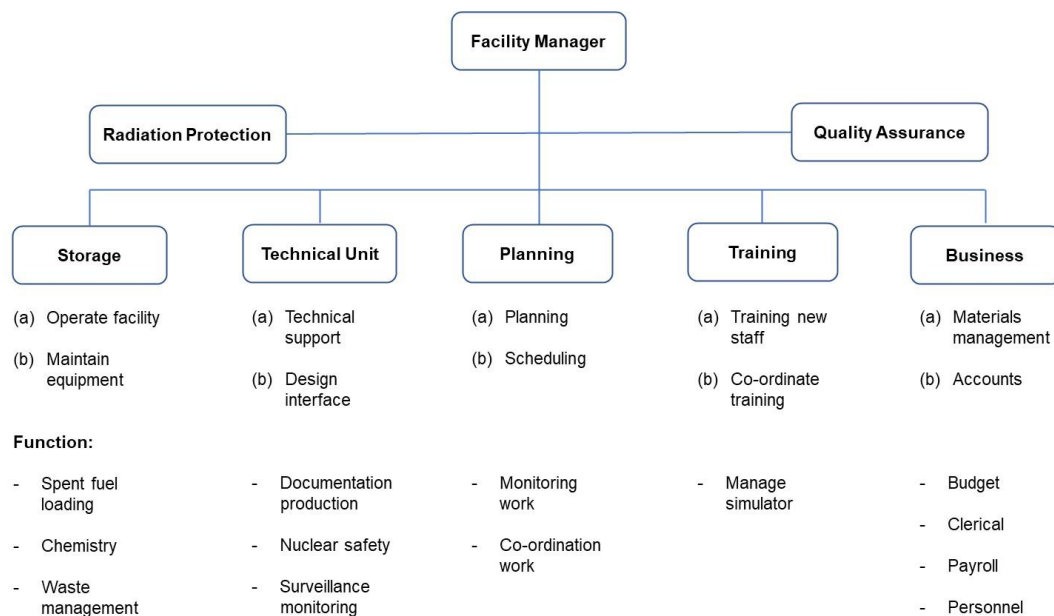
Alternative	Total CISF Staffing (Workers)	Maximum Throughput (MTHM/week)	CISF Requirements
ACCM (Aboveground Concrete Casks & Modules) storage	196	2.5	CHB with 2 TV bays, 2 cranes, 4 HCTs, 3 VCTs
UCMS (Underground Concrete Modular Silos) storage	185	2.5	CHB with 2 TV bays, 2 cranes, 4 VCTs
ESMV (Enclosed Surface Modular Vaults) storage	182	2.5	CHB with 2 TV bays, 2 cranes, 2 VCTs

CHB = Cask Handling Building; TV = Transport Vehicle; HCT = Horizontal Cask Transfer; VCT = Vertical Cask Transfer. Source: [48], adapted.

7.3.2 Organisation, Qualification and Staff by Function

Having established the staffing requirements and throughput for the size of the proposed CISF, its organisation, the staff qualifications and the allocation of staff by function are addressed in this section. The basic organisation is as shown in Figure 7.2.

The organisation has 5 main groups: operation, technical, planning, training and business with two support groups, QA and radiation protection. Table 7.2 gives a general account of the staff numbers and their respective function. Table 7.3 provides the main function and qualification of each group.



Source: [69, adapted]

Figure 7.1: Basic Organisation of the Proposed CISF

Table 7.2: CISF Staffing and Functions

Staff Designation	Staff Level	Function
Management	6	Various corporate support.
Facility Manager	1	Oversee entire facility operation.
Planning	3	Plan, schedule, monitor & coordinate all work.
Store (Supply)	7	Material management, spare part storage.
Operations Manager	1	Manage operation, maintenance, fuelling & chemistry.
Operations	30	Operate all facility equipment.
Maintenance	50	Maintain all facility equipment.
Spent Fuel Storage	10	Operate & maintain spent fuel handling systems.
Chemistry	5	Sample, monitor, initiate action to maintain chemistry specs.
Technical Manager	1	Manage technical unit to support production & ensure reactor safety.
Technical EC&I	10	Technical engineering specialists for electrical & instrumentation & control.
Technical Mechanical	11	Technical engineering specialist for mechanical & process systems.
Technical Specialists - Safety Systems	5	Technical engineering specialist for 4 special safety systems.
Technical Engineering Services	2	Technical engineering specialist for project management & contractor services.
Nuclear Safety Manager	1	Maintain nuclear safety analysis & licensing.
Nuclear Safety Analysis	4	Carry out safety evaluations & special analysis.
Regulatory Affairs (Licensing)	3	Deal with all licensing & related issues.
Nuclear Safety Reliability	2	Practical reliability model, monitor & evaluate facility performance.
Administration Manager	1	Manages administration, material procurement, accounts, security etc.
Public Affairs	1	Interface with plant and public, media, local community

Budget and Cost Control	1	Monitor budget and cost
Security	8	Provide facility security
Administrative Support (Clerical)	13	Services for typing, document management, procurement role.
Training	7	Coordinate & provide training for all staff.
Quality Assurance	3	Support the station manager with QA activities.
Radiation Protection	7	Define policy and develop procedures for radiation facility.
Radiation Protection (Laboratory)	3	Perform all lab work for dose monitoring programmes.
Total staff	196	

Table 7.2: CISF Main Functions and Staff Qualifications

Main Function	Description of Function	Qualifications
Operations	Operators to operate all systems; Trades staff for all maintenance; Spent fuel storage staff to load, unload, handle and manage spent fuel; Chemistry group to run lab and monitor/maintain chemistry.	Operators - high school grade 12 minimum. Preferences to those with community college science courses beyond high school. Hired as trainee and developed to the various operator levels through the company training programme.
Technical	Provide technical support for the production group. Prepare operating, maintenance and training manuals. Interface with design support groups. Develop staff to become system specialists to carry out system surveillance, facility monitoring and evaluation. Ensure documents and systems provide the required level of nuclear safety. Prepare detailed work plans for facility outages and breakdowns. Prepare facility performance reports.	An engineering degree is required. Previous industrial experience may be an asset. All technical staff complete the station training programme. Shift supervisors are drawn from this pool of technical staff.
Planning	Manage the work programme; to ensure maintenance is done during operation; prepare outage schedules and forced outage plans.	The planners are selected from control room operators or capable trades staff.
Training	The training group runs the training centre and simulator, coordinates the preparation and delivery of all the required training.	Trainers are selected from technical control room operators and capable trades staff.
Business	Provide all services to support the various station functions: for material management, clerical support, budget and accounting, personnel, payroll and security.	Manager is selected from corporate organisation. Business staff are from high school/college.
Quality Assurance	Carry out all quality assurance functions and audits for the facility manager.	A relevant university degree in QA. In-depth understanding of industry standards and company policies.
Radiation Protection	Support to the facility for radiation protection. Coordinate and prepare all procedures for facility emergencies and provide an interface for the various civil authorities. Provide training to all staff in scientific matters related to radiation and health.	Senior specialists with university degree. Support staff drawn from the headquarters staff and given special training in radiation protection group.

7.4 Summary and Conclusions

An effective organisational human resource management strategy and its implementation through HR processes in the organisation is critical to the success and sustainability of the CISF programme. There is significant investment required to ensure the availability of a competent workforce for each phase of the programme.

This chapter has outlined the key characteristics of the workforce for a nuclear programme, including development of a safety and security culture, the long lead times for recruitment, the investment required for education and training, the need to ensure retention of competent staff, and the need to build experience.

NRWDI as the implementation organisation and operator of the CISF will need to develop initially as a project management organisation, and, even with a turnkey approach, will need significant resources and competence to negotiate the required contracts and oversee construction. Early in the pre-operation phase it will need to start developing staff for the operational phase.

NRWDI will also need to carefully consider how it will secure experienced staff for the programme. This is likely to include a mixture of the early secondment of national staff abroad to gain experience and the recruitment of staff who already have experience from organisations in the country and in other countries.

Measures to assure staff qualification may include:

- Systematic competency analysis for each job including licensed positions should provide the basis for defining training requirements and logistics development;
- Job rotation, promoting multi-skills qualification, are of advantage to the optimisation of the number of staff; however, job rotation should not be imposed to the extent that it detracts from “task ownership”;
- Specialisation in certain key skills is necessary to provide competent and efficient operation; contractors can be efficiently utilised for many specialised tasks;
- Workers should be trained for radiation and personal safety, to assure that all required safety requirements are routinely satisfied.

Standards for entry-level qualifications and tests assure that recruited personnel can be qualified for the jobs in the planned time frame. The base entry requirements for specific staff on many existing nuclear facilities are increasing. Development of an integrated training infrastructure, encompassing on-the-job training, qualified trainers, training materials, and training tools such as simulators and mock-ups for developing skills should be given priority.

Creation of a common vision between management, facility operations staff, and facility maintenance and inspection staff, by focusing on the inter-linking roles they play towards sustaining high performance is important.

CHAPTER 8: PROJECT DEVELOPMENT

8.1 Introduction

Project development is the end-to-end process of conceptualising and delivering a project given a set of resources and constraints surrounding the project. For the CISF project, project development involves the seven stages defined in the Framework for Infrastructure Delivery and Procurement Management (FIDPM) [1], which are described in Appendix A. These are Prefeasibility, Feasibility, Design Development, Design Documentation, Works, Handover and Closeout. These stages are generally run sequentially as a one-time activity and the completion of each stage is subjected to a gateway review which determines if the project can proceed to the next stage. As part of the discussion of these stages in this chapter, aspects such as siting, construction, operation, regulatory requirements, risk management and budget requirements, inter alia, are addressed.

However, the project development must be based on a single option of the CISF design alternatives considered in Chapters 4 and 5. The following section includes the selection of a preferred alternative for the CISF design and the subsequent sections discuss the project development elements based on this preferred alternative.

8.2 Selection of a Preferred Alternative

A multi-criteria analysis (also known as multi-attribute analysis) has been chosen as the method for the selection of the preferred option amongst the CISF design alternatives considered in Chapters 4 and 4, namely:

- (1) An aboveground storage of spent fuel in vertical concrete casks and horizontal concrete modules, i.e., **ACCM** (Aboveground Concrete Casks and Modules);
- (2) An underground storage of spent fuel in underground vertical cylindrical concrete silos, i.e., **UCMS** (Underground Concrete Modular Silos); and
- (3) An enclosed storage of spent fuel in a surface modular vault dry storage system, i.e., **ESMV** (Enclosed Surface Modular Vaults).

8.2.1 Multi-Criteria Analysis

The three alternatives considered for CISF design are hereby subjected to multi-criteria analysis (MCA), which is used widely to assist in decision-making when one is faced with complex choices where there is a range of alternatives open to them and there are multiple, competing objectives to be accounted for [75]. A key feature of MCA is its emphasis on the judgement of the decision-making team in establishing objectives and criteria, in estimating relative importance weights and, to some extent, in quantifying the score of each option for each criterion. The subjectivity that pervades MCA can be a matter of some concern. However, MCA can bring a degree of structure, analysis and openness to classes of decision that lie beyond the practical reach of other decision analysis techniques such as cost benefit analysis.

In applying the MCA to the three CISF design alternatives, a set of criteria for the evaluation of the alternatives have been established. These evaluation criteria are listed and defined or described in Table 8.1.

Table 8.1: Criteria for Evaluation of CISF Design Alternatives

Criterion	Definition / Description
Health & Safety	A desired CISF design alternative should have: • low radiological risks and high protection against radionuclide releases to the environment and radiation doses to the members of the public during the normal operation of the facilities and transportation. • low accident risks and high defence-in-depth so that the probability of a severe accident leading to off-site releases is kept very small and the consequences of such releases, should they occur, are limited.
Environmental Protection	A desired CISF design alternative should have: • low possibility of direct ionising radiation exposures to workers and the public in the vicinity of the CISF and transportation routes. • minimal non-radiological effects such as traffic, noise, visual amenity, disturbance of natural habitats, restrictions on land use, as well as social and economic factors that may arise during construction, operation and decommissioning of the CISF.
Safeguards & Security	A desired CISF design alternative should have: • high proliferation resistance in terms of accounting for, controlling the use of and maximising the risk of early detection of nuclear materials in order to deter their diversion from peaceful use. • high physical security against theft of valuable materials and/or equipment in the CISF through use of protective measures, including surveillances and security guards, and against any act of sabotage the facility as it could create a radiological hazard to the personnel and a potential radioactive release to the public and the environment.
Policy & Strategy	A desired CISF design alternative should: • best adheres to the principles and processes embedded in the national radioactive waste management policy and strategy.
Societal Acceptance	A desired CISF design alternative should: • receive high public acceptance depending on the perceived risks associated with the types, volumes and toxicity of wastes to be managed at the facility and its deployment approach. • have high political support based on a broad array of policy concerns, public response and the rationality underlying determination of risk acceptability.
Cost & Affordability	A desired CISF design alternative should: • have low relative costs needed to achieve a complete life cycle of spent fuel storage, which include investment, operation, and decommissioning costs. • be in a state or position of being inexpensive enough for the country to purchase, pursue or establish considering the limited financial means of the country.
Executability & Deliverability	A desired CISF design alternative should have: • high capability of being successfully executed or carried out as a project from start to finish without undue impediments such as budget and schedule overruns. • high quality and possibility of being delivered as a project for the purpose it is intended and to the expectations of the end user.
Economic Benefit	A desired CISF design alternative should: • have the potential to result in benefits to the community in which it occurs, which are primarily economic and include employment, economic activity, government revenues and workforce training. • bring economic benefits to the country either by building national capabilities and infrastructure to allow export of technology and know-how, or by concentrating expenditure into the national economy rather than spending money outside the country.

A survey questionnaire, which was distributed by email to 18 participants who are members of the CISF Project Task Team and the CISF Project Steering Committee, was designed to include all three alternatives and the evaluation criteria with their definitions. To assist the participants, a table of pros and cons for each alternative, which were established in Chapter 4, were provided along with the questionnaire. The questionnaire required a participant to use the provided evaluation attributes/criteria for rating the alternatives on a scale of **1 to 5**, where **1** stands for “**least preferred**” and **5** stands for “**most preferred**” against the particular attribute, and provide a total score for each alternative that is rated. The ratings for each alternative were summed up, averaged by the number of participants and the resulting scores were compared. The alternative obtaining the highest average score was then declared the preferred alternative.

8.2.2 Results of the Multi-Criteria Analysis

In terms of the MCA results, out of the 18 participants who were sent the survey questionnaire, only 7 responded and returned completed questionnaires, as shown in Appendix B. All scores from the 7 participants for each CISF design alternative against each criterion were summed up and the total divided by 7 to yield average ratings for each alternative. The three alternatives were then compared with each other on the basis of their respective average ratings. Table 3 lists the results of the MCA process for the three alternatives.

Table 8.2: Results of the Multi-Criteria Analysis for CISF Design Alternatives

Criteria/Attributes	ACCM	UCMS	ESMV
	Score 1, 2, 3, 4 or 5		
Health & Safety	3,3	3,6	4,1
Environmental Protection	3,3	3,1	3,7
Safeguards & Security	2,6	4,1	3,7
Policy & Strategy	4,0	3,4	3,7
Societal Acceptance	3,0	2,9	3,1
Cost & Affordability	4,3	1,6	3,0
Executability & Deliverability	4,4	2,6	2,7
Economic Benefit	3,3	3,7	3,9
Total Average Score	28,1	25,0	28,0

The results indicate UCMS as the lowest ranked alternative and ACCM as the highest ranked alternative. So, clearly, the establishment of the proposed CISF should be based on the ACCM alternative since it is the most preferred alternative.

8.3 Prefeasibility Stage

The Prefeasibility Stage of the CISF project was completed by NRWDI in 2021 and it consisted of the development of a prefeasibility study report [70]. The report was tabled by the Department of Mineral Resources and Energy (DMRE) at and endorsed by Cabinet. According to the FIDPM, a prefeasibility study is required on mega capital projects to determine whether or not to proceed to the Feasibility Stage, where sufficient information is presented to enable a final decision to be made regarding the implementation of the project.

Following the demand analysis conducted in the prefeasibility study, nine technical schemes or options for addressing the challenge of spent fuel storage were identified and analysed for project appraisal:

- Option 1: Do nothing;
- Option 2: Expand at-reactor spent fuel pools;
- Option 3: Build an on-plant-site away-from-reactor (AFR) wet storage facility;
- Option 4: Build an off-plant-site centralised wet storage facility;
- Option 5: Build an on-plant-site AFR dry storage facility;
- Option 6: Build an off-plant-site centralised interim dry storage facility (CISF);
- Option 7: Build a domestic reprocessing plant for spent fuel reprocessing;
- Option 8: Ship spent fuel to an offshore reprocessing plant for reprocessing;
- Option 9: Build a deep geological repository for spent fuel reprocessing.

A multi-criteria analysis was chosen as the method for the selection of the preferred option. From this analysis of the options, the CISF option was determined and selected as the preferred option.

The prefeasibility study further determined that the CISF can only be established and operational by 2030 if all the necessary support such as funding and human resources are secured. According to the study, the inability to obtain funding for the CISF project presents a major risk to the project and its schedule. The schedule is likely to shift even further if funding for the execution of the project is not secured in time because all the subsequent stages following the Prefeasibility Stage require funding in order to be carried out.

The prefeasibility study does not provide a direct answer on how to secure funding required to execute the project, but it indicates that the project is achievable for the following reasons:

- The demand or need for the project is justified.
- The national radioactive waste management policy promotes the CISF establishment.
- The FIDPM provides a framework for the delivery of the project.
- A robust regulatory framework for siting, licensing and construction of the CISF exists.
- Expertise to deliver the project exist locally and internationally.
- CISF is not first-of-a-kind and can therefore be modelled on the existing ones in the world.

As a result, the prefeasibility study report recommended that the project advance to the Feasibility Stage in which a feasibility study will be performed to generate detailed information needed to decide on the successful implementation of the CISF project. The feasibility study would also be important in the negotiations for financing of the project with financing institutions. As part of the feasibility study, the funding options proposed in the prefeasibility study should be explored further for possible implementation.

8.4 Feasibility Stage

Based on the recommendation by the prefeasibility study report, the CISF project has entered the Feasibility Stage, which consists of the development a feasibility study report. The feasibility study has covered chapters on the review of dry storage alternatives, site selection and justification, design alternatives, cost estimates, financial and commercial considerations, and

staffing requirements. This section now extends the discussion to cover the following information which should be provided by the feasibility study report:

- Programme to develop project infrastructure;
- Regulatory requirements and due diligence;
- Risk assessment and management;
- Procurement and contract strategy.

8.4.1 Programme to Develop Project Infrastructure

The activities needed to prepare the infrastructure for CISF project can be split into three phases, with the duration of each dependent on the degree of commitment and resources applied. The term 'infrastructure milestone' is used to identify the point at which the activities required in that phase of development have been successfully completed [71]. Each 'infrastructure milestone' therefore corresponds to the completion of a set of activities, with no implications about the speed with which it is reached.

The three phases in developing the infrastructure necessary to support the CISF project are:

- Phase 1: Considerations before a decision to launch a CISF project is taken;
- Phase 2: Preparatory work for the contracting and construction of a CISF after a policy decision has been taken;
- Phase 3: Activities to establish the CISF.

The completion of each phase is marked by a specific milestone at which the progress of the development effort can be assessed and a decision can be made to move on to the next phase. These milestones are:

- Milestone 1: Ready to make a knowledgeable commitment to the CISF project;
- Milestone 2: Ready to invite bids/negotiate a contract for the CISF establishment;
- Milestone 3: Ready to commission and operate the CISF.

Figure 8.1 is a schematic representation of the phases and milestones.

The three phases and three milestones refer to developing the national infrastructure to support a spent fuel management programme. The programme includes one or more spent fuel management facilities, possible related projects, such as CISF, spent fuel transportation and storage cask manufacturing, and the supporting infrastructure. As the programme develops, many specific activities will be undertaken to implement the CISF project, and it is important that the distinction be clear. Projects are temporary undertakings to develop and construct spent fuel management facilities. The infrastructure provides the processes and capabilities to enable the project activities and the subsequent operation of the spent fuel management facilities to be implemented safely, securely and sustainably.

In the development of the nuclear infrastructure, three key organisations are involved: the government (represented by DMRE), the owner/operator of the CISF (being NRWDI) and the regulatory body (being NNR). Each has a specific role to play, with responsibilities changing as the project advances. The independence of NNR should be ensured so that in Phase 2 it is effectively independent in its regulatory decision making. It will not be entirely separate from

other governmental bodies, but must have sufficient authority, staffing and financial resources to be able to make independent regulatory decisions, free from any undue influences, such as pressures associated with changing political circumstances or economic conditions, or pressures from government departments or other organisations.



Source: [71, adapted]

Figure 8.1: Development of the Infrastructure for the CISF Project

The government will create a mechanism (which may involve high level and working level committees, such as the current CISF Project Steering Committee) to coordinate the work of these and other organisations involved in infrastructure development.

Table 8.3 shows a number of infrastructure issues that need to be considered for each milestone. The order does not indicate relative importance. Each issue is important and requires careful consideration.

Table 8.3: Infrastructure Issues for the CISF Project

The Infrastructure Issues for the CISF Project	
- National position - Nuclear safety - Management - Funding and financing - Legal framework - Safeguards - Regulatory framework - Radiation protection	- Stakeholder involvement - Site and supporting facilities - Environmental protection - Emergency planning - Nuclear security - Radioactive waste management - Industrial involvement - Procurement

• Water and electricity	• Human resource development
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8.4.1.1 Milestone 1: Ready to make a knowledgeable commitment to the CISF project

At the beginning of Phase 1, it is assumed or anticipated that additional spent fuel storage capacity will be required for continuation of reactor operation or decommissioning and that a CISF is considered as a possible option to meet this need. During Phase 1, analysis of all issues that would be involved in establishing the CISF, so at the end of Phase 1, the decision-makers are in a position to make a knowledgeable decision on whether or not to establish the CISF. In this phase, it is essential that the decision-makers acquire a comprehensive understanding of the obligations and commitments involved, and what would be required to fulfil them, before any decision on implementation be taken.

Fortunately, South Africa already has infrastructure for nuclear security, radiation safety and emergency preparedness covering its current facilities and activities. Building on the existing infrastructure and associated experience should greatly assist the country in establishing the necessary infrastructure for the CISF project.

In Phase 1, NRWDI should have ensured overall coordination, ensured the engagement of all important parties, compiled the information and studies necessary for a knowledgeable policy decision on whether to proceed with the CISF project and, at the end of Phase 1, provided a comprehensive report that, should it recommend a positive national decision, defines and justifies a national strategy for the CISF. The prefeasibility study performed during Phase 1 has been a significant input to the decision to proceed with the project.

8.4.1.2 Milestone 2: Ready to invite bids/negotiate a contract for the CISF establishment

Following the policy decision to proceed with the development of a CISF project, substantive work for achieving the necessary level of technical and institutional competence should be undertaken. This phase requires a significant, continuing commitment from the government, in particular DMRE as the responsibility of spent fuel management is ultimately vested in the minister of this department. It is also important that the work of all organisations continue to be well coordinated and driven through the CISF Project Steering Committee, whose key functions should include:

- Maintaining momentum and providing a continuing forum for communication and cooperation among the organisations affected by the project (e.g., NRWDI, NNR, Eskom, Necsa, relevant government agencies, legislators and other decision makers);
- Ensuring that the roles of the key organisations (i.e., the government, NRWDI and NNR) are well defined and understood by all stakeholders;
- Ensuring that the key organisations develop in line with the project schedule;
- Ensuring that the rationale for the national decision to establish the CISF is well understood by all stakeholders;
- Ensuring that the contracting approach and technical specifications remain consistent with the country's policies, strategies and legislations.

During Phase 2, NRWDI will carry out the work required to prepare for the contracting, financing and construction of the CISF. The necessary infrastructure (covering all the above infrastructure

issues) should be developed to the point of complete readiness to invite bids/negotiate a commercial contract between NRWDI and the supplier. NNR should be effectively independent and developed to a level at which it can fulfil all of its authorisation and inspection duties.

NRWDI has a key role at this time to ensure that, by the end of Phase 2, it has developed the competence to manage a CISF project, meet regulatory requirements and be a knowledgeable customer in Phase 3. NRWDI should also have, by the end of Phase 2, clear plans to develop or acquire during Phase 3 the capability to safely operate the facility.

8.4.1.3 Milestone 3: Ready to commission and operate the CISF

Phase 3 starts with competitive bidding and subsequent negotiation of the contract for the design, construction and commissioning of the CISF. Much of the work on infrastructure development will be well advanced by the beginning of Phase 3, but the greatest capital expenditure for the CISF will occur during Phase 3.

Depending on the specific agreements between NRWDI and the contractor(s), the contract may involve different phases of work (e.g., detailed design and construction) with different price agreements (e.g., fixed price or cost plus). After agreement on the contract, the final investment decision by investors may wait for final project cost and schedule agreements and other financial arrangements. Whatever the detailed contract arrangements are, the final investment decision is a pivotal step.

The initial work will be to develop the site-specific design, produce the preliminary safety analysis report and achieve all the required licensing and planning approvals. At this stage, the project costs and schedule can be finalised.

Subsequent work will then include all procurement and construction activities, under appropriate management arrangements, and will involve regulatory oversight and approvals throughout the phase.

Milestone 3 is reached when the entire infrastructure is in place to start the stages of CISF commissioning that involve nuclear testing. Some verification and non-nuclear testing of equipment and systems will start during Phase 3.

By successfully completing Phase 3, the CISF would have been established to realise the benefits of spent fuel storage capacity security and economic development envisioned in the initial policy decision. At the end of Phase 3, NRWDI must be fully capable of, and licensed for, commissioning and operating the storage facility. As NRWDI is newly created and new to such projects, this will require significant development and training for all staff and a demonstration that NRWDI can manage the project throughout the lifetime of the facility.

NNR has been in operation for some time, having developed safety regulations, reviewed contract specifications, licensed construction of nuclear facilities and carried out inspections during construction. It should now be clearly seen as a competent, effectively independent regulatory body to provide continuing oversight of all facilities and activities, and to enforce continuing compliance with all regulatory requirements.

The competence of both NRWDI and NNR may well be ensured through expertise and support from experienced foreign organisations, including the CISF supplier. Consideration should be given to the need to ensure competence throughout the lifetime of the facility.

While achieving Milestone 3 is a major accomplishment, it should be remembered that it is only the beginning of a lasting commitment to the safe, secure and sustainable storage of spent fuel from the country's reactors.

8.4.2 Regulatory Requirements and Due Diligence

8.4.2.1 General

The nuclear regulatory body in South Africa is the National Nuclear Regulator (NNR) established by the National Nuclear Regulator Act (Act No 47 of 1999), which deals exclusively with the regulation of the nuclear industry. The basic mandate of the NNR is “to provide for the protection of persons, property and the environment against potential nuclear damage.” The provision of this protection is accomplished partly through:

- Establishing safety standards,
- Issuing nuclear licenses and certificates of authorisations
- Conducting compliance assurance inspections
- Taking necessary enforcement where necessary

The NNR has well-established and internationally-recognised safety standards and regulatory practices for the purposes of fulfilling its present mandate. In terms of nuclear licensing requirements to be applied to potential future new nuclear facilities, the approach of the NNR is that all current safety standards and regulatory practices and associated relevant NNR Requirements and Guidelines will, as a minimum, be applicable to new builds. In terms of internal processes, the NNR has review processes and inspection programmes developed for the regulatory oversight of Koeberg Nuclear Power Station. These will be adapted to take account of the siting, construction, commissioning and operational phases of new build programmes and other nuclear facilities including the proposed CISF.

8.4.2.2 Regulatory framework

The relevant legislation providing the framework within which radioactive waste and spent fuel are managed are summarised as follows:

- *Nuclear Energy Act, No.46 of 1999* – The Act stipulates that the Minister of Energy (previously the Department of Minerals and Energy) has the authority over the management and discarding/disposal of radioactive waste and the storage of spent nuclear fuel generated in the country.
- *National Nuclear Regulator Act, No.47 of 1999* – All spent fuel storage facilities fall under the regulatory authority of the NNR in terms of this Act. The regulator's responsibilities include the siting, design, construction, operation, manufacture of component parts, and decontamination, decommissioning and closure of nuclear installations. The NNR is obliged to establish cooperative governance agreements with other relevant regulators, notably the Department of Fisheries, Forestry and Environment, regarding the environmental impact assessment process where cooperative governance is important.

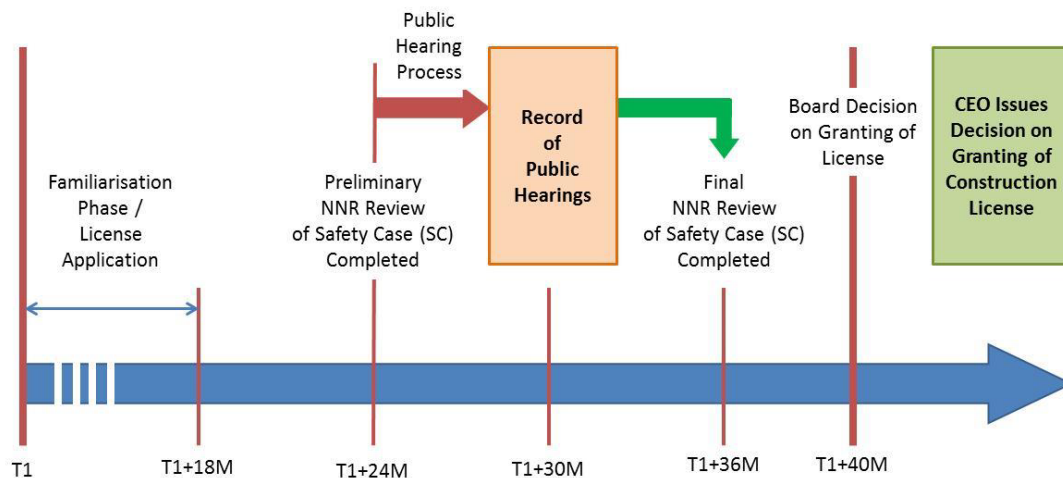
8.4.2.3 Licensing

The NNR requires various licensing phases for a new nuclear facility which needs to be done in conformance with the regulatory requirements. These include the application, approval, and implementation of each separate phase. A safety case needs to be prepared for each phase of the project. A Nuclear Installation Siting License (NISL) will be required for the siting phase. The various phases are listed as follows:

- Site selection
- Design
- Procurement and construction
- Operation
- Decontamination and decommissioning
- Closure

A safety case needs to demonstrate compliance with health, safety and environmental requirements. The safety case includes a Safety Assessment Report (SAR).

The NNR estimated timescales for the licensing of a new nuclear installation/technology are indicated in Figure 8.2. These estimated timescales are subject to the design being internationally accepted/proven, and are therefore very dependent on selected technology, as well as availability of the necessary documentation.



Source: [72]

Figure 8.2: Estimated Timescales for Licensing of New Nuclear Installation

For a Nuclear Installation License (NIL) to site or construct a nuclear installation the NNR must be provided with sufficient information, in the form of a safety case [73], covering the full technical safety basis, to enable the NNR to perform a detail assessment to the extent possible and therefore determine whether the proposed design will meet the requirements and that all safety issues identified during the safety case review will be mitigated at the appropriate stage of

the licensing process. In so doing the NNR will formulate its position whether to grant or refuse the NIL application to site or construct. This will also take into consideration all the public comments emanating from the public participation process.

Once the decision is taken to grant a NIL to site or construct, the NNR may impose in terms of section 23 of the NNR Act specific conditions related to the respective stage such as mandatory hold and/or witness points beyond which work must not proceed without the approval of the NNR. These hold points, depending on the type of installation and the associated nuclear risk as well as the completeness of the safety assessment, could be for important steps such as:

- Site establishment
- Early site activities
- Component manufacturing (Otherwise authorised under an Authorisation to Manufacture)
- Carrying out of civil works
- Installation of components and equipment
- Performance of pre-commissioning or functional tests of individual subsystems of components
- Cold commissioning testing up to and including non-nuclear integrated tests
- Hot commissioning testing (including nuclear material on site, loading of nuclear material, initial criticality, low power testing, full power testing)

For subsequent licensing stages the applicant will request a variation (amendments to the conditions) to this NIL supported by the relevant information. Subject to the NNR review of the submitted documents, the conditions of the NIL will be amended for the specific stage of licensing and a variation of the NIL will be issued to the applicant.

Regarding a NIL for the operation of a nuclear installation, safety assessment documentation (i.e., a safety case) must accompany and support the application for a variation to the NIL. The safety case for a NIL to operate must consider the results of the commissioning testing and should address all outstanding issues. Subject to the NNR review, the conditions of the NIL will be amended to allow for the operation of the nuclear installation and a variation of the NIL will be issued to the applicant.

At the end of its operating lifetime, the nuclear installation should enter post-operational decontamination and reduction of hazards to move towards a more passively safe state. A decommissioning strategy and plan must be included in the prior safety assessment for this stage of the lifecycle of the nuclear installation. An updated, detailed final decommissioning plan and its supporting safety assessment has to be submitted by the licensee to the NNR for acceptance, prior to commencement of dismantling activities in support of the application for the variation of the NIL to decontaminate and/or decommission a nuclear installation. The decommissioning plan must specify any institutional controls that are required to maintain radiation safety after termination of the period of responsibility of the holder consistent with NNR standards and requirements. The nuclear installation will remain licensed throughout the period of decommissioning, with appropriate safety measures maintained by the licensee and with appropriate regulatory control by the NNR.

Subject to the NNR review, the conditions of the NIL will be amended for the decommissioning and/or decontamination of the nuclear installation and a variation of the NIL will be issued to the applicant with mandatory hold and witness points and conditions of authorisation relating to decommissioning management, implementation, reporting and the period of responsibility.

8.4.3 Risk Assessment and Management

Initial risks involved with this project were identified in the Prefeasibility Stage [70]. If the project is allocated resources, then it will require a Risk Workshop to develop a formal risk register – either in GRACE or other suitable Risk Register Template.

A risk is an uncertain event or set of events which, if encountered, will impact on a project ability to deliver the outcomes. Exposure to risks must be expected in this CISF project as in the case of any other industrial projects. NRWDI is accountable to its stakeholders and has a range of obligations to be met, such as in terms of cost, quality, legislative compliance, safety and environmental protection, financial liability and political support.

Major risks to the project include but are not limited to:

- Potential delay in implementing the project resulting from delay in legislative and regulatory authorisations, delay in licensing, prolonged EIA process, and a lack of funding;
- A disruption to the delivery of spent fuel;
- A significant cost overrun on the CISF that occurs after the financial investment date;
- An incident either to the CISF or elsewhere that causes a disruption to operations, a requirement to rectify or re-engineering of the CISF.

In Table 8.4, a preliminary risk identification and analysis is carried out.

Table 8.4: Risk Identification and Analysis

Risk Type	Risk Description	Root Cause	Consequence	Mitigation Action
Financial	Inability to finance the CISF project	• Delays in the promulgation of the Fund Bill • Incomplete financing model • Lack of funding from other sources (waste generators, government, investors, etc.)	• Inability to safely manage spent fuel • Duplication of costs with the extension the TISF	• Enter into contracts (SLAs) with waste generators to source funds
Legislative	Reliance on the completion of legislation (Fund Bill)	• The iterative nature of the legislative process • Incomplete financing model	• Inability to safely manage spent fuel • Cost escalations due to delayed promulgation of the Fund Bill • Uncertainty on funding provision of spent fuel • Duplication of	• Source seed capital from fiscus through MTEF process

Risk Type	Risk Description	Root Cause	Consequence	Mitigation Action
			costs with the extension of the TISF Inability to establish the CISF timeously	
Regulatory	Delays in licensing of the CISF	- Iterative process of licensing - Non-prescriptive regulatory requirements of the NNR	Inability to establish the CISF timeously	- Use the TISF licensing experience - Early engagement with NNR
Technology	Storage systems not compatible with the waste generator designs	Misalignment between waste generator technological designs to those of NRWDI	- CISF not licensed easily - Duplication of costs - Legal disputes with waste generators	- Early engagement with waste generators - Establish a communication strategy with waste generators
Social	Non-acceptance of the CISF by the public	Lack of stakeholder engagement strategy	CISF project rejected and stopped	Early engagement with the public

8.4.4 Procurement and Contract Strategy

8.4.4.1 Types of contractual approach

Basically, there are three different types of contractual approach which have been applied so far for nuclear facilities, namely:

- Turnkey approach, where a single contractor or a consortium of contractors takes the overall technical responsibility for the whole works;
- Hybrid- or Split-package approach, where the overall technical responsibility is divided between a relatively small number of contractors, each building a large section of the works;
- Multi-contract approach, where the owner or his architect-engineer (AE) assumes overall responsibility for engineering the facility, issuing a large number of contracts.

The possible lead technical responsibilities for the different types of contractual approach are shown in Table 8.5.

Table 8.5: Usual Lead Technical Responsibilities for Different Contract Types

Activity	Lead Responsibility		
	Turnkey	Hybrid / Split Package	Multiple Package
Pre-project activities	IO	IO	IO
Project management	MC	AE or IO	IO + AE
Project engineering	MC	AE + SS	IO or AE

Quality assurance	MC + IO	AE + SS + IO	IO + AE
Procurement	MC	AE + SS	IO or AE
Application for license	IO	IO	IO
Licensing	RA	RA	RA
Safeguards, physical protection	IO	IO	IO
Manufacturing	MC	SS + EM	EM
Site preparation	IO or MC	IO or AE	IO or AE
Erection	MC	AE + SS	IO or AE
Equipment installation	MC	AE + SS	IO or AE
Commissioning	MC	AE + IO	IO or AE
Facility operation and maintenance	IO	IO	IO

Acronyms: AE: Architect-Engineer; MC: Main Contractor; EM: Equipment Manufacturer; RA: Regulatory Authority; SS: System supplier; IO: Implementing Organisation

8.4.4.2 New Engineering Contract (NEC)

The Nuclear Engineering Contract (NEC) is a set of standard form contracts. Its differences from traditional construction contracts range from the simple and brief language, less detailed terms and conditions, clause numbering, absence of numbered cross-references to the use of the present tense.

The intention of the NEC is to shift from the old-fashioned, adversarial forms of contract and to establish a new, collaborative model based on modern principles of project management. Clients who do not have sufficient in-house resources or are used to a more “hands off” approach as seen in the EPC/turnkey contracts may have difficulties with using NEC as it requires them to have a more proactive role in risk management and problem-solving. The project manager has a pivotal role in the efficient administration and management of a successful NEC contract and it is crucial for the employer to ensure that the right person or organisation is appointed for the job.

When assembling the contract documents, the works information is vital and must contain more information than a typical bill of quantities or employer’s requirements document. In order for the contract to work properly, the works information must also include, among other things, details of the extent to which the Contractor is responsible for design, works to be carried out by the Employer or third parties and procedures for submission and review of information.

8.4.4.3 Preferred contract strategy for the CISF

For the CISF establishment, the procurement route should be EPC (engineering, procurement and construction) turnkey using the NEC standard form incorporating amendments to make it project specific and comply with the regulatory regime.

EPC contracts have been the traditional model used in the energy industry to deliver projects. EPC contracts have a single-point of responsibility, a fixed programme with a certain date for completion, a fixed price, guaranteed performance and reliability levels. The contractor is obliged to deliver a complete facility to the client on a ‘turnkey’ basis. Not surprisingly, such projects are more expensive, to reflect the risk taken on by the contractor.

Since the EPC approach shifts all major risks (including but not limited to price, programme, design and construction) to the contractor, it is important that there is a realistic work schedule,

a completed design before the start of work, a skilled and experienced workforce and a clear understanding of regulatory requirements.

The other procurement strategies are less preferred for the CISF for a variety of reasons.

Multi-contracting is less popular with funders as less risk is passed to the contractors and a greater risk remains with the client. In multi-contracting, the client is responsible for co-ordinating the separate packages of work and ensuring effective communication and interfacing between them. The main disadvantage of multi-contracting is that a failure in co-ordination could lead to significant delays, cost overruns and performance issues. If any issues occur, it could also be difficult to disentangle and attribute the causes of delay and cost overruns, especially due to the technical complexity of nuclear facilities.

Some delay risk may also rest with the client. For example, one contractor's delay may result in delay to later programmed packages. The client will then try to recover costs arising from the delay from the late contractor in the form of liquidated damages. However, the client may not be able to recover such losses if the delay arose from an event entitling the contractor to an extension of time. Other contractors who have been subsequently delayed may also be entitled to claim corresponding extensions of time or additional costs, without the client being able to recover its losses.

The difference between a hybrid- or split-package and a multi-contract approach is that there are fewer contracts and less co-ordination risk in a hybrid package for the client to manage. Otherwise, the risks in this hybrid model are similar to the multi-contracting approach.

8.5 Design Development Stage

After completing a feasibility study, NRWDI must now proceed to the Design Development Stage of the CISF project and develop a preliminary design of the CISF and, in parallel, engage in the environment impact assessment (EIA) process.

8.5.1 Preliminary Design

The principal purpose of the preliminary design is to specify the structural framework of physical components which will implement the CISF system at the Vaalputs national radioactive waste disposal facility site.

Preliminary design refers to that part of the development phase where all of the geometric design elements, including a preliminary estimate of the preferred design solution are documented for input to the detailed design stage. The preliminary design often bridges a gap between design conception (established in the Feasibility Stage) and detailed design, particularly in cases where the level of conceptualisation achieved during ideation is not sufficient for full evaluation.

During the preliminary design stage, major emphasis is put upon civil, mechanical, and architectural design. The design of all the mechanical processes will also be completed at this stage to ensure that they are integrated properly into the structures. Architectural concepts will be developed, and structural systems identified. So, in this task, the overall CISF system configuration will be defined, and schematics, diagrams and layouts of the project will be developed to contribute to the project configuration.

The contracted designer is expected to:

- Develop and describe a CISF design concept and system configuration;
- Provide a design that meets safety requirements;
- Provide an analysis of the CISF design concept;
- Generate cost estimates for the CISF design and construction;
- Develop a flowchart (or other schematic) of each system of the CISF;
- Define clearly each system's, subsystem's and component's requirements;
- Provide a high-level outline of design features that meet each of these requirements;
- Produce a preliminary design document consisting of the above elements, all of the geometric design elements, and sketches/figures.

NRWDI is expected to:

- Conclude a professional services contract with a service provider, manage the contract from start to end and ensure that the terms and conditions of the contract are met.
- Review and monitor the contractual deliverables due to the service provider.
- Submit the final draft Preliminary Design report to the Gateway Review Team for review.
- Accept and approve the final report, close the contract and ensure that the service provider is duly paid for the completed services.

8.5.2 Environmental Impact Assessment

Usually for a new installation such as the CISF it is necessary to provide an environmental impact study as part of the documentation supporting the request for a license. The purpose of such a study is to ensure that adequate attention is given to the short-term and long-term effects on the environment. The environmental impacts are regulated through a dedicated environmental impact assessment (EIA) process that is often coordinated and harmonised with the nuclear licensing process.

A decision to build the CISF would trigger an EIA process legislated by the government in the form of the National Environmental Management Act No.107 of 1998. Environmental impact assessment is a focused response to the protection of the human and natural environment. The objective in general terms is to inform the regulators if there are significant adverse effects from the project. Due to the long-term nature of the CISF, environmental stewardship requirements over the storage period would be a key consideration.

An EIA process would generally include assessments of environmental impacts of the facility over its life cycle from the range of activities involved, primarily construction, operation and decommissioning. Effects of the project on the biophysical environment in terms of land, water, air and noise would be assessed. The process would be designed to provide opportunities for the public and affected communities to participate in the decision-making processes through consultation, which may include public hearings. It could include elements of other assessments such as feasibility and licensing assessments. The environmental decisions to proceed with the project are given by DFFE, a regulatory body in charge of the EIA process.

Preparation of the environmental impact statement is a complex multi-disciplinary activity that may involve diverse activities, such as evaluation of conformity with regulations at all levels of

government, involving land use, environmental quality, community socio-economic impacts, and various other legal mandates. The process may include a formal set of evaluations and activities such as defining the proposed project, identifying alternatives and evaluating them, quantifying environmental effects from the project, and public and government consultation. The lead time and strategies for such activities have to be carefully judged and built into the project schedule to avoid unexpected delays and hurdles.

To facilitate the EIA process for the CISF establishment at the Vaalputs site, an Environmental Assessment Practitioner (EAP) will be required, as a matter of legal requirement. An EAP is an individual responsible for the planning, management, coordination or review of EIAs, strategic EIAs and environmental management programmes.

For the CISF project, the EAP is expected to:

- Conduct an Impact Assessment process including looking at alternatives at the Vaalputs site;
- Consult the public (public participation);
- Assess the impact of the proposed project on the environment of Vaalputs;
- Lodge EIA application to Competent Authority with a Draft Scoping Report;
- Facilitate and ensure granting of Environmental Authorisation; and
- Produce a report.

NRWDI is expected to:

- Conclude a professional services contract with the EAP, manage the contract from start to end and ensure that the terms and conditions of the contract are met.
- Review and monitor the contractual deliverables due to the EAP.
- Accept and approve the final report, close the contract and ensure that the EAP is duly paid for the completed services.

An expected outcome from this exercise is a comprehensive EIA report that will enable decision making for the CISF project to move forward to the next stages.

8.6 Design Documentation Stage

After completing the Design Development Stage, NRWDI must now proceed to the Design Documentation Stage of the CISF project and develop a detailed design of the CISF and, in parallel, develop a safety case for supporting the license application.

8.6.1 Detailed Design

In the detailed design phase, analyses are taken to the next level, either refined to be more accurate, or extended to additional operating conditions. This phase of the project can be the most cost and schedule intensive phase.

Detailed design, which takes on and develops the approved conceptual design, is a stage where the design is refined and plans are set. The result of the detailed design is the complete and precise physical description of all parts of the structure (the blueprints) and how they are fit together. It also involves the investigation of the stability, strength and rigidity of the structure to be built, based upon the physical requirements of the building and an understanding of the structural performance, materials, and geometries used.

Adequate detail must be provided by the drawings and the report to permit reasonably accurate estimates of construction, operating cost, and the construction scheduling. Revisions to construction materials, machinery, and equipment specifications are made. The final design report should contain updated schedule, cost estimates, and specifications.

So, the detailed design serves as the basis for the construction phase. Appropriate cut in entire project cost can be made at this stage. Additionally, the detailed design needs to ensure that the design solution satisfies objectives of the project. Finally, it is necessary to verify at the end of the final design stage that the project remains economically viable.

The completed detailed design needs to involve the following components:

- Overall layout;
- Structural plan sections, elevations, and specifications. This involves the location of all structural elements in relation to gridlines, dimensions and sizes of beams, columns, walls, and slabs, sketch details of junctions and proposed fixings, superimposed loading allowances for each floor slab, the proposed discipline for all holes giving range and sizes permissible, and an outline specification including total weights of reinforcement;
- Road layouts and landscape;
- Horizontal and vertical circulation routes;
- Operational flows and departmental operational policies;
- Building dimensions and gridlines;
- Architectural plans, sections, and elevation of buildings block plans, site plans;
- Elements of design that require early choice of manufacturer;
- Requirements for mock-ups, testing, samples necessary to satisfy performance requirements;
- Key assemblies, component drawings, and schedules with special attention to junctions and interfaces between elements that influence the structural or service designs. Key assemblies include external walls, lining, cladding, roofing, floor construction and finishes, staircases;
- Building service plans, sections, and elevations showing plumbing, drainage, ductwork, heavy pipework, light pipework, and access requirements;
- Define phases if the project is to be phased;
- Safety strategy;
- Fire strategy including compartmentalisation, separation, protected shafts, surface spread of flame and escape strategy;
- The use of materials and the potential for recycling and waste handling;
- Risk assessment.

8.6.2 Safety Case Development

Due to licensing being a time-consuming activity owing to the extensive analysis required for supporting safety design of the facility, some planning may be required to assess the timelines and ensure that licensing activities are taken up sufficiently in advance and in parallel with other project activities, where feasible, such that any negative impact on project schedule is

minimised. Hence, the need for the development of a safety case is addressed in the Documentation Stage.

The safety case is the integration of arguments and evidence that describe, quantify and substantiate the safety, and the level of confidence in the safety, of a facility or activity. It must include the following:

- (1) A *framework* within which the information – arguments or analyses and facts or evidence – must be presented. The key categories describing the framework for the Safety Case are:
 - Organisation and Scope
 - Quality Assurance
 - Safety Philosophy, Principles and Criteria
- (2) A *complete set of facts* about the undertaking that provide the base of information for further analyses and assessments. This should include a description of the facilities and the activities proposed; a description of the procedures and processes for decision making; and the criteria and limits that will be imposed for the operation or performance of activities. The key categories describing the base of information for the Safety Case are:
 - Documented Design
 - Description of Activities and Facility Operation Program
 - Public Safety and Protection of the Environment
 - Occupational Safety
 - Security and Safeguards
- (3) The *analyses, assessments and arguments* that demonstrate satisfactory resolution of the safety issues raised. The set of information provided, specifically including the documented design and description of operation, is used to analyse the proposed facilities and activities and to evaluate the potential hazards. The ability of the design to address any issues raised is then evaluated by applying specifications for safety, determined through regulations, international recommendations, or best practices. Naturally, radiological hazards are emphasized in performing analyses for nuclear facilities, however all hazards must be addressed in the Safety Case. The analyses and assessments must be performed within the framework described and shown to be consistent with the collection of facts as documented. The key categories describing the analyses and assessments for the Safety Case are:
 - Safety Analysis
 - Accident Management
 - External Hazards

The challenge in developing the safety case for the long-term management of spent fuel is to address all the phases of activity before and after long-term storage and before and after final disposal. This would include the overall approach to the long-term management solution being addressed, which includes the activities to handle the spent fuel, to contain and package it as required, transportation of spent fuel, handling the receipt of the spent fuel and its interim storage or final disposal.

8.7 Works Stage

The largest, longest and most capital-intensive stage of the CISF project is the Works Stage. It involves licensing, construction, commissioning and related activities. According to FIDPM, the following is required for completion of the Works Stage:

- Completion of the works is certified in accordance with the provisions of the contract; or
- The goods and associated services are certified as being delivered in accordance with the provisions of the contract.

This stage is then complete when the Works Completion Report is approved.

8.7.1 Licensing

The key objective of the licensing is identifying and evaluating effects of the CISF on human health and safety considering both the public and the workers at the CISF, and the environment. National regulations as developed by NNR specify allowable radiological exposure limits (for both the public and the workers) and limits that may be applicable to environmental protection. As indicated earlier, license conditions include a few traditional stages, such as:

- Site approval
- Construction permit
- Operational permit
- Decommissioning license.

Each of the licensing stages requires preparation of an appropriate Safety Analysis Report (SAR) to support the application for the relevant stage. The content will reflect the particular stage of licensing, gradually increasing in scope to support an application to operate the constructed CISF.

8.7.2 Construction

8.7.2.1 Bid invitation

All technical and contractual information needed for the invitation of bids will be compiled. The functional specification will provide the bidders a full outline of the work to be done, including specifications, drawings, site details, and any special conditions affecting the work.

Bid invitation includes pre-qualification of bidders and suppliers and issuing of Bid Invitations Specifications (BIS). The objective of the BIS is to request for quotation by soliciting appropriately prepared bids from suppliers or vendors, complying with the scope of supply and services desired by the project and as outlined in the functional specification.

8.7.2.2 Awarding the contract

In this step, the bids are evaluated for their economics and other merits, and the supplier and the technology offered by the supplier are finally selected.

The main objective of the evaluation is to establish costs of procurement of the CISF in each bid and rank the available bids based not only on an economic figure of merit but also other non-economic evaluation criteria. Negotiations are conducted as may be needed. The contract is then awarded.

The contract is then managed through its various stages such as detailed design, procurement, construction, technology transfer and commissioning. Contract specialists in the project organisation carry out the management role in the procurement cycle throughout the various stages of procurement.

8.7.3 Commissioning

Commissioning of the CISF involves a logical progression of tasks intended to demonstrate the correct functioning of features specifically incorporated into the design to provide for safe storage of spent fuel [74]. In addition, operational procedures are confirmed and the readiness of staff to operate the facility is demonstrated. These procedures should cover both operational states and accident conditions.

The basis for commissioning should be established at an early stage as an intrinsic part of the project, and commissioning plans should be reviewed and, where appropriate, approved by NNR. The responsibilities of the different groups typically involved in commissioning (design, construction, commissioning, operating groups) should be clearly established. Arrangements should be established to cover:

- Specification of test work;
- Documentation provision and approval;
- Responsibilities;
- Safety of testing;
- Control of test work;
- Recording and review of test results;
- Modifications and re-testing;
- Regulatory requirements;
- Progression through stages of commissioning;
- Reporting of results and approval for operation;
- Retention of records.

For a modular system such as the proposed CISF, most of the commissioning is completed with the loading of the first storage module. However, some of the commissioning process becomes a part of routine operation as new modules are placed in service. A change in module design may also require some of the commissioning steps to be repeated for the new design.

Commissioning will usually be completed in several stages:

- Construction completion;
- Equipment testing;
- Performance demonstration;
- Inactive commissioning (cold testing);
- Active commissioning (hot testing).

Upon completion of commissioning, a final commissioning report shall be produced. This shall detail all testing and provide evidence of its successful completion. This report will provide assurance to NNR that its requirements have been satisfied and may provide the basis for the

subsequent licensing of the facility for full operation. Additionally, any changes to the CISF or procedures implemented during commissioning should be documented in an appropriate way.

8.8 Handover and Closeout Stages

8.8.1 Handover

The following activities shall be undertaken during the Handover Stage:

- Finalise and assemble record information which accurately reflects CISF and its associated infrastructure;
- Hand over the works and record information to NRWDI and if necessary, train NRWDI staff in the operation of the CISF.

This stage will be complete when the Handover/Record Information Report is approved.

8.8.2 Closeout

The Closeout Stage commences when the end user accepts liability for the works. It is complete when:

- Record information is archived;
- Defects certificates and certificates of final completion are issued in terms of the contract;
- Final amount due to the contractor is certified, in terms of the contract;
- Closeout Report is prepared by the Implementer and approved by the Client Department.

8.9 Project Schedule and Cost

A project schedule, listing activities, deliverables, and milestones within the CISF project, is developed as shown in Figure 8.3. the largest, longest and most capital-intensive stage of the project is the Works Stage. Licensing is the chief factor in the length of this stage, taking about 40 months to accomplish. Construction is expected to take about two years prior to commissioning of the facility and handing it over to NRWDI for operation.

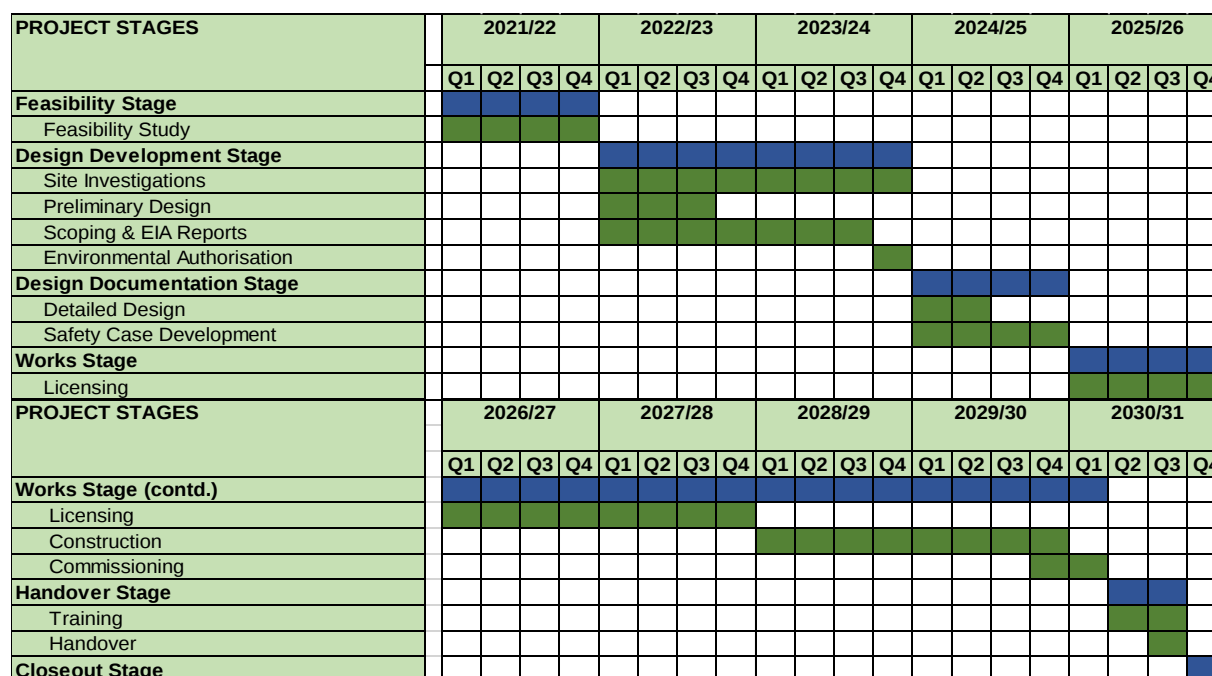


Figure 8.3: CISF Project Schedule

The cost for the CISF establishment is estimated as indicated in Table 8.6

Table 8.6: CISF Establishment Cost

PROJECT STAGES & TASKS	COST (ZAR '000)	
Initiation / Prefeasibility		1 900
Develop prefeasibility report & project plan		1 900
Concept / Feasibility		27 109
Conduct feasibility study & produce report		0
Siting		11 484
Environmental impact assessment	3 000	
Candidate sites (areas)	5 822	
Preferred site (area)	2 662	
Gateway review of feasibility information		2 000
Public affairs & stakeholder engagement		8 225
Project management		5 400
Design Development		74 099
Develop preliminary design		3 600
System development		47 274
System development management	5 984	
System optimisation	3 275	
Process system engineering	28 875	
Storage system engineering	7 700	
Security & safeguard engineering	1 440	
Develop detailed design & report		7 600

Gateway review of design development		2 000
Public affairs & stakeholder engagement		8 225
Project management		5 400
Design Documentation		67 879
Safety Assessment		27 654
<i>Safety assessment management</i>	6 303	
<i>Safety assessment - siting</i>	6 375	
<i>Safety assessment - operating license</i>	1 911	
<i>Safety assessment - facility operations</i>	10 210	
<i>Safety assessment - decommissioning (processing facilities)</i>	2 855	
Safety case compilation		15 000
Compile design documentation & produce report		6 000
Gateway review of design documentation		2 000
Public affairs & stakeholder engagement		8 225
Project management		9 000
Works		1 494 686
License application preparation		2 975
Licensing and approvals		11 211
Liaison with regulator	574	
Construction license	8 579	
Other government approvals/permits	808	
Operating license	1 250	
Review detailed design of disposal facility		2 000
Respond to requests for additional information		1 500
Develop disposal site infrastructure		247 100
<i>Access road and land improvements</i>	233 800	
<i>Security fence</i>	1 700	
<i>Security system</i>	11 600	
Construct disposal facility & auxiliary structures		1 086 771
<i>Excavation and grading</i>	3 800	
<i>Energy consumption</i>	272	
<i>Administration building</i>	61 700	
<i>Security/radiation protection building</i>	46 700	
<i>Processing building</i>	750 850	
<i>Operations/maintenance building</i>	100 100	
<i>Cask reception/transfer building</i>	99 250	
<i>Common ancillary facilities</i>	23 652	
<i>Commission management</i>	204	
<i>Equipment, spares and consumables</i>	243	
Engineering and legal support		37 800
Training of staff to operate the facility		20 000
Conduct system start-up & dry-run testing		28 000
Develop & produce Works Completion Report		6 000

Gateway review of Works information		2 000
Public affairs & stakeholder engagement		23 614
Project management		25 715
Handover		15 825
Finalise & assemble record information		2 000
Gateway review of Handover/Record Info		2 000
Public affairs & stakeholder engagement		8 225
Project management		3 600
Closeout		5 800
Prepare Closeout Report		2 000
Gateway review of Closeout information		2 000
Project management		1 800
Sub-total (ZAR '000)		1 687 298
Contingency / level of uncertainty (15%)		253 095
TOTAL (ZAR '000)		1 940 393

8.10 Concluding Summary

The development of the CISF project is guided by the FIDPM and its seven project stages, starting with prefeasibility stage and concluding with the closeout stage. The prefeasibility study determined that the CISF is doable but can only be established and operational by 2030 if all the necessary support such as funding and human resources are secured.

Based on the recommendation by the prefeasibility study report, the CISF project has entered the Feasibility Stage which, through a feasibility study, has adequately addressed: the programme to develop project infrastructure; regulatory requirements and due diligence; risk assessment and management; and procurement and contract strategy.

After completing a feasibility study, NRWDI must now proceed to the Design Development and Documentation Stages of the CISF project and develop both Preliminary and Detailed Designs of the CISF, respectively. In parallel with these activities, NRWDI should engage in the EIA process and develop a safety case for supporting a license application.

The largest, longest and most capital-intensive stage of the CISF project is the Works Stage. It involves licensing, construction, commissioning and related activities, and it is complete when the Works Completion Report is approved.

The Handover Stage, which succeeds the Works Stage, involves finalising and assembling record information which accurately reflects the CISF and its infrastructure and handing over the works and record information to NRWDI and, if necessary, training NRWDI staff in the operation of the CISF.

CHAPTER 9: CONCLUSIONS AND RECOMMENDATIONS

9.1 Overview

This Feasibility Study report was prepared by the National Radioactive Waste Disposal Institute (NRWDI) with the objective of (1) determining the technical feasibility of establishing (i.e., siting, designing, constructing and operating) the proposed centralised interim storage facility (CISF) on the Vaalputs national radioactive waste disposal facility site (in Northern Cape Province) for long-term storage of spent nuclear fuel arising from the country's nuclear reactors and (2) developing cost and schedule estimates for the CISF establishment.

The study has provided a review of centralised interim storage of spent fuel, covering the storage framework and systems in various countries as well as technological options for centralised storage. It then focused on site selection for a CISF, looking at the framework for siting (laws and regulations), site alternatives in site selection, Vaalputs site characterisation and justification and environmental impact assessment. The study further identified design alternatives for the CISF and established design criteria, requirements and characteristics; site structure and layout and storage facility and auxiliary structures; and cask operations methods and configurations.

The study established cost estimates for the CISF based on the three identified design alternatives and discussed estimating approach and reference for cost; basis of cost estimates; pre-operation, operation and decommissioning costs; and concluded with cost comparison and analysis. At this point, it was established that the Aboveground Concrete Cask and Module (ACCM) storage alternative is the most preferred option for the CISF, based on cost and other qualitative parameters.

In the study, financing and commercial aspects relating to the CISF establishment are considered and discussed. The discussion covered methods for spent fuel storage financing; financial review of implementing organisation; financial requirements of spent fuel storage

project; survey of financing sources; and commercial analysis of storage services. The study then focused on staffing and training requirements, including recruitment and qualification of personnel for the CISF, and concluded with describing project development, focusing on the seven project stages that guide the development of the CISF project and are based on the Framework for Infrastructure Delivery and Procurement Management (FIDPM).

The following conclusions and recommendations are drawn from the analyses and discussions in various chapters of the study.

9.2 Conclusions

- (1) The development of the CISF project is guided by the FIDPM and its seven project stages, starting with prefeasibility stage and concluding with the closeout stage. The feasibility study has confirmed that the CISF is doable and that it can only be established and operational by 2030 if all the necessary support such as funding and human resources are secured. The largest, longest and most capital-intensive stage of the CISF project is the Works Stage. It involves licensing, construction, commissioning and related activities, and it is complete when the Works Completion Report is approved.
- (2) The CISF concept is technically feasible and potentially economically viable. The study did not identify any obvious institutional deficiencies that would prevent completion of such a project. Storing South Africa's spent fuel in a single, safe, reliable, secure facility could enhance safeguards, physical protection and non-proliferation benefits.
- (3) Spent fuel storage in dry storage facilities (casks, modules, silos, vaults) on and away from the reactor site is not a new concept but has been in practice for decades. However, the concept has been bedevilled by a number of technical issues such as fuel behaviour (hydrogen effects, fuel drying, high burnup fuel, transport implications), fuel design and monitoring, and aging of facilities. All these remain a subject of research.
- (4) Vaalputs already has excellent features for a radioactive waste disposal site and these include factors such as: remoteness from international boundaries, low population density, low mineral potential, small growth and agricultural potential, and low rainfall and groundwater recharge. The site is an accepted and established low- and intermediate-level radioactive waste disposal site.
- (5) The ACCM design alternative is the most attractive of the considered CISF options in terms of cost. However, this option is not only the most favourable in terms of cost but also the most preferred in terms of the other qualitative considerations addressed in the study than the other alternatives. It is the quickest and easiest to implement because it is already licensed. Its performance capabilities are known, and it can be constructed in phases allowing earlier operations. These qualities are very important in light of the tight schedule and timelines the project is facing.
- (6) Information on alternative financing mechanisms for establishment of a CISF for long-term interim storage of spent fuel exists. The study addresses the financing requirements in the life cycle of the CISF from pre-operation phase (planning, siting, design, development and construction), through operation phase, to decommissioning phase. This information is

intended to contribute to timely, systematic and comprehensive consideration of the financial aspects of CISF planning and development beginning at an early stage in this process.

- (7) An effective organisational human resource management strategy and its implementation through HR processes in the organisation is critical to the success and sustainability of the CISF programme. There is significant investment required to ensure the availability of a competent workforce for each phase of the programme.

9.3 Recommendations

- (1) The CISF must, at a minimum, comply with the national regulations and with internationally accepted other requirements. For that reason, it should be in accordance at least with: (1) Joint Convention on the Safety of Spent Fuel Management and the Safety of Radioactive Waste Management, and (2) International Basic Safety Standards for Protection against Ionising Radiation and for the Safety of Radiation Sources.
- (2) State of the art technology for the CISF should be used to adhere to the ALARA principle and in order to enhance public acceptance. It is recommended that equipment should be available for repackaging defective fuel at the CISF in order to keep radioactive effluents reasonably low.
- (3) It is recommended that the measures taken for safeguards and physical protection should be based on experience and sound knowledge of the latest developments in these areas. Design and operations of the CISF should take into account the optimisation of safeguards and security concerns, including international terrorist activities and actions of sabotage. In addition, the consequences resulting from future changes in properties of the spent fuel should be considered.
- (4) All types of spent fuel related items should be accommodated by a properly designed CISF, i.e., spent fuel from various types of power reactors, spent fuel from research reactors and residues from reprocessing, e.g., vitrified high-level waste. Criteria for acceptance will be developed depending upon the expected types of spent fuel or other materials to be stored. Defective fuel may also be accommodated at the CISF, provided technology is available dealing with such defects.
- (5) During the successive phases of construction, operation and decommissioning of the CISF, a different set of industrial services is needed. These could include production of heavy mechanical equipment, maintenance workshops for equipment, etc. Easy access to such services could be an advantage, especially if the CISF offers additional services such as repackaging, consolidation, etc.
- (6) Human resources of different levels of qualification are needed for operation, maintenance and security. The infrastructure needed to provide acceptable living conditions for these employees and their families must either exist or need to be established within acceptable distance from the CISF.
- (7) As part of the licensing procedure, a systematic safety assessment will be carried out. Such a safety assessment should cover the entire lifetime of the facility, demonstrating that the

safety measures to manage the fuel will ensure compliance with the design values for: radiation exposure to personnel, radiation exposure to the public, and radioactive discharges. With this safety assessment, the overall feasibility of all handling, transport and other procedures affecting radiation protection and safety must also be demonstrated.

- (8) Due to licensing being a time-consuming activity owing to the extensive analysis required for supporting safety design of the facility, some planning may be required to assess the timelines and ensure that licensing activities are taken up sufficiently in advance and in parallel with other project activities, where feasible, such that any negative impact on project schedule is minimised. Hence, the need for the development of a safety case is addressed in the Documentation Stage.
- (9) Due to the extended storage periods (up to 100 years) and considering the rapid changes of information technology, the transfer of data in a usable form to future generations could become difficult. Special attention must be paid to the standardisation of data formats, content of the information, and data management. The facilities should implement and maintain a data processing and preservation system that would accept the data from the spent fuel generators and create and keep the history data records.
- (10) A decommissioning plan should be prepared prior to construction of the CISF, subject to regular updating throughout the operational period. The respective parties should agree upon responsibilities and funding for decommissioning in advance.
- (11) In determining whether to establish the CISF, the costs and liabilities to all affected parties must be weighed against benefits. Costs will be incurred for all activities over many years from site selection for the facility (including phased development or capacity extension of an existing facility) through construction, licensing procedure, start-up, operation, transport, maintenance and decommissioning of the facility. Thus, economic considerations would normally be an important (but not the only) driving force for a centralised storage solution.
- (12) Since CISF storage is not the final stage in the disposition of spent fuel, retrieval is important at any time during the storage period and in particular at the end of the lifetime of the CISF. To this end, fuel handling and loading systems and equipment would be an integral part of the storage system, the need for spent fuel handling during long-term storage may arise from the transfer to another storage system for various reasons. The lifetime of the CISF should be determined based on the necessary storage period prior to any future disposition, be it reprocessing or disposal.

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APPENDIX A: PROJECT STAGES AND DELIVERABLES IN TERMS OF THE FRAMEWORK FOR INFRASTRUCTURE DELIVERY AND PROCUREMENT MANAGEMENT

Stage		Project Stage Deliverables
No.	Name	End of Stage Deliverable
1	Initiation or Prefeasibility	Initiation Report or Prefeasibility Report (i) The Initiation Report, which defines project objectives, needs, acceptance criteria, organisation's priorities and aspirations, procurement strategies, and which sets out the basis for the development of the Concept Report. Or (ii) A Prefeasibility Report, is required on mega capital projects to determine whether or not to proceed to the Feasibility Stage, where sufficient information is presented to enable a final decision to be made regarding the implementation of the project. Stage 1 is complete when the Initiation Report or Prefeasibility Report is approved.
2	Concept or Feasibility	Concept Report or Feasibility Report The Concept Stage represents an opportunity for the development of different design concepts to satisfy the project requirements, as developed during Stage 1. It also presents, through the testing of alternative approaches, an opportunity to select a particular conceptual approach. The ultimate objective of this stage is to determine whether the project is viable to proceed, with respect to available budget, technical solutions, time-frame and other information that may be

		required. The Concept Report should as a minimum, provide the following information: - Document the initial design criteria, cost plan, design options and the selection of the preferred design option, or the methods and procedures required to maintain the condition of infrastructure for the project. - Establish the detailed brief, scope, scale, form and cost plan for the project, including, where necessary, the obtaining of site studies and construction and specialist advice. - Provide an indicative schedule for documentation and construction or maintenance services, associated with the project. - Include a site development plan, or other suitable schematic layouts of the works. - Describe the statutory permissions, funding approvals and utility approvals required to proceed with the works associated with the project. - Include a baseline risk assessment for the project, and a health and safety plan, which is a requirement of the Construction Regulations, issued in terms of the Occupational Health and Safety Act No.85 of 1993. - Contain a risk report linked to the need for further surveys, tests, other investigations and consents and approvals, if any, during subsequent stages and identified health, safety and environmental risk. A Feasibility Report shall, as a minimum, provide the following information: - Details regarding the preparatory work covering: - A needs and demand analysis with output specifications. - An options analysis. - A viability evaluation covering: - A financial analysis. - An economic analysis, if necessary. - A risk assessment and sensitivity analysis; - A professional analysis covering: - A technology options assessment. - An environmental impact assessment. - A regulatory due diligence. - An implementation readiness assessment covering: - Institutional capacity. - A procurement plan. Stage 2 is complete when the Concept Report or the Feasibility Report is approved.
3	Design Development	Design Development Report The Design Development Report shall as necessary: - Develop in detail the approved concept to finalise the design and definition criteria. - Establish the detailed form, character, function and costings. - Define all components in terms of overall size, typical detail, performance and outline specification. - Describe how infrastructure or elements or components thereof are to function, how they are to be safely constructed, how they are to be maintained and how they are to be commissioned. - Confirm that the project scope can be completed within the budget or propose a revision to the budget.

		Stage 3 is complete when the Design Development Report is approved.
4	Design Documentation	Design Documentation Design documentation provides the: a) production information that details, performance definition, specification, sizing and positioning of all systems and components that would enable construction; b) manufacture, fabrication and construction information for specific components of the work informed by the production information. Stage 4 is complete when the Design Documentation Report is approved.
5	Works	Completed Works (capable of being used or occupied) The following is required for completion of the Works Stage: a) Completion of the works is certified in accordance with the provisions of the contract; or b) The goods and associated services are certified as being delivered in accordance with the provisions of the contract. Stage 5 is complete when the Works Completion Report is approved.
6	Handover	Handover (works taken over by user or owner); Completed Training; Record Information The following activities shall be undertaken during the handover stage: a) Finalise and assemble record information which accurately reflects the infrastructure that is acquired, rehabilitated, refurbished or maintained; b) Hand over the works and record information to the user organisation and if necessary, train end user staff in the operation of the works. Stage 6 is complete when the Handover/Record Information Report is approved.
7	Closeout	Defects Certificate or Certificate of Final Completion; Final Account; Closeout Report The Closeout Stage commences when the end user accepts liability for the works. It is complete when: a) Record information is archived; b) Defects certificates and certificates of final completion are issued in terms of the contract; c) Final amount due to the contractor is certified, in terms of the contract; d) Closeout Report is prepared by the Implementer and approved by the Client Department. Stage 7 is complete when the Closeout Report is approved.

APPENDIX B: RATINGS OF CISF DESIGN ALTERNATIVES BY PARTICIPANTS IN MULTI-CRITERIA ANALYSIS

Rating from Participant 1:

Criteria/Attributes	ACCM	UCMS	ESMV
	Score 1, 2, 3, 4 or 5		
Health & Safety	3	4	3
Environmental Protection	3	4	3
Safeguards & Security	3	4	3
Policy & Strategy	4	3	2
Societal Acceptance	4	4	3
Cost & Affordability	5	2	4
Executability & Deliverability	4	3	3
Economic Benefit	4	3	4
Total Score	30	27	25

Rating from Participant 2:

Criteria/Attributes	ACCM	UCMS	ESMV
	Score 1, 2, 3, 4 or 5		
Health & Safety	4	3	4
Environmental Protection	3	3	4
Safeguards & Security	2	3	4
Policy & Strategy	5	5	5
Societal Acceptance	3	2	2
Cost & Affordability	4	2	3

Executability & Deliverability	4	3	2
Economic Benefit	4	4	4
Total Score	29	25	28

Rating from Participant 3:

Criteria/Attributes	ACCM	UCMS	ESMV
	Score 1, 2, 3, 4 or 5		
Health & Safety	3	4	4
Environmental Protection	3	4	4
Safeguards & Security	3	4	4
Policy & Strategy	4	4	4
Societal Acceptance	3	3	3
Cost & Affordability	4	3	2
Executability & Deliverability	4	3	2
Economic Benefit	4	3	2
Total Score	28	28	25

Rating from Participant 4:

Criteria/Attributes	ACCM	UCMS	ESMV
	Score 1, 2, 3, 4 or 5		
Health & Safety	3	5	4
Environmental Protection	5	3	4
Safeguards & Security	3	5	4
Policy & Strategy	5	1	3
Societal Acceptance	5	3	4
Cost & Affordability	5	1	3
Executability & Deliverability	5	1	3
Economic Benefit	3	5	4
Total Score	34	24	29

Rating from Participant 5:

Criteria/Attributes	ACCM	UCMS	ESMV
	Score 1, 2, 3, 4 or 5		
Health & Safety	3	2	5
Environmental Protection	1	1	4
Safeguards & Security	1	5	4
Policy & Strategy	2	3	4
Societal Acceptance	1	4	3
Cost & Affordability	5	1	4
Executability & Deliverability	5	2	4
Economic Benefit	1	3	4
Total Score	19	21	32

Rating from Participant 6:

Criteria/Attributes	ACCM	UCMS	ESMV
	Score 1, 2, 3, 4 or 5		
Health & Safety	4	3	5
Environmental Protection	5	3	5
Safeguards & Security	3	4	3
Policy & Strategy	4	4	4
Societal Acceptance	2	1	3
Cost & Affordability	2	1	2
Executability & Deliverability	4	3	3
Economic Benefit	4	4	4
Total Score	28	23	29

Rating from Participant 7:

Criteria/Attributes	ACCM	UCMS	ESMV
	Score 1, 2, 3, 4 or 5		
Health & Safety	1	2	2
Environmental Protection	1	2	3
Safeguards & Security	3	2	1
Policy & Strategy	1	3	2
Societal Acceptance	3	2	1
Cost & Affordability	1	3	2
Executability & Deliverability	1	2	3
Economic Benefit	1	1	1
Total Score	12	17	15

Sum of Ratings from All 7 Participants:

Criteria/Attributes	ACCM	UCMS	ESMV
	Score 1, 2, 3, 4 or 5		
Health & Safety	23	25	29
Environmental Protection	23	22	26
Safeguards & Security	18	29	26
Policy & Strategy	28	24	26
Societal Acceptance	21	20	22
Cost & Affordability	30	11	21
Executability & Deliverability	31	18	19
Economic Benefit	23	26	27
Total Score	197	175	196

Average Ratings from All 7 Participants:

Criteria/Attributes	ACCM	UCMS	ESMV
	Score 1, 2, 3, 4 or 5		
Health & Safety	3,3	3,6	4,1
Environmental Protection	3,3	3,1	3,7
Safeguards & Security	2,6	4,1	3,7
Policy & Strategy	4,0	3,4	3,7
Societal Acceptance	3,0	2,9	3,1
Cost & Affordability	4,3	1,6	3,0
Executability & Deliverability	4,4	2,6	2,7
Economic Benefit	3,3	3,7	3,9
Total Score	28,1	25,0	28,0