A quick guide for multipurpose dry cask storage of VVER-440 nuclear fuel

GUIDELINES

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Foreword

In 2021, the European Commission (EC) adopted a new proposal for a Council Regulation[1] establishing a dedicated financial programme for decommissioning nuclear facilities and managing Radioactive Waste (RAW). This instrument covers the co-funding of the decommissioning programmes of Bulgaria, Slovakia, and the decommissioning of the Joint Research Centre (JRC). A separate Council Regulation[2] was adopted for the decommissioning programme of Lithuania.

The EC JRC is mandated to foster the spread of decommissioning knowledge across all the European Union Member States and facilitate knowledge sharing arising from implementing the abovementioned decommissioning programmes, funded by the Nuclear Decommissioning Assistance Programme (NDAP).

The decommissioning operators from the NDAP (NDAP Operators) implemented and tested a knowledge management methodology in 2021 through Project ENER/D2/2020-273. Using this methodology, the NDAP Operators can develop Knowledge Products that are currently available to share with other European stakeholders. In addition, this methodology is under implementation in the JRC Nuclear Decommissioning and Waste Management Directorate (NDWMD), which becomes a knowledge generator extracting the knowledge from the ongoing decommissioning activities at the different sites (Geel, Ispra, Karlsruhe, and Petten).

The JRC NDWMD aims to become a Centre of Excellence in nuclear decommissioning knowledge management and develop a decommissioning knowledge platform which allows exchanging information and building on the best practices in the EU inside the multi-annual financial framework (2021 – 2027) strategy. The operational phase of the project is expected to start in 2024 to develop ties and exchanges among EU stakeholders and document explicit knowledge and make it available through multi-lateral knowledge transfers on decommissioning and waste management governance issues, managerial best practices, technological challenges, and decommissioning processes at both operational and organisational level, to develop potential EU synergies.

This is a Knowledge Product prepared by the IDOM Consulting, Engineering, Architecture S.A.U. for the NDWMD.

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[1] Council Regulation (Euratom) 2021/100 of 25 January 2021 establishing a dedicated financial programme for the decommissioning of nuclear facilities and the management of RAW, and repealing Regulation (Euratom) No 1368/2013

[2] Council Regulation (EU) 2021/101 of 25 January 2021 establishing the nuclear decommissioning assistance programme of the Ignalina nuclear power plant in Lithuania and repealing Regulation (EU) No 1369/2013

PRODUCT DESCRIPTION

The present knowledge product, prepared by IDOM Consulting, Engineering, Architecture S.A.U., is guidance and recommendations based on the experience gained during the study and the implementation of the methodology used to manage spent fuel from VVER-400 and VVER-1000 reactors at nuclear power plants in Eastern Europe. This product was developed as part of an effort to disseminate and share with all EU State Members the knowledge acquired during the decommissioning and radioactive waste management activities performed with NDAP funding under the Council Regulation (Euratom) 2021/100 of 25 January 2021.

ABSTRACT

Currently, in Eastern Europe, VVER nuclear facilities will require transferring their irradiated fuel to optimised interim storage systems, either due to the cost/ageing of the current facilities or due to the dismantling of their plants. One of the most popular options is dry storage using multipurpose casks. This solution has proven to be the best-optimised technology because it is versatile and economical. However, many nuclear facilities do not have the experience or design necessary for transferring, transporting, and storing this type of technology. Users of this guidance will gain valuable insights into using this technology and will learn practical strategies for its implementation.

OBJECTIVE

This knowledge product establishes a basic guideline to facilitate decommissioning operators' decision-making regarding extracting, transporting, and storing VVER spent fuel when a Ventilated Vertical Storage system is used.

APPROACH

This product provides guidance for extracting, transporting, and storing VVER irradiated fuel in multipurpose dry cask storage.

RESULTS, FINDINGS, AND INSIGHTS

This guidance covers the following key points:

- Introduction to multipurpose dry storage technology
- Loading and packaging process
- Commonly used auxiliary equipment
- Fuel loading and storage strategies
- Fuel transportation strategies
- Maintenance and operation
- Analysis of plant spaces for locating auxiliary equipment, performing manoeuvres, and transferring casks to the Independent Spent fuel Storage Installation (ISFSI)
- ISFSI maintenance and operation

TARGET USERS

This document's objective is to provide EU Decommissioning Operators with decision-making support in extracting, transporting, and storing VVER spent fuel when a Ventilated Vertical Storage system is used. This guidance provides users with valuable insights into utilising this technology and offers practical strategies for its implementation.

KEYWORDS

NUCLEAR DECOMMISSIONING, POST-SHUTDOWN ACTIVITIES, SPENT FUEL REMOVAL

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LIST OF ACRONYMS AND DEFINITIONS

ALARA	As Low As Reasonably Achievable
CTB	Cask Transfer Building
CTF	Canister Transfer Facility
DPC	Dual-purpose Cask
DS	Drying System
HLW	High-level Radioactive Waste
LWR	Light Water Reactor
MPC	Multi-Purpose Canister
MSC	Multipurpose Sealed Capsule
TM	Transfer Module
VVSU	Ventilated Vertical Storage Unit
ZPT	Zero Profile Transporter
SC	Storage Cask

LIST OF FIGURES

1. INTRODUCTION

Currently, in Eastern Europe, nuclear facilities will require transferring their VVER irradiated fuel to other types of storage systems, either due to the cost/ageing of the facilities or due to the dismantling of their plants. One of the most popular options is dry storage using Multi-Purpose Canisters (MPCs). This solution has proven to be versatile and economical. However, many nuclear facilities do not have the experience or design necessary for transferring, transporting, and storing this type of technology. Users of this guidance will gain valuable insights into using this technology and will learn practical strategies for its implementation.

1.1. An Introduction to Dry Storage Casks

Over the last decades, intensive development work and progress have been made on various dry storage technologies. For practical and economic reasons, various dry spent fuel storage technologies have been developed to meet the specific requirements of different reactor fuels, e.g., maximum allowable cladding temperature and cover gas environment (air, CO_2, or helium).

A dry storage cask contains the spent fuel using physical barriers, including a metal body or concrete body with a metal liner. In addition to storage, some casks can also be used to transport spent fuel and other radioactive materials. Although multiple designs are available, with some examples presented in **Figure 1**, the following features are standard:

Fixed position	Cask sealing	Passive cooling	Radiation shielding

Spent fuel assemblies are fixed using a basket or holding them within a metal canister.	The cask is sealed using either a bolted closure with seals or welding.	Decay heat is removed through conduction, radiation, and natural convection.	The cask body and the outermost fuel bundles provide radiological shielding.

Figure 1. Examples of different cask types at Idaho National Laboratory, USA *[1]*

Initially, dry storage systems were designed to provide storage for a single purpose. As an alternative to single-purpose (storage only) systems, dual-purpose cask (DPC) designs followed, allowing for storage and transport in the same cask without rehandling the fuel assemblies. Dry storage systems planned to meet disposal requirements, in addition to storage and transportation, are referred to as **Multi-Purpose Canisters**; these systems are conceptual at present as the disposal stage is yet to be implemented.

Loading of fuel and drying is undertaken in the spent fuel pool (depending on the type of system, further steps may be required once removed from the pool). Concerning the subsequent handling of the fuel, two major types of dry storage systems can be distinguished:

Bare fuel systems

The fuel is stored within a single unit (e.g., a dual-purpose cask) that provides all safety functions, such as containment and shielding and is closed using a bolted lid. The entire system can be stored and transported as a single package.

Canisterised systems

The fuel is stored within a thin-walled canister welded closed post-drying. The canister provides a containment function, but shielding is provided by either a storage or transport overpack (e.g., cask or Storage Cask). The canister must be moved between the storage shielding structure and the transportation overpack for subsequent transport. The internal structure of the canister is in the shape of a "honeycomb" and is referred to as a “basket”. An example of a basket and canister can be seen in **Figure 2**.

In both systems, internal baskets can maintain the fuel in a subcritical array and may contain neutron-absorbing materials.

Figure 2. Appearance of the basket (left) and a canister with the basket inside (right) *[2]*

Containers can also be classified by their construction materials (metal and concrete) and orientation (vertical or horizontal). **Figure 3** shows a schematic view of the main designs of dry storage systems.

This guideline will focus on vertical concrete multipurpose containers with a passive ventilation cooling system (highlighted with the red circle in **Figure 3**), a versatile and economical design with proven great potential in spent fuel management.

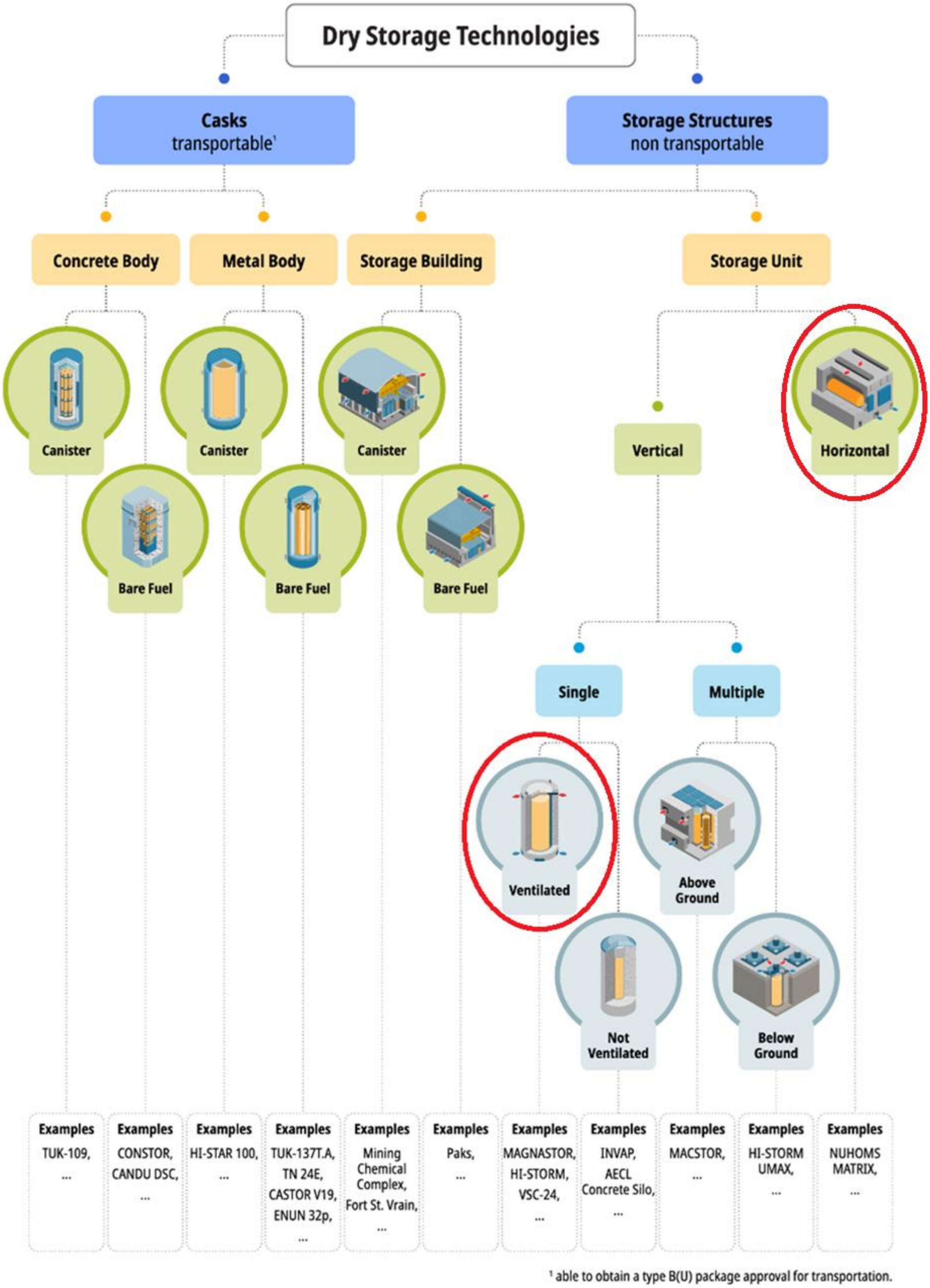

Figure 3. Currently available dry storage technologies *[2]*

1.2. Dry Storage Units

Dry storage units are monolithic or modular reinforced concrete structures. The concrete provides shielding, while containment is provided by either an integral inner metal liner that can be sealed after fuel loading or by a separate sealed metal canister. More than half of the spent fuel inventory in storage units is in the USA. Brazil, Mexico, Slovakia, Slovenia, Spain, Switzerland, Ukraine, and the United Kingdom are all at different stages of introducing storage units as part of their storage strategies.

Dry storage units can be arranged either in a vertical or horizontal configuration. **Figure 4** shows the spent fuel inventory distribution between vertical ventilated, vertical non-ventilated and horizontal storage units by region. The horizontal configuration is mainly distributed in North America. The VVER fuel this guide focuses on has a higher burnup and heat output than non-ventilated vertical units are typically designed for, which is why we will focus solely on the ventilated units.

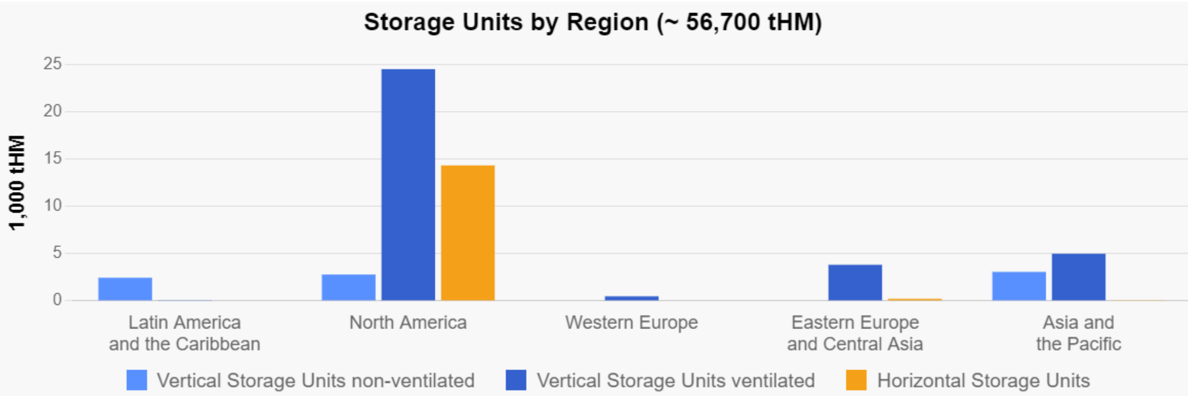

Figure 4. Regional overview of spent fuel in dry storage units in 2019 *[2]*

1.2.1. Ventilated Vertical Storage Units (VVSU)

Ventilated vertical storage units can house LWR fuel and/or high-level waste (HLW) in a seal-welded dual-purpose canister (**Figure 5**). The vertical storage cask (VSC) was developed by Sierra Nuclear, MAGNASTOR (Nuclear Assurance Corporation, NAC Intl.). MAGNASTOR and HI-STORM (Holtec International Storage Module) are examples of ventilated vertical storage units (see **Figure 6**). Air inlets at the bottom of the unit and an outlet at the top ensure sufficient cooling by natural convection. These storage units have been mainly deployed in Ukraine and the USA. The other example of a silo type is Holtec International's underground storage facility (HI-STORM UMAX).

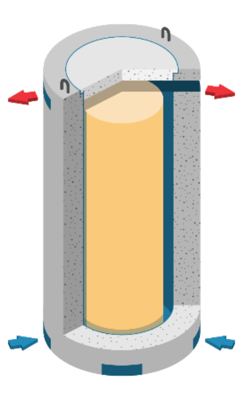

Figure 5. Ventilated vertical storage unit *[2]*

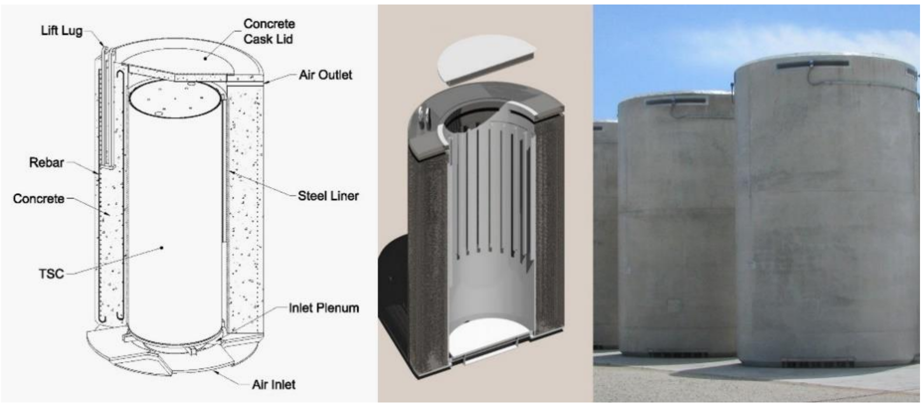

Figure 6. Vertical storage unit (MAGNASTOR, NAC) system with a canister inside [2]

1.2.2. Ventilated Horizontal Storage Units (VHSU)

Horizontal units use the same concept as vertical monolithic units in a different orientation. These storage units can be arranged in one or two levels and monitored for dose rate and leak tightness. **Figure 7** shows a diagram of the system. Orano TN's matrix horizontal storage module (HSM) in **Figure 8** is an example of a two-level unit designed to reduce the storage footprint. Spent fuel is loaded vertically into metal canisters, which are welded shut and taken to the storage area inside a transfer cask. The canister is pushed out of the transfer cask horizontally and placed inside the concrete storage module (**¡Error! No se encuentra el origen de la referencia.**).

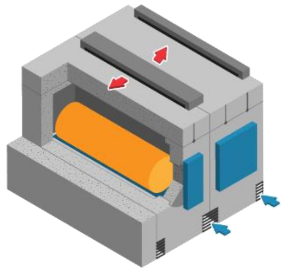

Figure 7. Cut-away view of a horizontal storage unit [2]

Figure 8. Horizontal multiple storage unit *[3]*

Figure 9. Process of introducing a cask into the HSM *[4]*

1.3. Main typical components

CANISTER AND TRANSFER MODULE

The canister is a fully welded stainless-steel capsule that houses the spent fuel assemblies in a stainless-steel frame (see **Figure 10**). The Transfer Module (TM) is designed to contain the canister during the loading and unloading processes and its transfer from the spent fuel pool to the storage or transport module and to provide a radiological and structural barrier during these operations (see **Figure 11**).

TRANSPORT CASK

The Transport Cask (TC) is a metal cask that transports fuel elements over long distances (see **Figure 12**). Local companies may fabricate transfer and transport casks under the supplier's supervision.

STORAGE CASK (for VVSU)

The Storage Cask (SC) is a robust, heavy-walled, cylindrical steel and concrete vessel positioned vertically without anchoring on slabs. It consists of a lid incorporating concrete shielding, the principal body formed by the inner and outer ferrules connected by radial ribs, top and bottom plates that encase the concrete, and the canister support plate (see **Figure 13**).

STORAGE MODULE (for HVSU)

The Storage Module (SM) is robust and heavy-walled, allowing the loaded canister to be stored horizontally. It comprises a concrete module that protects the canister from the outside while providing radiological shielding. This construction enables passive cooling by air convection and monitoring of the canister status (see **Figure 14**).

TRANSPORT VEHICLE

The transport vehicle is a tracked type used for the vertical handling and transporting loaded or empty containers from outside the fuel building to the ISFSI or vice versa. The major components of the transport vehicle are the structural members, lifting devices, and supports that support all or a portion of the SC's weight in moving operations. There are many vehicles for transporting SC, from cars with tyre systems with independent mobility (**Figure 15**) to heavy trailers for trucks (**Figure 16**).

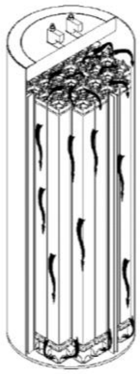

Figure 10. Canister [5]

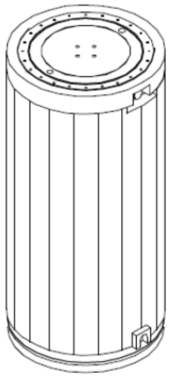

Figure 11. Transfer Module [5]

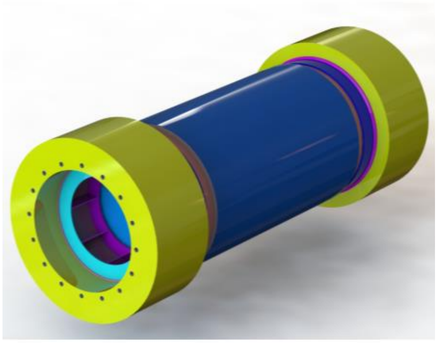

Figure 12. Transport Cask [6]

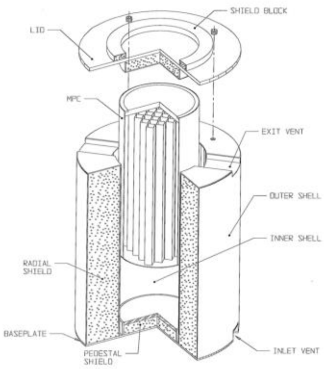

Figure 13. Storage cask with the multi-purpose cask partially inserted [5]

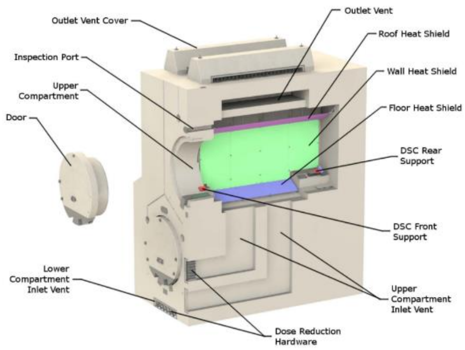

Figure 14. Storage Module [7]

Figure 15. Vehicle for transporting SCs with tyres [8]

Figure 16. Heavy trailer to move SCs with truck [9]

2. SPENT FUEL ACCEPTANCE CRITERIA

Specific parameters must be met for the spent fuel to be suitable for storage within the canister. The most important parameters are listed below.

Dimensions & Shape	Maximum FA initial enrichment	Maximum FA discharge burnup	Maximum total thermal power	Maximum FA averaged thermal power	Maximum FA individual thermal power

The size and shape of the canister (and the basket) shall be compatible with the introduced fuel elements. For example, the canister shown in **Figure 17** is specially designed for VVER-440 and VVER-1000 fuel, and the basket is shaped like a hexagonal beehive. The maximum thermal power for one spent fuel assembly (uniform pattern) is an average of the thermal power that the fuel elements can have. The maximum thermal power for one spent fuel assembly (regionalised pattern) defines the maximum thermal power that a fuel element can have depending on the area where it will be stored within the canister.

The arrangement of fuel elements according to their thermal power can follow an "out-in" power pattern from yellow to red in decreasing order (see **Figure 17** - left).

From the **radiological safety** and **thermal control** perspective, the most relevant parameters are the initial fuel enrichment, burnup, and cooling time since being removed from the reactor. The remaining parameters can be estimated from these.

Thermal load evacuation: The heat evacuated from a particular fuel assembly will depend on its position within the MPC canister. Since heat transfer occurs on the outer surface of the canister, fuel elements placed in the outermost area will dissipate a more significant thermal load than those found in the inner part.

Shuffling for shielding: When the heat released by the fuel elements is below the canister requirements, the pattern can be reversed to minimise the radiological impact. In this way, the elements with the highest radiological emitter can be placed in the centre, thus taking advantage of the shielding effect of the surrounding fuel assemblies.

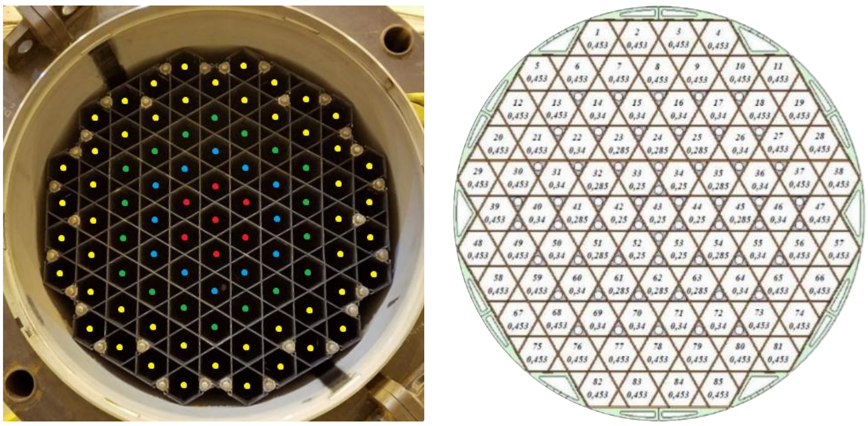

Figure 17. canister Multi-Purpose Canister basket structure for VVER-440 spent fuel [10] [11]

3. OVERPACK LOADING AND PACKAGING

This section briefly reviews the sequence of common loading activities described by the cask supplier. The equipment involved in this sequence is described in the following section.

3.1. Overpack Loading and Packaging Process

This is a common loading and storage procedure, but the sequence can vary due to site-specific conditions or strategies analysed in Section 5. The following is a standard procedure for spent fuel loading, transportation, and storage in a vertical ventilated storage system:

1. Perform TM receipt inspection, cleanliness inspection and preparation for loading.
2. Perform canister receipt inspection, cleanliness inspection and preparation for loading.
3. Install the canister inside TM following site-approved rigging procedures.
4. Fill the annulus between the canister and TM with non-contaminated water just below the inflatable seal seating surface and install the inflatable annulus seal around the canister.
5. Fill the canister with water with the same properties as spent fuel pool water.
6. Place the TM in the designated cask loading area.
7. Verify the spent fuel pool meets boron concentration requirements.
8. Following the approved fuel loading pattern, load the pre-selected fuel assemblies into the canister.
9. Install the canister's primary lid.
10. Remove the TM from the spent fuel pool while performing outer decontamination and place it on the drying platform.
11. Weld the canister lid.
12. Drain, dry (vacuum or DS drying method) and backfill the canister with helium.
13. Pressure and leakage tests.
14. Installation and weld of the canister secondary lid.
15. TM Top Lid Installation and drain the remaining water from the annulus.
16. Transfer TM to the ISFSI using equipment designed for such a function.
17. The final step, storing the canister in the ISFSI, varies depending on the system used. In the VVSU the canister is transferred to an SC or a VSM in the HVSU, while it is entered into an HSM.

3.2. Important aspects in the implementation

Implementing the spent fuel storage system requires considering several key aspects to ensure efficiency and safety. This comprehensive approach involves understanding the various phases of the process, such as planning, design, construction, and operation. Each phase presents unique requirements and challenges that must be addressed to avoid delays and ensure seamless integration with existing infrastructure.

PHASES OF THE PROCESS

A thorough understanding of each phase is crucial. The planning phase involves initial assessments and feasibility studies to determine the best approach. The design phase requires detailed engineering to create blueprints and specifications. Construction involves the physical building of the storage system, and the operation phase focuses on maintaining and monitoring the system to ensure its longevity and safety.

DIMENSIONS AND LOADS

The dimensions and loads of the components and vehicles involved are critical factors. Precise measurements and weight calculations are necessary to ensure that all equipment can be safely transported and installed. This involves detailed engineering assessments to confirm that the storage system can handle the physical stresses and loads it will encounter during its operational lifespan.

INTERFERENCE WITH EXISTING EQUIPMENT

Managing interferences with the plant's existing equipment is crucial. This involves mapping out the entire facility to identify potential conflicts and designing solutions to mitigate any issues. A top priority is ensuring that new installations do not disrupt current operations or threaten plant safety.

ACCESS TO UTILITIES

Access to essential utilities such as power outlets, water, and compressed air is another critical consideration. These resources must be readily available at the installation site to support the operation of various tools and machinery. Adequate planning is required to ensure no interruptions to these services during the implementation phase.

CRITICAL PATH FOR CANISTER TRANSFER

The critical path for the canister transfer process must be meticulously planned and executed. This involves identifying the most efficient route and method for moving the spent fuel canisters from their current location to the new storage system. Safety, speed, and cost-effectiveness must be balanced to determine the optimal transfer strategy.

3.3. Auxiliary Equipment

This section will review the main features of the auxiliary equipment involved in the SC cask system loading and storing procedures.

DRYING SYSTEM (DS)

The DS (see **Figure 18**) is the equipment used to "dry" the canister capsule [5] and [12]. Recirculating helium through the canister capsule at elevated temperature and pressure removes moisture to achieve certain gas dew point temperatures. To dry the capsule, the gas from the canister, loaded with moisture, enters the DS and passes through a heat exchanger with a fan. The moisture from the helium in the capsule condenses in the heat exchanger, and the water is subsequently collected in the machine's drains. Once condensed to room temperature, it passes through a separator and filters to be pressurised and heated again. This cycle is repeated until certain helium dew point temperatures are achieved. At this time, the antifreeze from the cooler (equipment associated with the DS) is passed through a secondary exchanger of the DS.

The helium moisture from the canister will condense well below ambient temperature. Once certain dew point temperatures are achieved, the canister capsule will be filled at a known pressure and temperature (using the DS) and sealed. The DS should be located as close as possible to the vent and drain penetrations of the canister capsule to minimise heat loss from the DS to the canister as much as possible.

Figure 18. Drying system [13]

DRYING SYSTEM CHILLER

The chiller is equipment associated with the DS, whose mission is to maintain the antifreeze circulating in the DS in a drying phase at a low temperature [5] and [12]. The chiller should be located close to the DS and have sufficient adjacent space for cooling. The connection hoses between the DS and the chiller will be as short as possible, thus minimising the antifreeze's heat gain.

SHUT-OFF AND BY-PASS VALVE SYSTEM

The shut-off and by-pass valve system and the particle pre-filter are designed to allow helium to pass through the canister or recirculate it through the DS and allow container draining, water recirculation or hydraulic testing. This system must be connected between the canister's vent and drain penetrations and the DS system. The valve system should be as close as possible to the canister, and the particulate filter should be located away from the DS to prevent unnecessary radiation doses to the DS operators in case of filter contamination.

WELDING EQUIPMENT

The welding equipment comprises a power source, a remote monitor viewing unit, and a welding head. The equipment has the necessary hose lengths to allow the welding head to be placed on top of the lid and the power source and control console to be away from the container.

YOKES AND EXTENSIONS

A hitch-yoke is necessary for the TM's movement. This yoke has 2 pins that attach directly to the TM's lugs. It is also used to position the canister lid under water. An extension will be necessary to extract the TM container from the cask loading pit without introducing the crane cables into the fuel pool. It will also be required to use a "short" extension to transfer the canister from the TM to the SC.

The cask system designer is responsible for designing all these tools, and the necessary support stands must be provided to carry out the manoeuvres in complete safety.

SEALING RING AND OVERPRESSURE SYSTEM

The sealing ring is an inflatable gasket that seals the space between the canister and the TM container. This space must be kept free of contamination. The inflatable seal ring is installed at the top to prevent contaminated pool water from entering the annular space. The annular space is also filled with demineralised water and kept at a slight overpressure, thus ensuring that any small leakage from the ring does not result in contaminated pool water entering the annular space.

Due to the importance of this system, IDOM recommends using instrumentation air to fill and maintain the inflatable seal ring.

EXTRACTION HOOD

The drains of the DS, prefilter, valve system, and accumulator tanks must be connected to a liquid/gas treatment system.

The best option for treating these drains is through a floating bell (see **¡Error! No se encuentra el origen de la referencia.**), which could be in the corner of the cask pit. This stainless-steel hood allows easy decontamination.

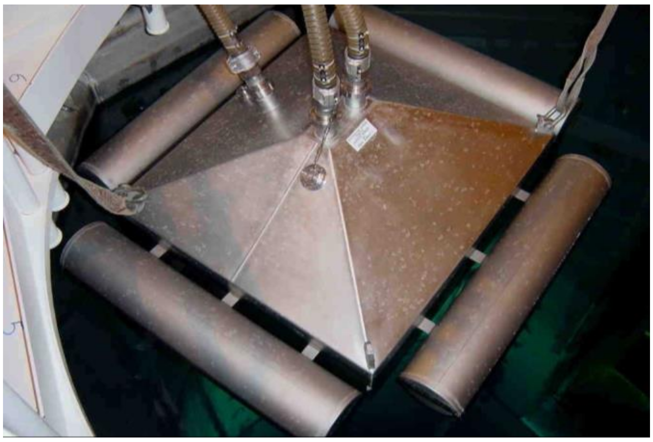

Figure 19. Top view of the floating bell

ASSEMBLY OF ELECTRICAL CONNECTIONS

During the container drying and welding phases, all activities will be subject to the correct operation of the electrical equipment supplied. Any equipment failure during these activities would mean having to apply special procedures and conditions to keep the spent fuel safe. Once the system to be used has been determined, the different consumptions of the associated equipment must be studied to design the switchboard.

IDOM recommends assembling a single electrical panel to avoid a failure in the electrical supply.

DRAINAGE TABLE ASSEMBLY

Due to the SC container's special characteristics, demineralised water, borated water, and compressed air must be used during the different drying and testing activities.

- Compressed air is used to operate the diaphragm pumps for water recirculation in the canister and partial water suction during welding. In this case, a second compressed air intake from instrumentation should be available for inflation and the annular space seal ring pressurisation.
- Vent intakes shall be connected to the plant's gas treatment system: one intake shall be connected to the fume hood and the other to the DS vents.
- A borated water intake will be required. This would be used to fill the canister capsule before introducing it into the water and for performing the hydraulic test of the canister. The borated water can be cleaned or contaminated to avoid generating more waste.
- Two demineralised water intakes are needed, used in different container handling activities, such as filling the annular space with water or container decontaminating.
- Two contaminated water drains are needed, connected to the plant's liquid treatment system.

4. LOADING, TRANSPORT & STORAGE STRATEGIES

Moving spent fuel from the reactor to its final storage location offers several possibilities. This section will develop what is thought to be the most reasonable strategy. It is important to note that this strategy comprises three solutions, which only differ in a few steps. These "sub-strategies" are identified as:

- Transport of spent fuel using the TM
- Transportation of spent fuel using the TC
- Transportation of spent fuel using the SC

In section 4.4, there is a brief comparison highlighting each strategy's main advantages and disadvantages. Choosing the most convenient strategy will depend on the specific characteristics and final requirements implemented in the power plant.

4.1. Spent fuel Load

The spent fuel will be transferred from the spent fuel pool to the TM in this first step. The TM shall be placed in the cask loading pit using the existing crane in the reactor building. Once loaded, the TM shall be removed from the cask loading pit and repositioned inside one of the transfer pits [14]. Once there, the canister's drying and sealing tasks shall be undertaken.

Figure 20 and **Figure 21** show a diagram of the VVER-440/213 reactor building, highlighting the reactor access (1), the spent fuel pool (2), and the cask loading pit (3). **Figure 22** includes details of the cask transfer pits (4).

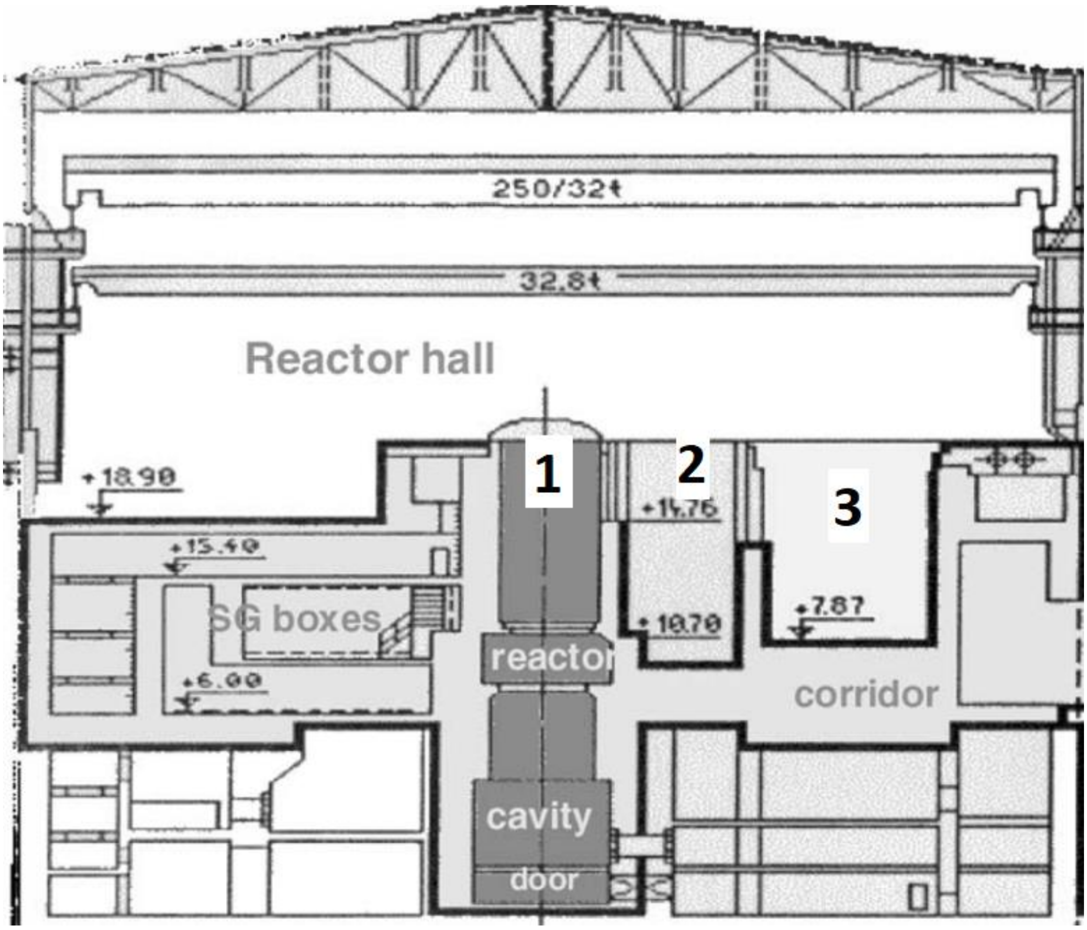

Figure 20. Diagram of a VVER-440/213 reactor building [15]

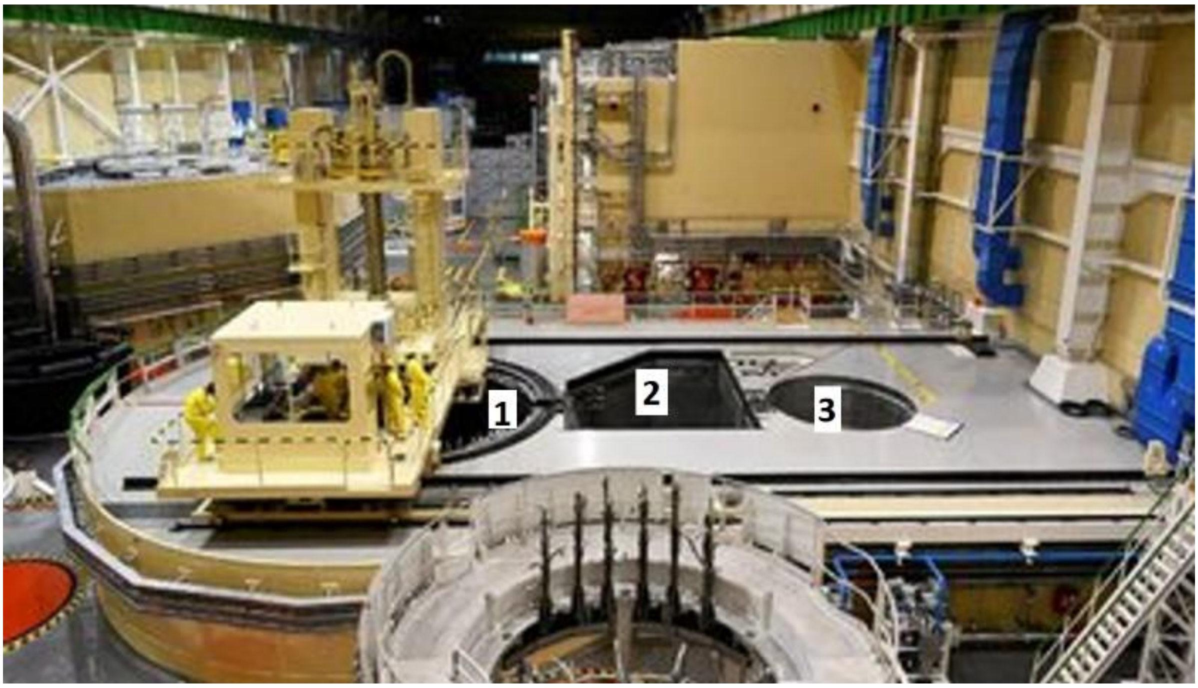

Figure 21. Photograph of the open accesses adjacent to a VVER-440/213 reactor [16]

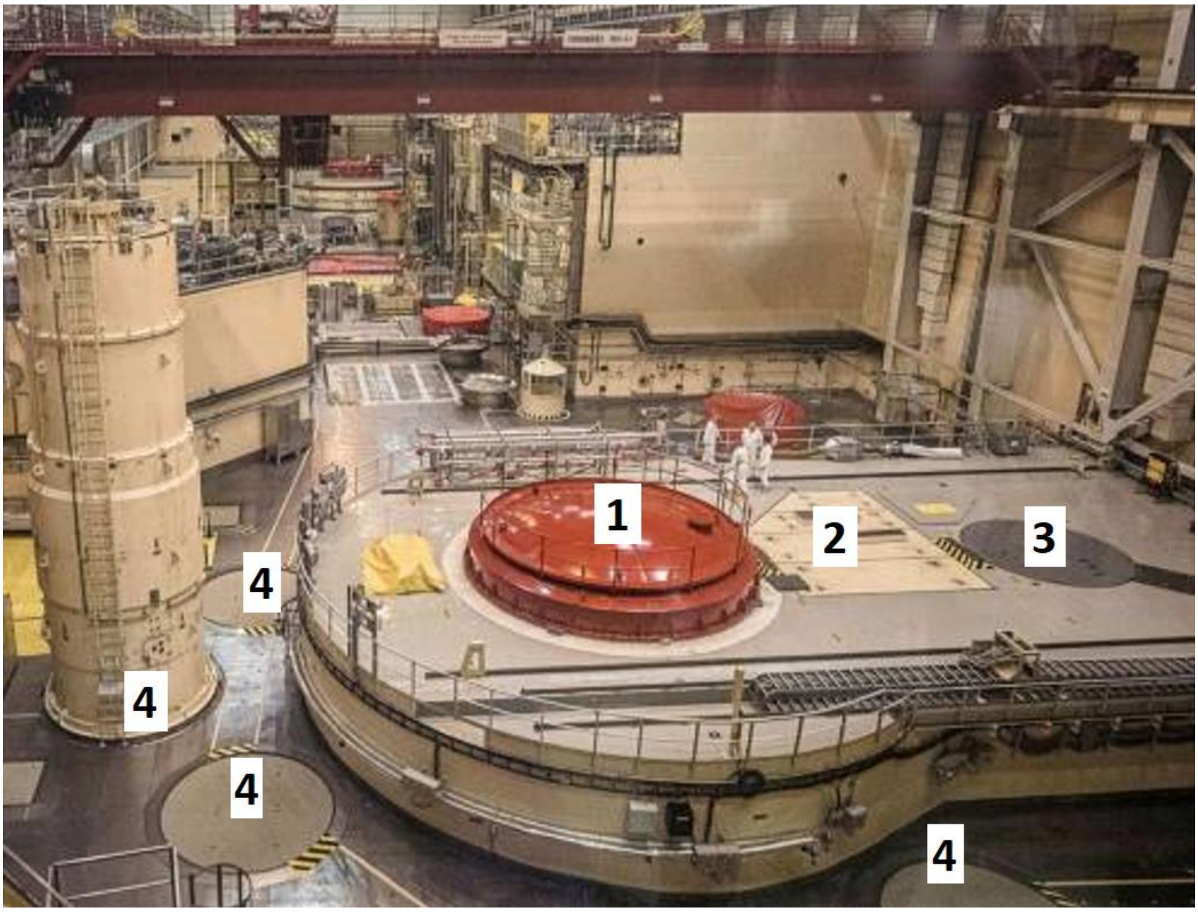

Figure 22. Photograph of the closed accesses adjacent to a VVER-440/213 reactor [17]

4.2. Canister Transfer

This section describes three options for transferring the loaded cask from the transfer pit to the transport railway: directly, using a TC, or using an SC.

A. DIRECT TRANSFER USING THE TM

In this option, the TM is extracted from the transfer pit with the help of the crane upending and downending to the flatbed rail car or other transport vehicle using the upending frame, as shown in **Figure 23** [4].

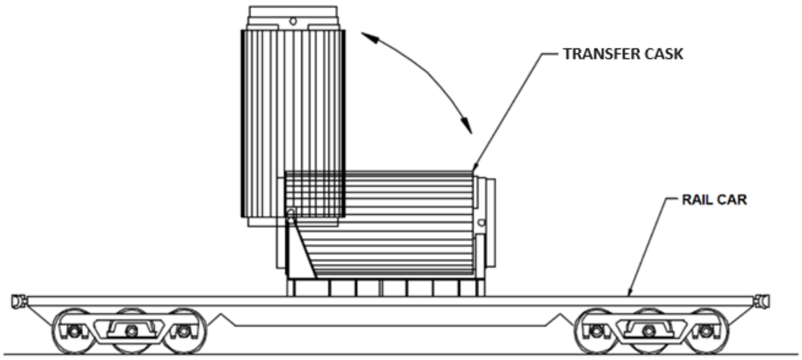

Figure 23. Placing the TM in the rail car [5]

B. INDIRECT TRANSFER USING THE TC

The spent fuel is introduced into the rail car using the TC barrel in this option. The canister is transferred from the TM to the TC using a second transfer pit. Once the container is placed, the canister will be transferred to the TC. The TC shall be empty, and the TM will be removed from the first transfer pit and moved to the top of the TC using the crane. Then, the TM can be removed, and the TC can be closed. Once loaded and sealed, the TC can be transferred to the train car, where, with the help of a turning platform, it shall be placed in a horizontal position for transport using the upending frame in the same way as in option A, as can be seen in **Figure 23** [4].

C. INDIRECT TRANSFER USING THE SC (only for VVSU)

In this version of the solution, the spent fuel will be fed into the train car directly through the SC. For this, the canister is transferred from the TM to the SC through a second transfer pit or, if it does not fit, in a different area. In this second well, the SC will be empty, and the crane will remove the TM from the first transfer pit and place it on top of the SC. Once the cask is placed, the canister will be transferred to the SC. Then, proceed to remove the TM and close the SC. Once loaded and sealed, the SC will be transported to the train wagon; in this case, the container must be kept in a vertical position since the SC is not designed to be kept in a horizontal position, as shown in **Figure 24**.

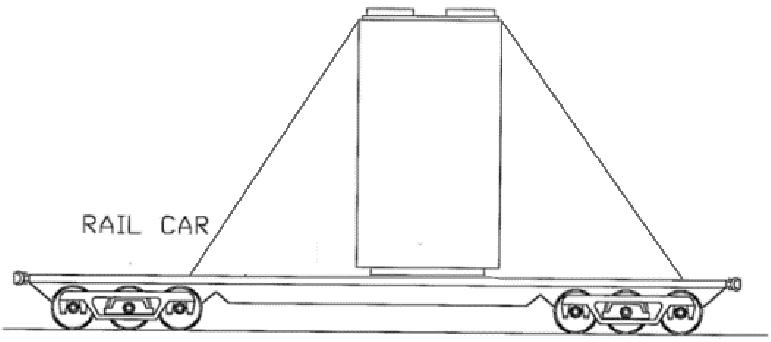

Figure 24. Vertical transport of the SC in a railway wagon [5]

Suppose problems arise related to the size of the entrance doors. In that case, the height can be reduced by using a Zero Profile Transporter (ZPT) (see **Figure 25**) or an air cushion (the same operating principle as the hovercraft) like the one used at the José Cabrera nuclear power plant.

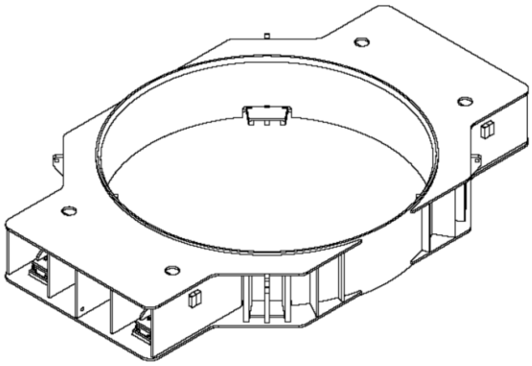

Figure 25. Diagram of a ZPT (left) and ZPT transporting a SC at Ascó NPP (right) [5]

4.3. Positioning to the ISFSI

At this stage, the loaded container (TM, TC, or SC) shall be transported by rail to the ISFSF Installation, following the loading and transportation regulations set by the corresponding regulatory body. A transport vehicle can also be used to transport the loaded container to the ISFSI. In this case, the transport vehicle shall lift the container. However, the vehicle must be suitable for entering the reactor building. If not, a ZPT solution could be considered.

When the cask arrives at the storage site, it must be removed from the rail car and prepared for final storage. However, this last step may differ depending on which sub-strategy has been chosen. In this section, the three different transport options are developed:

- **A. Transfer from a TM to an SC** (if transfer option A was chosen in Section 4.2).
- **B. Transfer from a TC to an SC** (if transfer option B was chosen in Section 4.2).
- **C. Transport the SC** (if transfer option C was chosen in Section 4.2).

The similarities between transport options A and B are explained together, while transport option C will be described in a separate section.

A AND B. TRANSFER FROM A TM OR TC TO A SC

In these options, the canister shall be transferred from the TM (option A) or the TC (option B) that transported the railway wagon to the SC container. To do this, the following steps must be followed as described in reference [18] [7].

For VVSU Systems

1 The transportation cask (TM or TC) is received and inspected at the Cask Transfer Building (CTB); the personnel barrier and transportation tie-down are removed.

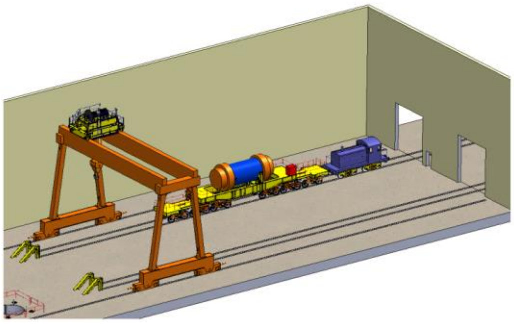

Figure 26. Cask arrival

2 Lifting equipment is installed, and the transportation cask is removed from the vehicle.

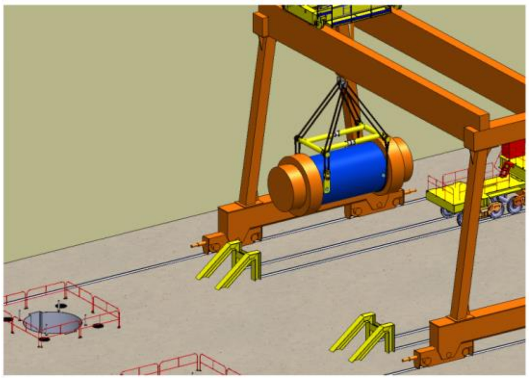

Figure 27. Hoisting of the cask

3 The transportation cask is moved and placed in the tilt frame.

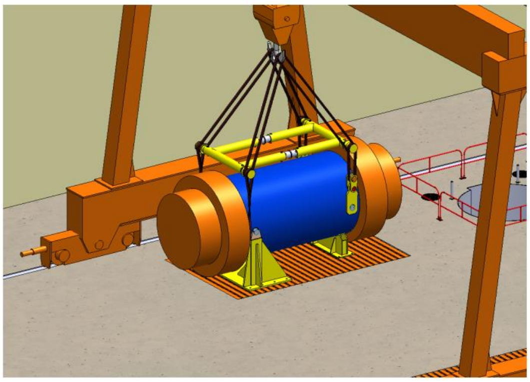

Figure 28. Anchorage in the tilt frame

4 Impact limiters are removed from the transportation cask.

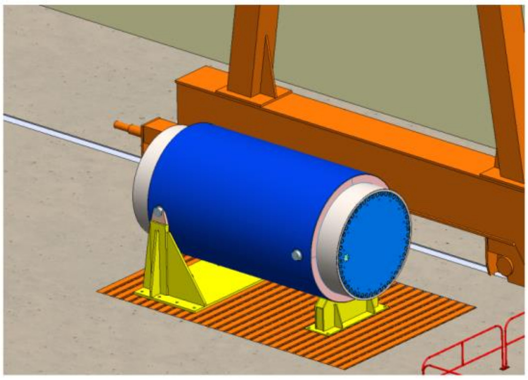

Figure 29. Impact limiters removal

5 The canister is tested for integrity.

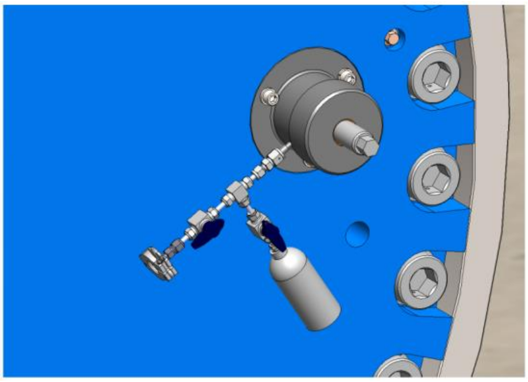

Figure 30. Testing

6 The canister bolts are removed.

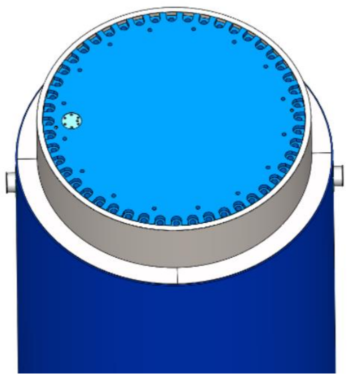

Figure 31. Bolts removal

7 The lift yoke is attached, and the transportation cask is positioned vertically.

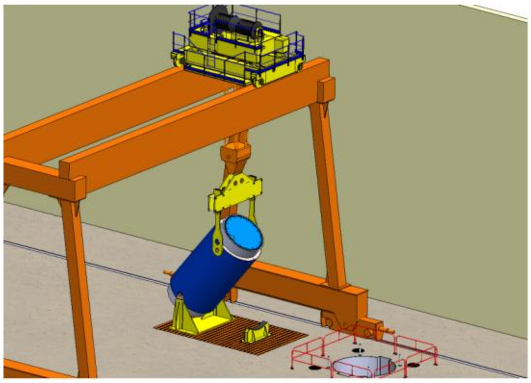

Figure 32. Cask tracking

8 The transportation cask is placed in the Canister Transfer Facility (CTF).

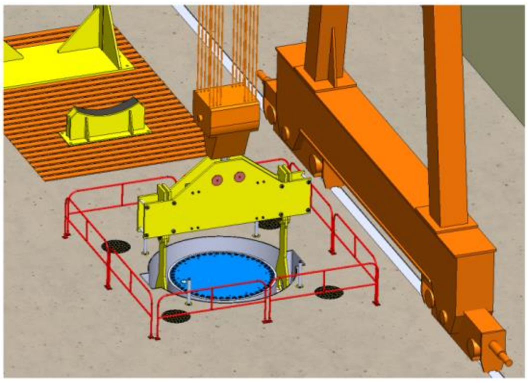

Figure 33. Introduction to CTF

9 The closure lid is removed, and the seal surface protector, CTF alignment plate, and canister lift attachment are installed.

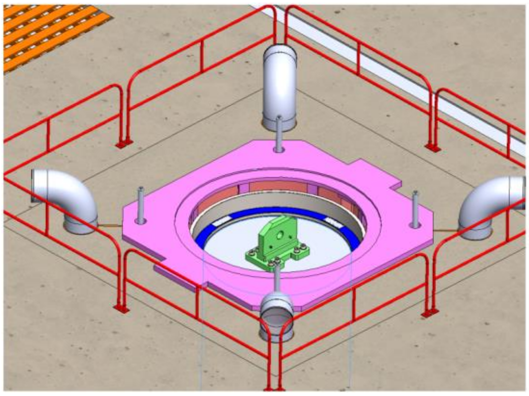

Figure 34. Cask preparation

10 The SC is placed over the CTF.

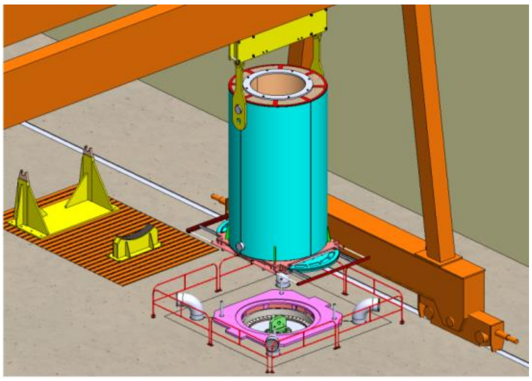

Figure 35. SC placement

11 The canister lifting device extension is attached to the canister lift attachment.

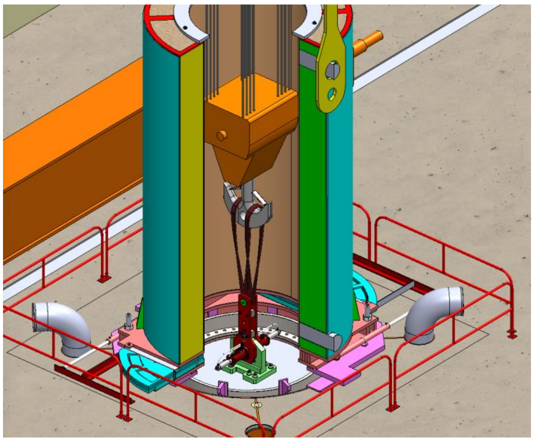

Figure 36. canister attachment

12 The canister is raised into the SC.

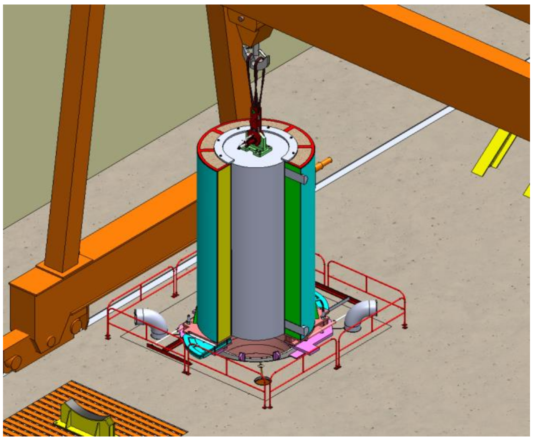

Figure 37. canister transfer

13 The shield gates are closed, and SC is removed from the CTF.

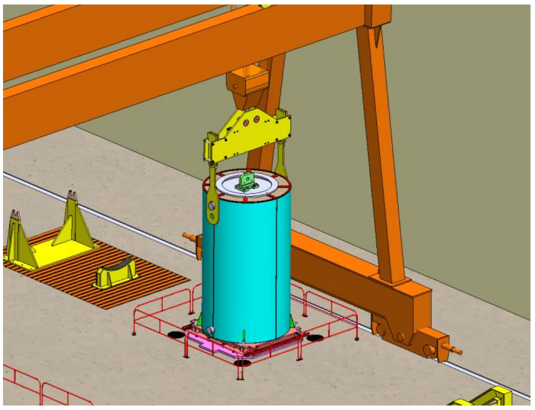

Figure 38. SC removal

14 The SC is placed for transfer to crawler track.

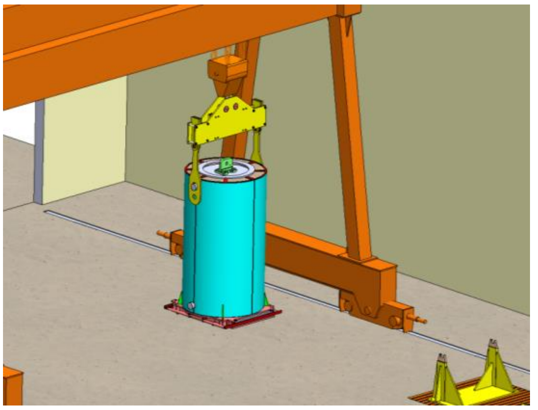

Figure 39. SC relocation

15 Crawler track engages SC and transports it to the storage place. Once there, crawler track places the SC in the designated storage area.

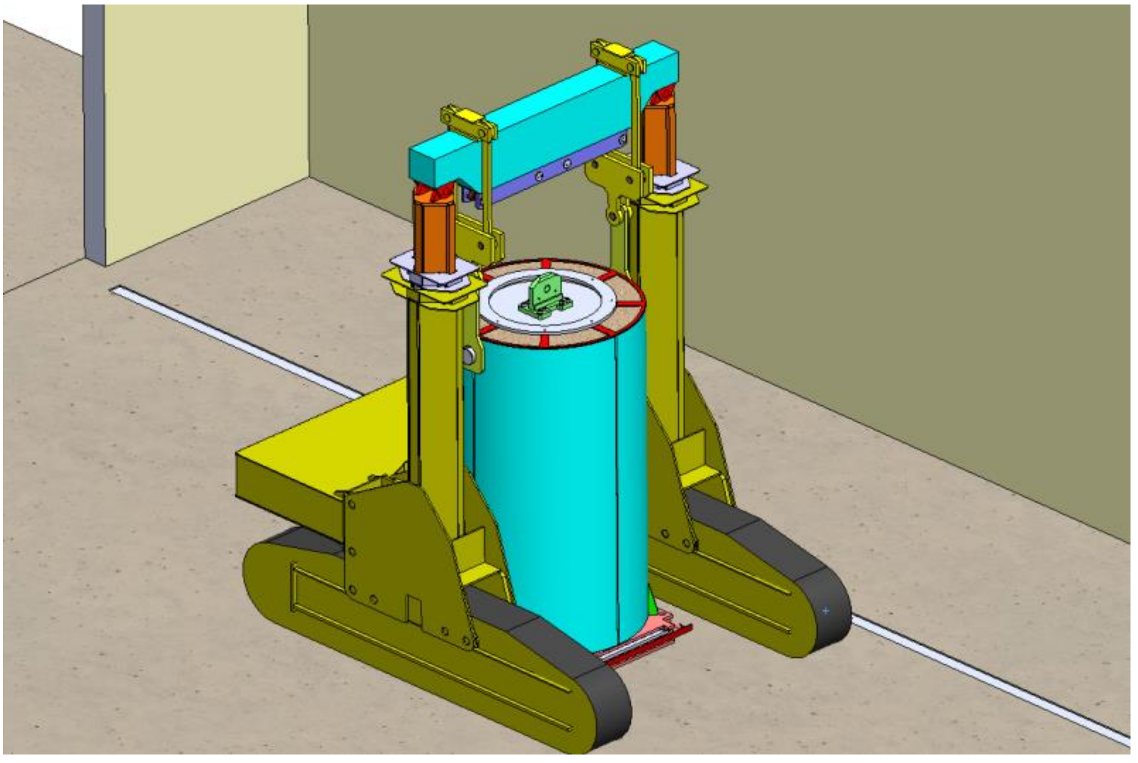

Figure 40. SC transport and storage

For HVSU Systems

1 The TM is transported by the transport vehicle until stopping in front of the HSM.

Figure 41. TM arrival

2 Using the transport vehicle and the platform where the TM resides, it is aligned and fitted with the HSM.

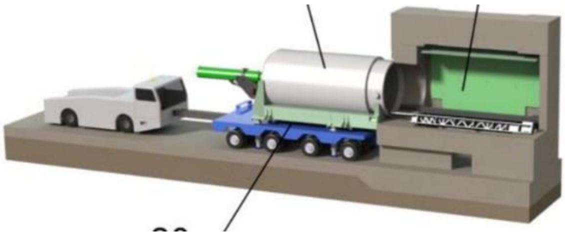

Figure 42. Align and dock TM with HSM

3 The grapple of the vehicle is positioned and fits with the canister so that it can be pushed.

Figure 43. Engage grapple with canister

4 The grapple progressively propels the canister, and it is introduced into the interior of the HSM.

Figure 44. Transfer canister to HSM

5 Once the canister is inserted, the TM is removed and the HSM closing process begins.

Figure 45. Remove the cask and install the HSM door

C. DIRECT TRANSPORT OF THE SC

In this other strategy, in which the train wagon or the transport vehicle transports the SC directly, the process is greatly simplified. The first step when using a rail wagon is to unload the SC from the train car utilising a crane. If the SC has been transported using a ZPT, the transport vehicle can be used directly for the unloading. Once the transport vehicle engages SC, it can be transported directly to the designated area of the ISFSI.

4.4. Strategies Assessment

This section involves the assessment of the proposed sub-strategies to identify their strengths.

SUB-STRATEGY A

- The TM is a smaller, lighter cask facilitating transfer and transport operations.
- This option is more straightforward than B; it requires fewer steps and transference of the canister.
- It does not require transferring the canister in the nuclear power plant building.

SUB-STRATEGY B

- Using the TC offers greater radiation protection to workers than when using the TM.
- It presents a greater degree of security in the transport stage.
- Suppose a problem arises during the transport procedure or some other mishap occurs. In that case, the TC offers the possibility of keeping the fuel stored indefinitely inside and outside the facilities since it is a dual-purpose cask.

SUB-STRATEGY C

- This method requires fewer operations in the ISFSF. It does not require the construction of a transfer pit in the ISFSI.
- If a ZPT is used for transportation, you can also dispense with the use of cranes at the ISFSI.
- This is the option that offers greater radiological protection.

5. MAINTENANCE AND OPERATION

Due to the design and easy access of this type of storage system, the maintenance and operation of the ISFSI (Independent Spent Fuel Storage Installation) are straightforward and efficient. The specific maintenance requirements during the operational phase are as follows:

MAINTENANCE REQUIREMENTS

Annual Inspection

- Conduct a comprehensive inspection of the storage system annually to ensure all components function correctly and identify potential issues early.
- Check for any signs of wear, corrosion, or damage to the structural components of the ISFSI.

Corrosion inhibitors

- Apply corrosion inhibitor materials to external surfaces, especially in moisture-prone areas and areas exposed to environmental conditions. This helps prolong the lifespan of storage containers and infrastructure.

Ventilation maintenance

- Regularly inspect and clean the ventilation holes of the storage containers. This involves removing accumulated debris, such as leaves, branches, or other objects that obstruct proper ventilation.

OPERATION REQUIREMENTS

Monitoring ventilation openings

- Continuously monitor the ventilation openings (screens) to ensure they remain unobstructed and functional. Proper ventilation is crucial for maintaining safe temperature levels within the storage containers.

Inspection options

- **Option 1 – Inspection for damage to screen openings:** Conduct monthly inspections to check for damage or blockages in the screen openings. This helps identify and address any issues that could impair ventilation efficiency.
- **Option 2 – Temperature monitoring:** Implement a temperature monitoring system with regular record-keeping. This requires a dedicated maintenance and calibration program to ensure the accuracy and reliability of temperature data. Any significant deviations in temperature readings should trigger immediate investigation and corrective actions.

Radiological control

- Conduct regular ISFSI radiological control measures to ensure and confirm the integrity of the radiation shielding. This involves monitoring radiation levels around the storage area.
- If an increase in dose rates is detected, initiate additional monitoring of the container to determine the cause and implement necessary corrective actions. This may involve more frequent inspections, repairs, or adjustments to the shielding materials.

Adhering to these maintenance and operational guidelines can maintain the ISFSI in optimal condition, ensuring the storage system's safety, efficiency, and longevity.

6. CONCLUSIONS

Throughout this document, spent fuel dry storage solutions have been analysed to collect the necessary information to understand the operations and actions required to design a VVSU dry correctly spent fuel storage system.

The steps necessary for spent fuel loading, the most relevant auxiliary equipment, the main unloading, transport and storage strategies, and critical points in operation and maintenance have been reviewed and developed.

A specific overview of each module and cask that conforms to this system has been performed, focusing on their principal structural aspects and technical features regarding the loading limitations for fuel designs VVER-440 and VVER-1000.

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