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THE ENTROPIC FIELD

Italian National Repository of Nuclear Waste in Alessandria

Relatore
Prof. Giovanni Corbellini

Candidato
Hajar Younes

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Candidate Hajar Younes
Matricola 300066
Contact hajaryounes98@gmail.com

Advisor: Professor Giovanni Corbellini

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Abstract

Nuclear science and technology have prompted remarkable advancements in medicine, electricity production, and other essential industries. However, like many other human endeavors, such activities generate hazardous by-products, particularly, nuclear waste.
Due to its relatively long isolation period which ranges from a hundred to thousands of years, nuclear waste poses a challenging issue to tackle. In Italy, a National Repository for very low- and low-level nuclear waste is to be developed by SOGIN; as such, establishing a facility to be operated and controlled for about 350 years.

This thesis aims to address the repository not only as a technical infrastructure, but also as a layer of memory subject to reinterpretation over time, through utilizing time as design tool and embracing entropy as an inevitable condition. The proposal targets the instructive memory through an ordered, conserved archive center on one hand and marks the subjective memory by creating a “Third Landscape” that engages with decay, ambiguity and uncertainness on the other hand. By implementing design strategies that exploit the design constraints, the containment barrier becomes a visual obstruction that conceals the undesirable industrial facility, while acting as an elevated vantage point to observe the facility and provide a threshold of transparency. In addition, the barrier, made of the excavated soil from the construction process, forms a circular geometric shape that evokes mystery and attention. This paradoxical perimeter creates the platform for the third landscape, producing entropy by design.

In brief, the design of this temporal infrastructure explores how architecture can influence memory without depending on permanence and control. It speculates how a territory that holds what society dismissed might unfold into a landscape of paradoxical encounters - fear and desire, containment and openness, neglect and conservation. Hence, entropy compels the continual re-interpretation of the past, keeping both “memory and forgetting” active, as a necessary living force.

1

A NOTION OF WASTE

1.1 Definition of Waste

According to the European council, wastes are substances to be discarded/disposed or have been discarded/disposed. But waste is a concept that transcends the tangible material; thus, it is perceived through several dimensions.

Waste refers to any material, resource, or by-product that is no longer deemed useful or has outlived its intended purpose, often requiring disposal, recycling, or repurposing. In modern contexts, waste encompasses a broader range of materials, including solid, liquid, and gaseous forms, but also accounts for digital waste (such as electronic data or devices) and inefficiencies in energy or time use. Decline, decay and wasting are a necessary part of life and growth; we must learn to value them and to do them well. (Lynch, 1991)

By removing the human species from the center of the universe, waste disposal is originally a physiological phenomenon in the universe. The relationship between organisms and their environment depends on the notion of wasting. For example, Oxygen disposed by plants during the day, is a natural byproduct released after photosynthesis, which is a crucial phenomenon in the ecosystem. Shed skin, sea shells, and leaves can be categorized as waste. Although waste disposal is fundamental to life's processes.(Cunningham et al., 2019)

From an ecological perspective, Braungart, and McDonough believe that there is no such thing as waste in nature's course, for oxygen, carbon, hydrogen, and nitrogen are cycled and recycled nutrients. Until recent history, this cradle-to-cradle system of operation governed earth's natural mechanisms. But the industry shifted the inherent balance of material on the planet, by extracting substances from the earth and transforming them into materials that are unsuitable for reintegration into the soil. Therefore, the flow of materials on our planet is categorized into biological and technological nutrients. (Braungart et al., 2009)

In relation to power, Mary Douglas defines waste as "matter out of place", implying that waste is the byproduct of a social system which classifies matter according to cultural boundaries and values. Where analysing what is rejected and oppressed can help investigate a system of power, revealing what is destructive and dangerous to its existing patterns. (Douglas, 1966)

1.2 The Perception of Waste

According to Cullen Murphy, waste holds a key to the past. It holds a physical legacy for the future generation about our time in the present. For archaeologists, garbage near an archaeological site is the most reliable evidence to understand the human behaviour of those who used them. (Rathje et al., 1992)

Kevin Lynch states that waste is time and culture specific, determined by what society perceives as valueless or unnecessary at a given time. Lynch highlights that the notion of waste stretches from wasted material, to wasted space, reaching wasted potential. “Hidden behind the polite façade of living, its presence preoccupies us; it is an affair of the mind. Might there be pleasures in it, and practical opportunities? Could we be at ease with it?” (Lynch., 1991)

Moreover, he notion of “waste land” is addressed by the French landscape architect Gilles Clément in the concept of the “Third Landscape”, defined as the neglected, unmanaged, and unproductive spaces. Similar to material waste that is unused for human purposes, these spatial wastes are discarded from institutional control, and treated as residues of productive landscapes. However, Clement argues that this institutional abandonment allows these areas to become reservoirs of biodiversity, serving as ecological shelters and seed banks. (Clément, 2004)

1.4 Hazardous Waste

The definition of hazardous waste varies across countries and regulators, but according to the European environmental agency, hazardous waste is any discarded material that could pose a threat to health or the environment due to its chemical reactivity, toxicity, explosiveness, corrosive characteristics, or radioactivity. The generators of these wastes vary from manufacturing-based industries, to hospitals, universities, military sectors, and even households. It can range from nuclear spent fuel, to discarded batteries. (Stafford, 2023)
Bearing in mind that the longest lasting human production are accumulation of waste, the next chapter will tackle a long enduring human discard: nuclear waste.

2

RADIOACTIVE WASTE

2.1 Definition of radioactive waste

Radioactive waste is the material remaining from the military and civilian nuclear processes that generate energy through manipulating the structure of the atom, creating radioactive byproducts. These technologies emit radioactive wastes at every stage of the production cycle, from mining, to nuclear power generation, to the decontamination, to decommissioning. And the location of these activities can range from hospitals, to research centers, universities and industrial facilities.

(Joyce, 2020)

2.2 What is radioactivity

Radiation is the emission or transmission of energy in the form of waves or particles. It exists from both artificial sources like the microwave and natural sources like the sun. Fundamentally, radioactivity exists on 2 scientific levels, atomic and nuclear. The atomic level denotes the chemical process, while the term nuclear refers to the energetic process.
It is substantial to comprehend the composition of the atom, made of protons and neutrons in the nucleus, and electrons. Most atoms are stable, meaning that each element is composed of a stable composition of neutrons and protons. But other unstable atoms lack a sufficient composition of number of particles to hold them together, which can result in the release of energy to stabilize the atom, known as radioactive decay. These radioactive atoms are classified into two categories: non-ionizing radiation, which does not have enough energy to move electrons, and ionizing decay which releases relatively more energy and can inflict chemical changes when in contact with matter including living organism. Therefore, the level of risk on health varies according to the dose of radiation. In high doses, ionizing radiation can damage the DNA and cells causing cancer or radiation sickness. While radiation techniques in the correct doses are a normal of daily life, such as in the diagnostics of several medical conditions. (Galindo, 2023)

Radioactive atoms have other parameters which allows to determine the appropriate method of handling, using, and disposing of the material. Such as the activity of a given radioactive material, which refers to the rate of decay or disintegrations per second. In addition to the half-life: the time required for half of the radioactive atoms in a sample to decay, which can range from fractions of a second to billions of years. (IAEA, 2014)

2.3 Types of radioactive waste

• **Exempt waste (EW):** refers to radioactive waste that contains such small concentrations of radionuclides that it is deemed exempted from stringent institutional control.

• **Very short-lived waste (VSLW):** waste which can be deposited for disintegration for a relatively short period of time, up to few years. After which it will no longer require special handling. This type of waste is usually a byproduct of medical and research activities. Very low-level waste (VLLW): waste which doesn't call for a high level of isolation. usually disposed in a near surface landfill, this type of waste needs limited regulatory control.

• **Low level waste (LLW):**
Due to the limited concentration of long-lived radionuclides, strict isolation is required for this type of waste for a couple hundred years in near surface disposal sites. But this type of waste is associated with a wide range of half-lives, thus the design of the near-surface disposal system varies significantly, encompassing simple and more sophisticated approaches, usually at the depth of up to 30m. regulatory control, in some cases, is required for almost 3oo years.

• **Intermediate level waste (ILW):** Due to the long-enduring radionuclides, higher level of isolation is required at even larger depth. Regulatory control is not mandatory, due to the disposal at tens to hundreds of meters, which should provide a sufficient seclusion from human interaction.

• **High-level waste (HLW):** Comprises a large concentration of long half-life radionuclides. This demands deep stable geological formations as disposal sites, with engineered isolation systems, buried at several hundred meters below the surface. It is the byproduct of spent fuel from nuclear energy power plants, in addition to nuclear military industries. Up until 2024, according to IAEA, 392,000 tonnes of spent fuel have been discharged worldwide. This approach is applied to gaseous and liquid radioactive waste, after processing it into solid form that is suitable for long term disposal. (IAEA, 2009)

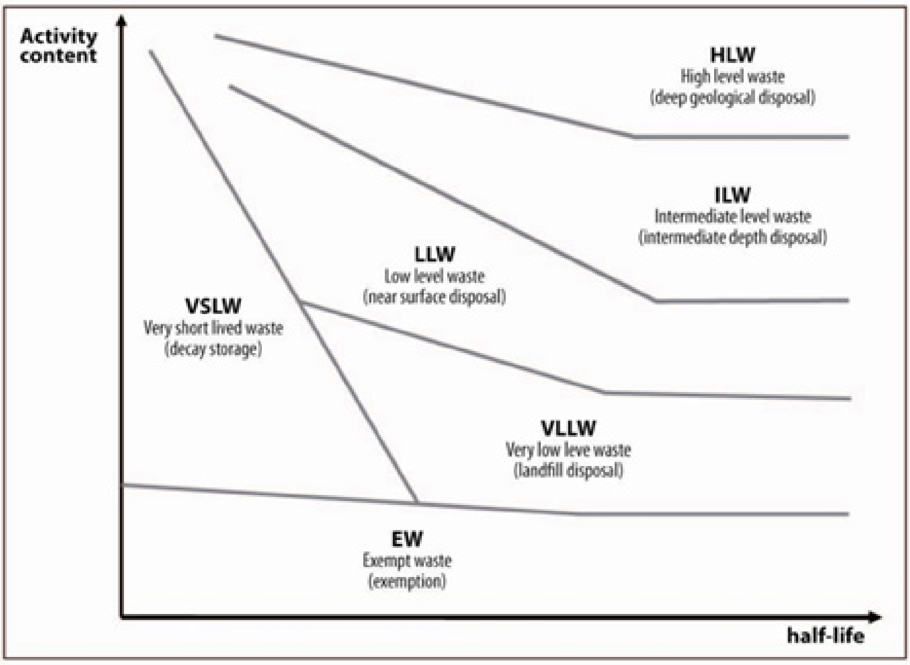


Figure 1.1 : graph showing the variation of activity content of different types of radioactive waste in relation to their half-life

2.4 Management of radioactive waste

The management of waste comprises several stages before the final disposal. This predisposal stage includes decommissioning, pre-treatment, treatment, conditioning, immobilisation, storage, and transport.

This predisposal phase prepares the waste for its final destination. After collection of the contaminated waste, it may be transported to a centralised storage facility awaiting treatment or re-use. Treatment comprises of volume reduction, removal of radionuclides, or changes in composition.

Very low-level waste (VLLW) produced in association with decommissioning of nuclear installations, simplified pretreatment steps can generally be used. VLLW often consists of concrete, scrap metal, refuse and contaminated soil. Pretreatment is often limited to simple size reduction to allow for easier handling and transport, while preventing dust dispersion and containing loose materials. VLLW can often be contained in large bags, standard transportation drums or other simple containers.

Low-Level Waste (LLW) may require shielding for handling and storage. It typically includes contaminated protective gear, tools, filters, construction debris, and scrap metal. LLW is treated by volume reduction (incineration, compaction) and immobilization (cement, polymer, or bitumen), then stored in appropriate containers.

Intermediate Level Waste (ILW) contains both short- and long-lived radioisotopes at concentrations requiring geological disposal. It typically includes reactor components, ion exchange resins, and filters from nuclear plants. ILW is treated (often cemented or vitrified) and placed in shielded containers to ensure safety.

High-Level Waste (HLW) and Spent Fuel (SF) (when classified as waste) require the highest level of isolation in geological disposal. Their intense heat and radioactivity, along with long-lived radionuclides, demand immobilization in stable, insoluble forms — typically vitrified glass or ceramics — to ensure long-term containment.
(IAEA, 2020)

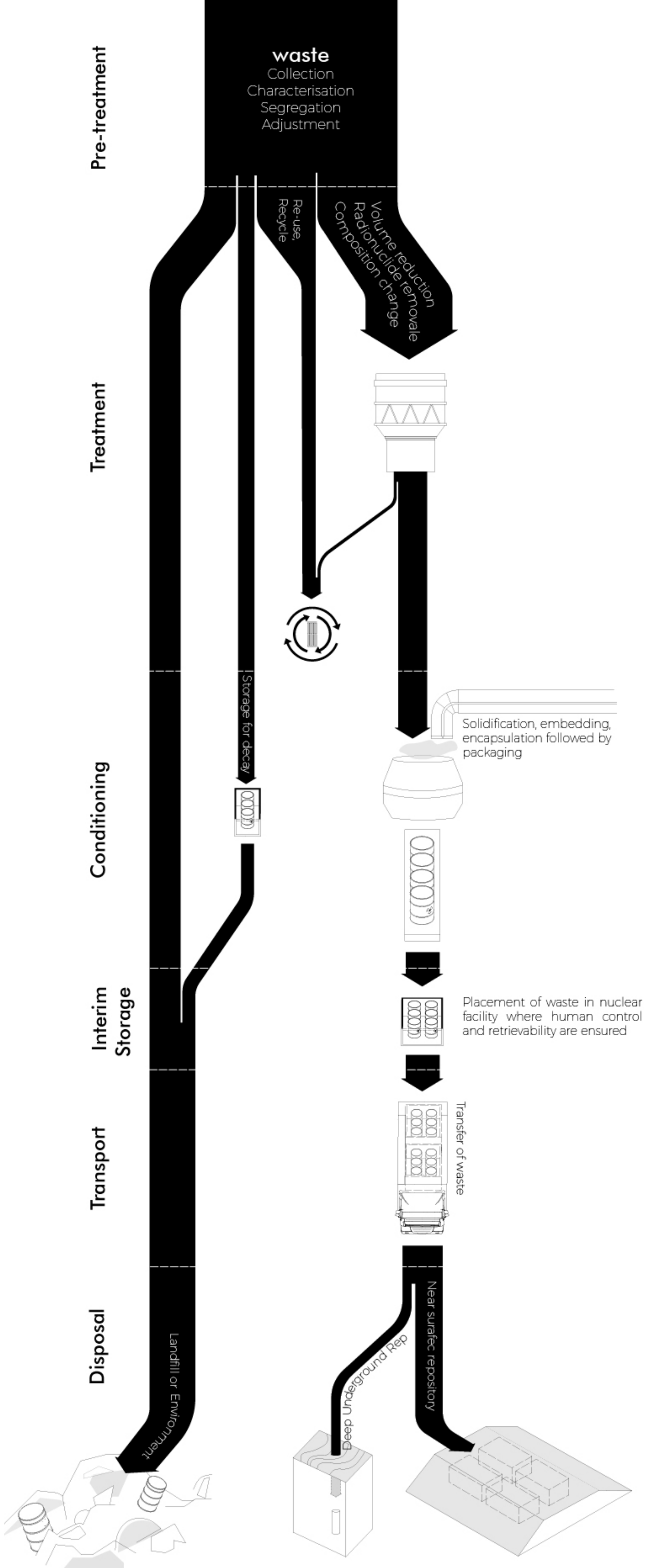


Figure 1.2 Image showing the process of Radioactive waste management

2.4.1 Disposal strategies

The disposal area is the main component of a nuclear waste repository. Its form varies according to the activity content of the waste involved, ranging from near surface repositories for very low and low-level waste classes, to geological repositories of depth reaching more than 1000m for intermediate and high-level waste classes. Near surface repositories include trenches, semi-buried and buried vaults, near-surface silos, and shallow tunnels, while geological repositories comprise of boreholes and tunnels of intermediate and deep depths.
The diagram below shows how the potential for isolation and containment increases with the level of radioactivity. (IAEA, 2020)

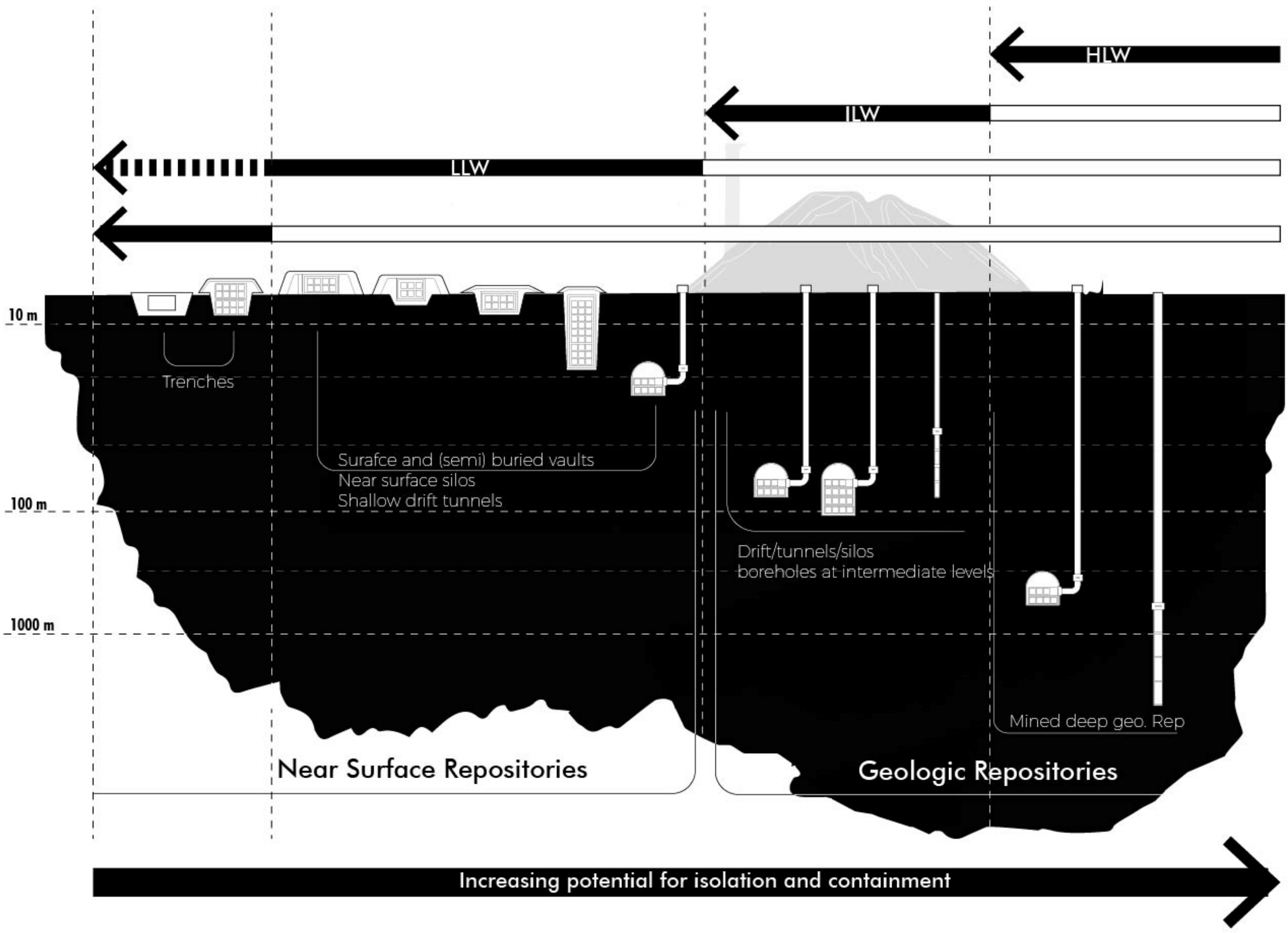


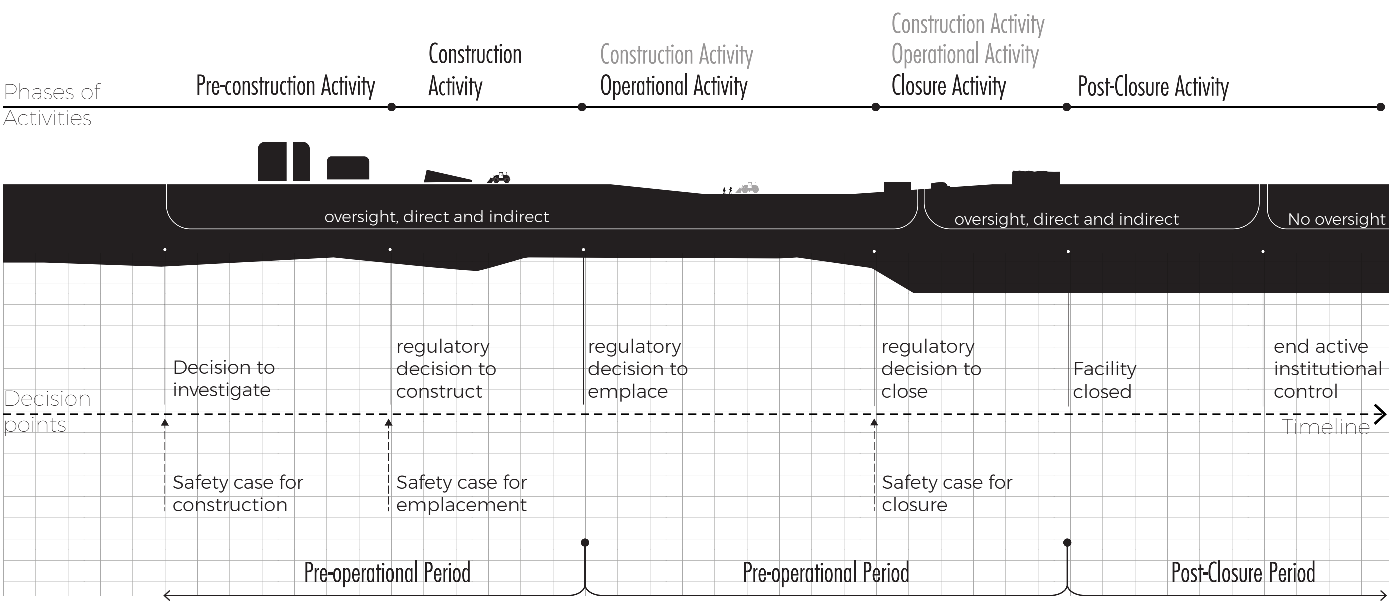
Figure 1.3 Image showing the disposal strategies

Source: IAEA

2.4.2 Time scale of containment

The timeline of the disposal process spans multiple decades. A typical outline would include a series of phases that precede and proceed the operation of the facility.

- **The preoperational phase:** the planning of the project, site selection, regulatory approvals., stakeholder's consultation, and construction of facilities.
- **The operational period:** initiates after receiving and managing nuclear waste. It comprises handling, transporting and disposal of the wastes. Throughout this period, activities are monitored to ensure the integrity of isolating strategies., where direct and indirect oversight are exercised by institutions and society to safeguard the repository.
- **Post closure period:** begins when the waste is emplaced and the containment measures have all been implemented to secure the radioactive materials, and prevent environmental damage. This phase focuses on long term monitoring and maintenance, knowing that support facilities have been decommissioned. Active monitoring and institutional control assure the integrity of the containment strategies. Direct oversite represents the institutional control and monitoring of accessible waste, while indirect oversight involves the containment and monitoring measure of waste after being emplaced in its final destination, such as sensors and marker systems for future generations.



"IAEA Safety Standards for protecting people and the environment Specific Safety Guide No. SSG-29 Near Surface Disposal Facilities for Radioactive Waste," VIENNA, 2014.

Figure 1.4: Timeline for the disposal of radiocative waste

Source: IAEA, 2014

2.4.3 Marker system: Nuclear Semiotics

If the aim of the near surface nuclear waste repository is to contain the radioactive waste for a period of 350 to 10000 years, it must prevent human intrusion for the same period of time. The marker system represents a unique challenge in the repository design, for it transcends the three-dimensional realm to include the time variable. This system must communicate danger to the surrounding in a mode that surpasses linguistic limitations to encompass the lifespan of civilizations, when languages, technologies, and values may change.

Various strategies were proposed in the field of nuclear semiotics, to warn future humans of the hazardous legacy. For example, the Waste Isolation Pilot Project (WIPP) approach was to create a visual deterrent rather than relying on linguistics only, in addition to adding warning messages on different levels of access in case of institutional collapse, which reads: “This place is not a place of honor. No highly esteemed dead is commemorated here… nothing valued is here. What is here was dangerous and repulsive to us. This message is a warning about danger”. Influenced by science fiction, planners in WIPP imagined 8m high concrete structures that portray the deep danger that lies within, in a sci-fi, dark theme approach.

The linguist Thomas Sebeok also proposed a notion of “Atomic Priesthood”, a panel of experts in charge of maintaining and passing down knowledge by creating myths and rituals. But due to ethical concerns like manipulation, deceit, and potential power imbalance it was disregarded as a formal marker system. (Damveld, 2016)

An emerging vision by the NEW forum on stakeholder conference states that it is crucial to design a repository a landmark and achievement to take pride in:

“Because a radioactive waste management facility and site will be present in a host community for a very long time, a fruitful, positive relationship must be established with those residing there, now and in the future. Simply put, designers have to make the radioactive waste management facility and site to suit people’s present needs, ambitions and likings, and to provide for evolutions to match at reasonable cost the needs and desires of future generations. A facility that upsets or repels residents or visitors will only be tolerated and will remain a stranger or an unwelcome presence in the community. The challenge is to design and implement a facility (with its surroundings) that is not only accepted, but in fact becomes a part of the fabric of local life and even something of which the community can be proud.” (Pescatore C., 2007)

In fact future-proofing the marker system relies on creating a “nuclear culture” with its exclusive set of monuments, markers and rituals, fostering skills of different scientific, artistic and academic experts to generate the nuclear memory of the future generations. (Pescatore C., 2007).

According to the Nuclear Culture Research Group, suggestions like time capsules, libraries, and physical markers can serve the purpose. Pointing that having thousands of small markers is more competent than a large monolith with a probability of being knocked down. In fact, it is advised to address the nuclear discussion as a holistic view globally, creating a global nuclear culture, rather than a site-specific issue.

In addition, the RK&M Initiative of the nuclear energy agency states that the key is to create a system of markers that complement each other, forging a deep line of defense by integrating the facility in future societies.

In the end, the RK&M Initiative came up with the idea that systems are the solution. “No one can say that this is the magic site,” says James Pearson, who worked on the initiative. “The most successful approach would have a number of systems that complement each other, such as a combination of physical markers with information about the site stored in numerous archives. It means that you have defence in depth. If one archive isn’t maintained or there’s a fire, then you have backups.” (Nea, 2019)

3

ITALY'S NUCLEAR ROADMAP

3.1 Scope of the Repository

The Italian national repository will be designed, built, and managed by SOGIN, a public company fully owned by the Italian Ministry of Economy and Finance, operating under the guidelines of the Italian government.
According to SOGIN, the Italian national repository is a near surface environmental facility that will hold the all-radioactive waste produced in Italy from decommissioned nuclear power plants and other nuclear-related medical, industrial, and research activities. In this present day, this waste is temporary stored in various storage sites across the country.
The facility features both engineered and natural barriers intended to contain radioactivity, following the latest international and national standards of the IAEA (International Atomic Energy Agency) and the ISIN (National Authority for Nuclear Safety and Radiological Protection).
The repository will permanently host 78 thousand m3 of very low- and low-level radioactive waste. The facility will temporarily host 17 thousand m3 of intermediate and high-level radioactive waste in a building complex, pending their permanent disposal in a deep geological repository.(SOGIN, 2024)

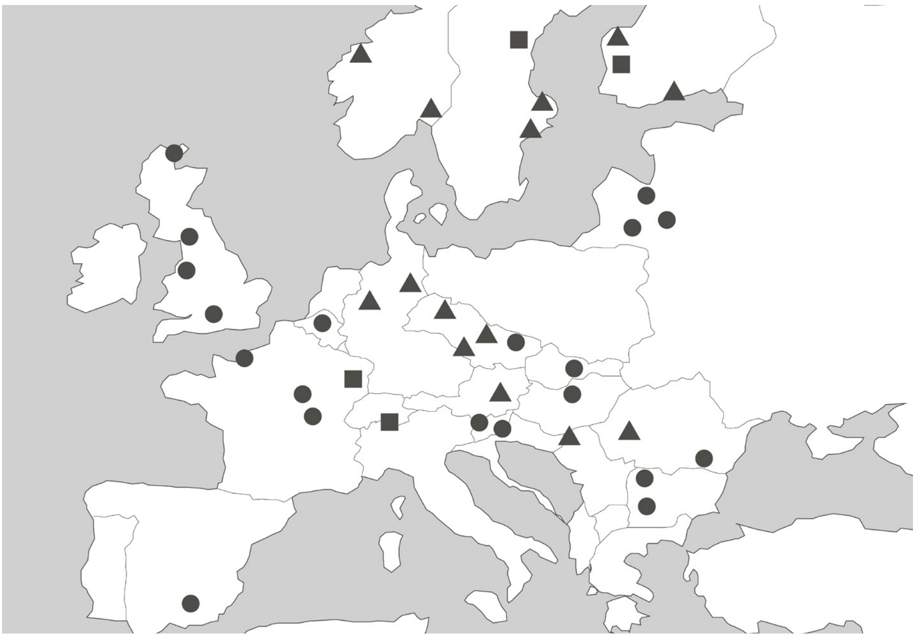
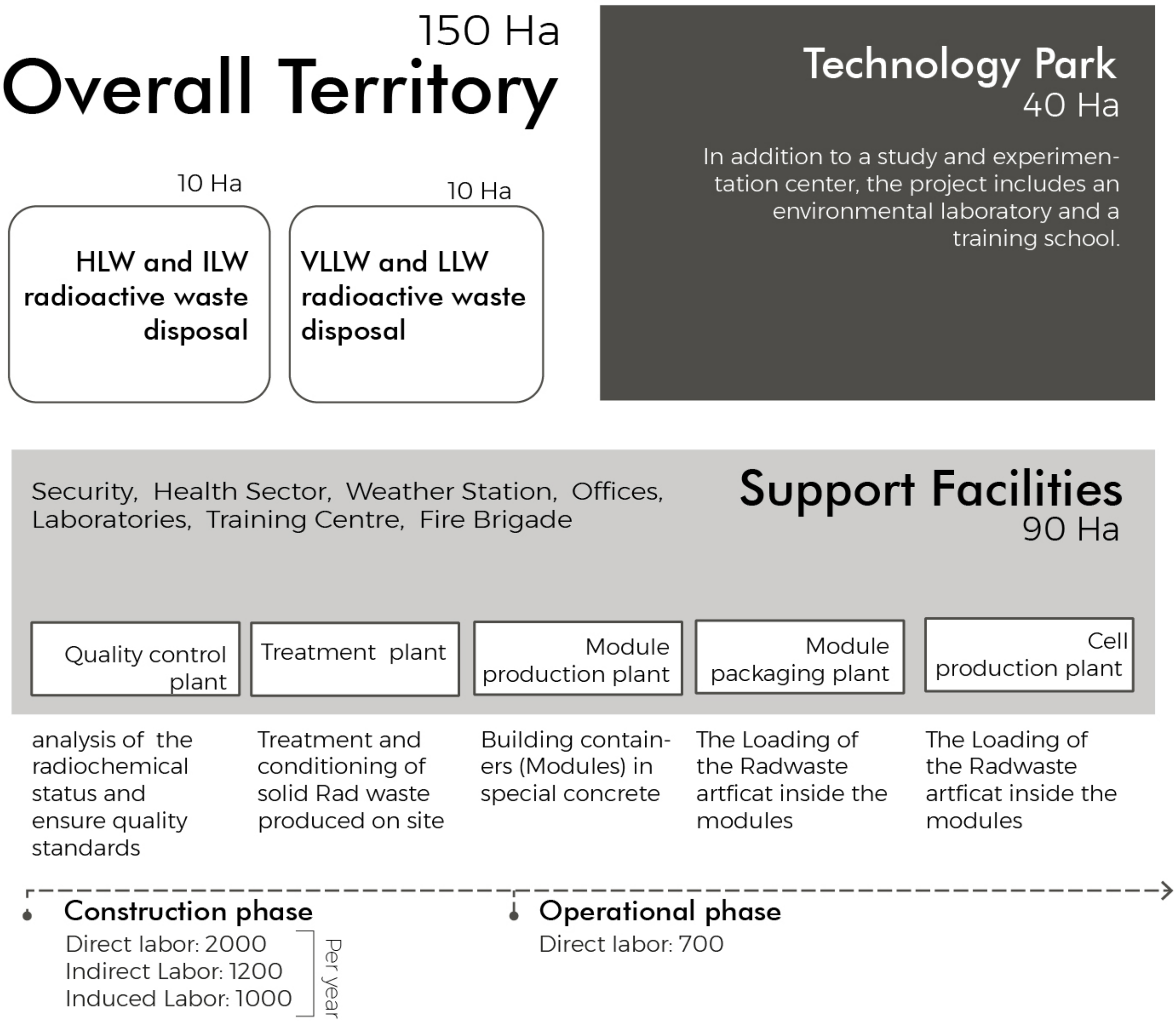


Figure 2.1:European permenant radioactive waste disposal sites. Source: SOGIN

On the scale of Europe, permanent repositories of very low and low radioactive waste are currently being operated by most EU member states. In addition, some countries are planning and designing geologic repositories for intermediate and high-level radioactive wastes, while states having lower amounts of high level radioactive waste are suggesting to establish a European Geologic Disposal. (SOGIN, 2024)

Overall, the repository will host 95,000 cubic meters of radioactive waste, including waste already produced, and waste Wpredicted to be produced in the upcoming years. The storage of radioactive waste in one confined facility guarantees safe and efficient management, in addition to allowing to conclude the decommissioning of Italian nuclear plants.
In addition, a Technology Park will be established dedicated to research in the field of energy, waste management, and sustainability, promoting international cooperation and creating employment opportunities.
The National Repository and Technology Park will cover an area of approximately 150 ha, 110 of which will be dedicated to the Repository and 40 to the Technology Park.(SOGIN, 2024)



3.2 VLLW and LLW Radioactive Waste

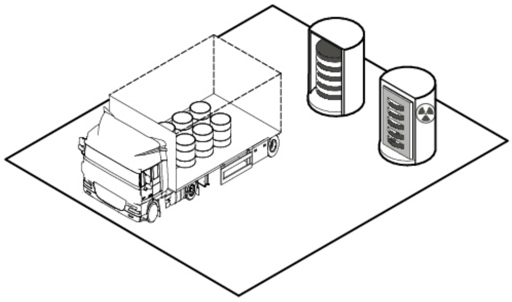
Following the scheme of SOGIN, the repository will implement a system of various natural and engineered barriers that contain the radioactive material and ensure its isolation. The engineered barriers will comprise of reinforced concrete, specially developed to isolate radioactive waste until it decays to reach a level compatible with the natural environmental radioactivity. This universal layering strategy serves as a valid protective measure that ensures the long-term safety of the human and the environment, while complying with IAEA and ISIN international standards.

These systems of containment barriers, in addition to the existing features of the site hosting the repository, will ensure the isolation and safe disposal of the very-low- and low-level radioactive waste for a period over 350 years, until its radioactivity becomes negligible with respect to the environment.

The transportation of the VLLW and the LLW is carried out in metal containers, after conditioning the waste with a cement matrix, representing “The Artifacts”. After which, these artifacts are collected and cemented in a 3m x 2m x 1.7m container, or “Module”, made of special concrete designed to endure ate least the 350 years of isolation. As a third barrier, these modules are then inserted in reinforced concrete “Cells” (27 m x 15.5 m x 10 m) that are also designed to withstand the isolation period. Last but not least, the cells are capped and buried in an artificial hill that prevents the infiltration of water.
(SOGIN, 2024)

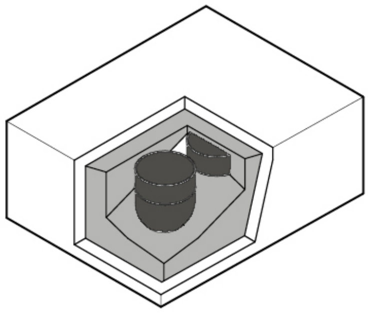
1 THE ARTIFACT
The First Barrier

Radioactive waste conditioned with a grouting matrix inside metallic containers, transported to the National Repository.



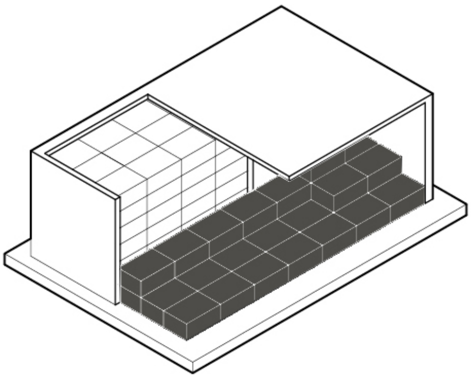
2 THE MODULE
The Second Barrier

Waste packages inserted and grouted inside reinforced concrete modules (3 m x 2 m x 1,7 m) qualified for 350 years duration.



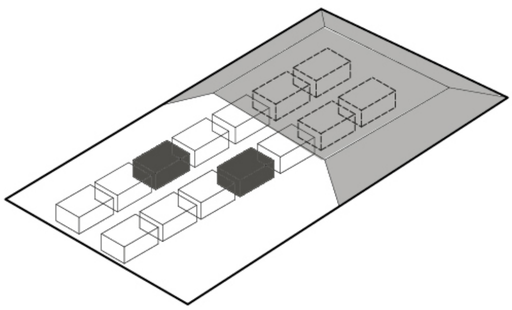
3 THE CELL
The Third Barrier

240 modules placed in a reinforced concrete vault (27 m x 15,5 m x 10 m) qualified for 350 years duration.
Within the National Repository, 90 cells will be built, organized in rows.



4 THE MULTI-LAYER COVER
The Fourth Barrier

Once filled with modules and sealed, the vaults are capped with a final multi-layer cover for protection against rainfalls, isolation of waste from the environment and better visual impact.



3.2.1 Module Disposal Unit

The module disposal unit (USM) represents the installation dedicated to permanently host the very low- and low-level nuclear waste conditioned in modules. This facility is composed of 90 large reinforced concrete storage cells designed to contain the hazardous waste, where each cell is capable of accommodating 240 modules. The cells are filled in rows consecutively through a mobile gantry crane and a cover that are transported on rails. The cell is waterproofed and sealed once it reaches its full capacity, and the mobile cover is moved to the next cell.

Each cell functions as an independent organism, with its own system of water drainage to prevent infiltration and is isolated as to protect the environment from any migration of radionuclides. Its foundation features a central gallery that extends through the length of the cell. Possessing a width of 2.2 and the height of 2.5, this gallery is accessible by workers to monitor the integrity of the cell, perform routine checks for any infiltration, and carry out operations such as those related to the water pipelines.

The storage is cell is capped by a precast concrete slab of 10cm thickness held by the cell wall on one side and an interior partition of the other, in addition to 40 cm thick concrete casting. After which, the roof is manipulated by a screed to form a slope that eases the flow of rainwater and then waterproofed to prevent water infiltration.

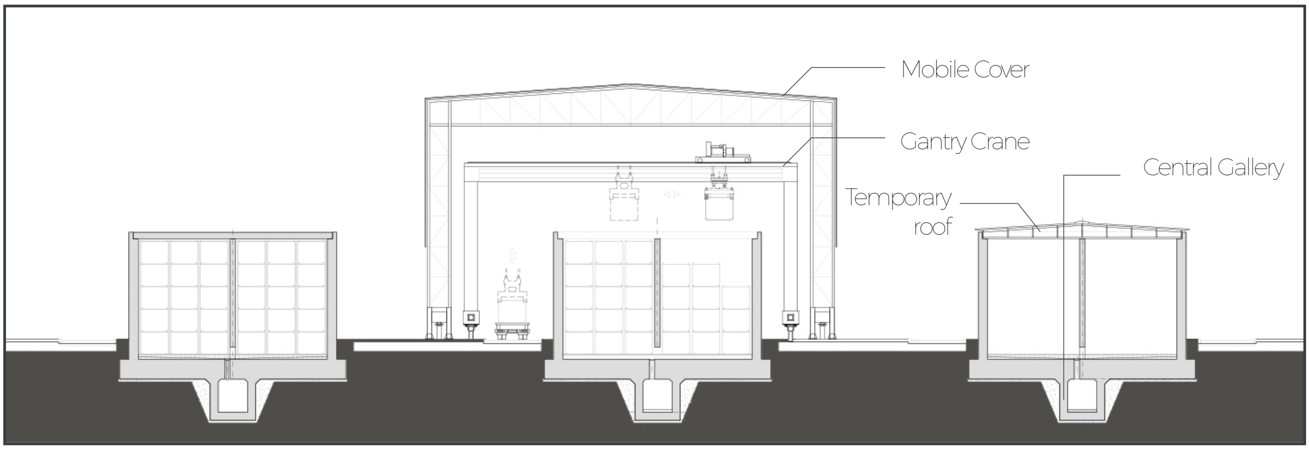


Figure 22 :Section of module disposal unit . Source: SOGIN

A temporary protective roof is installed on the empty cells that are yet to be filled with modules. it is composed of metal lattices that protects the cell form atmospheric conditions. Furthermore, it is covered with panels that extend to the periphery of the cell to allow external water flow. (SOGIN, 2018)

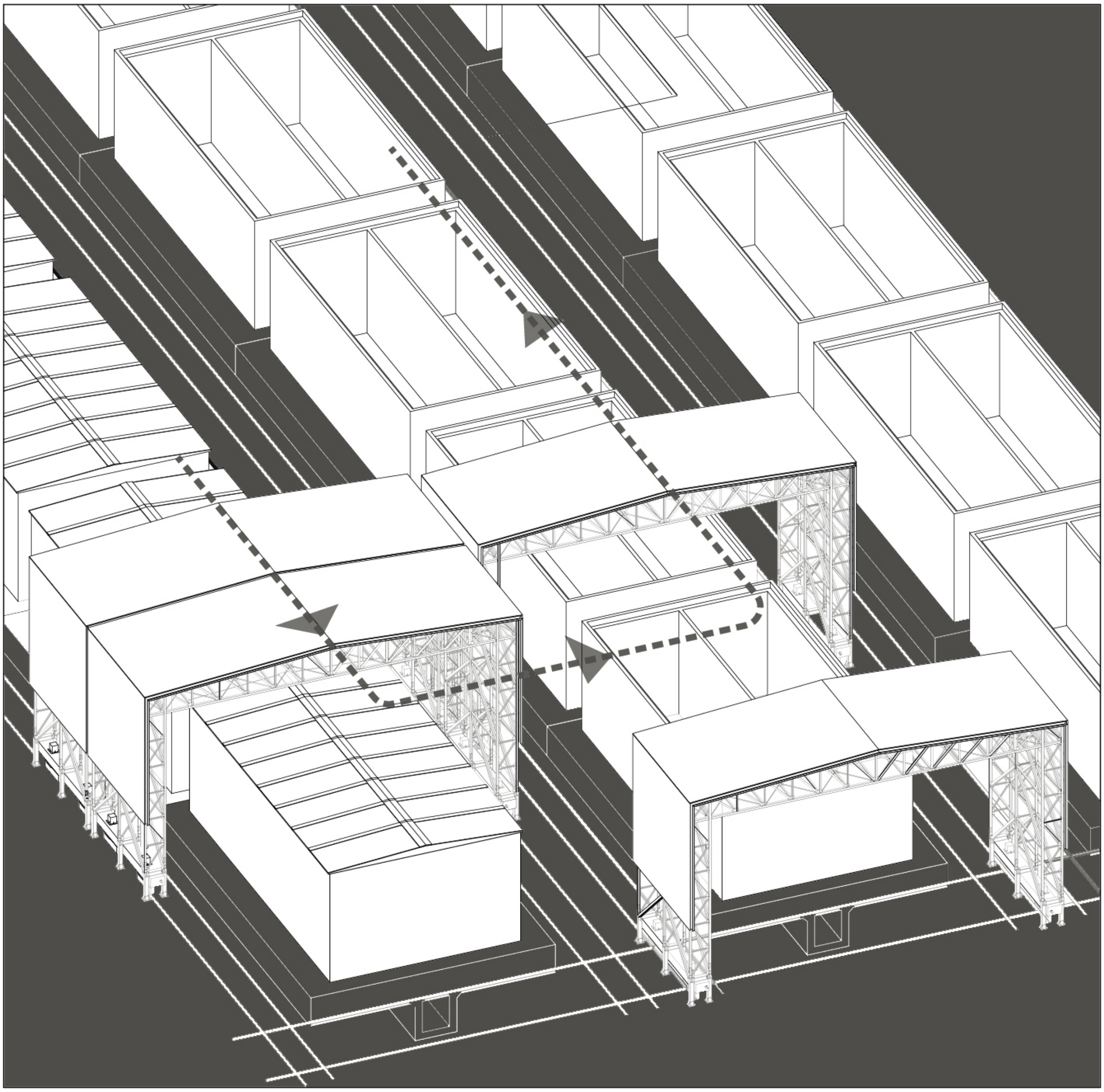
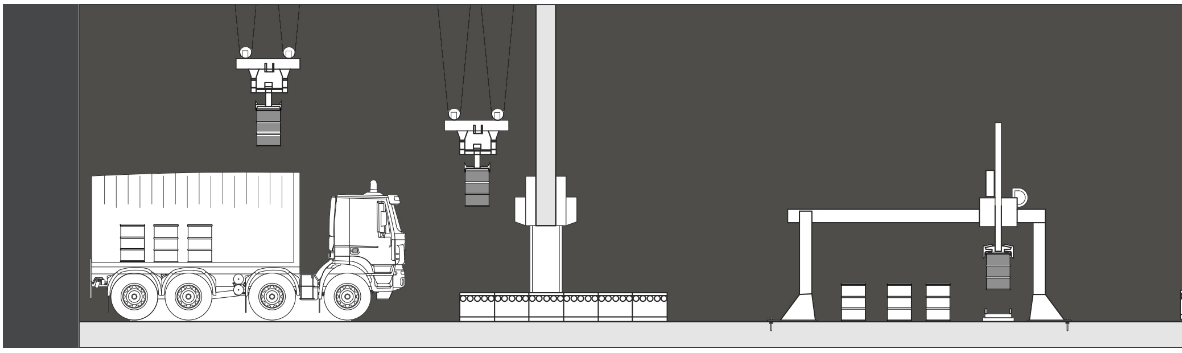


Figure 2.3: Flow of the mobile cover . Source: SOGIN

4.1.2 Waste Treatment Plant (ITR)



The artifacts arrive at the waste treatment plant for administrative processing, then are unloaded from the truck to be transported to a temporary holding space.

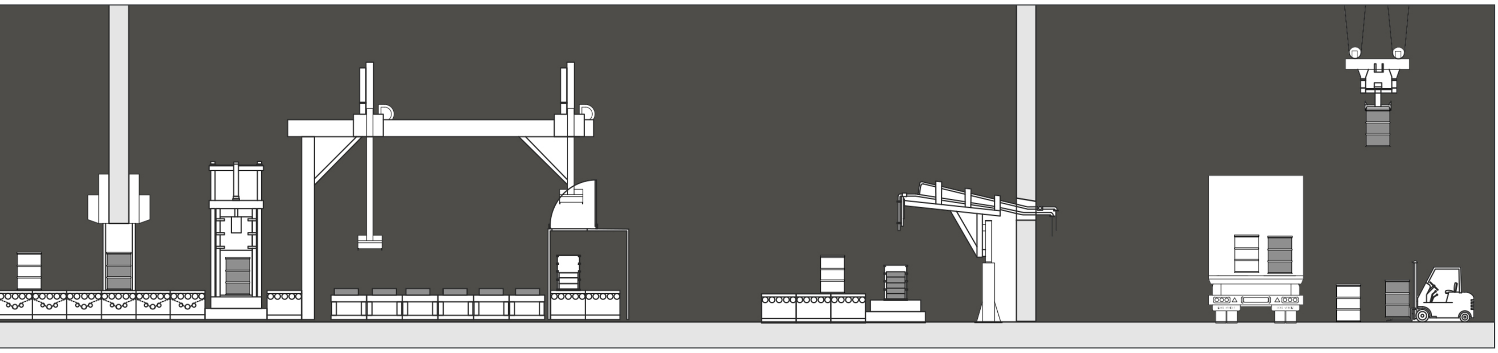
The selection of the compactable waste is undergone to be transported to the compression unit.

Following the preliminary design of SOGIN, the waste treatment plant (ITR) is the building allocated to the treatment and conditioning of the solid compactable and non-compactable radioactive waste produced onsite within the repository. Whereas, the radioactive waste received from external sources doesn't undergo treatment process within the repository.

This waste produced during the operation of the facility is compressed to reduce its volume, then placed in a cement grout mixture to ensure containment. After which, these artifacts are transported to the Module Packaging Plant (ICM) to be packed into modules, that will, in turn, be loaded into cells, awaiting permanent disposal in the Module Disposal Unit (USM). (Sogin, 2020a)

The building is organised in 5 main areas:

- Unloading and parking of incoming waste containers
- Waste treatment line
- Workshop for cutting lightly contaminated mechanical parts
- Storage of the final products in the output
- Control and services

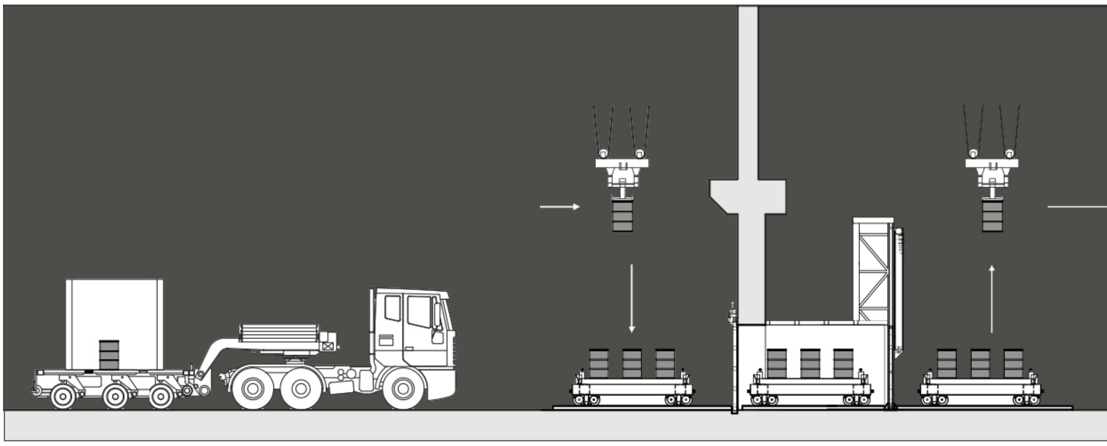


The waste is compressed and then selected for conditioning to ensure safe transport and isolation.

The compressed waste is then conditioned with cement grouting mix to increase security.

The artifacts are then transported in trucks to the module packing plant pending to be stored along with the externally produced waste.

4.1.2 Module Packaging Plant (ICM)

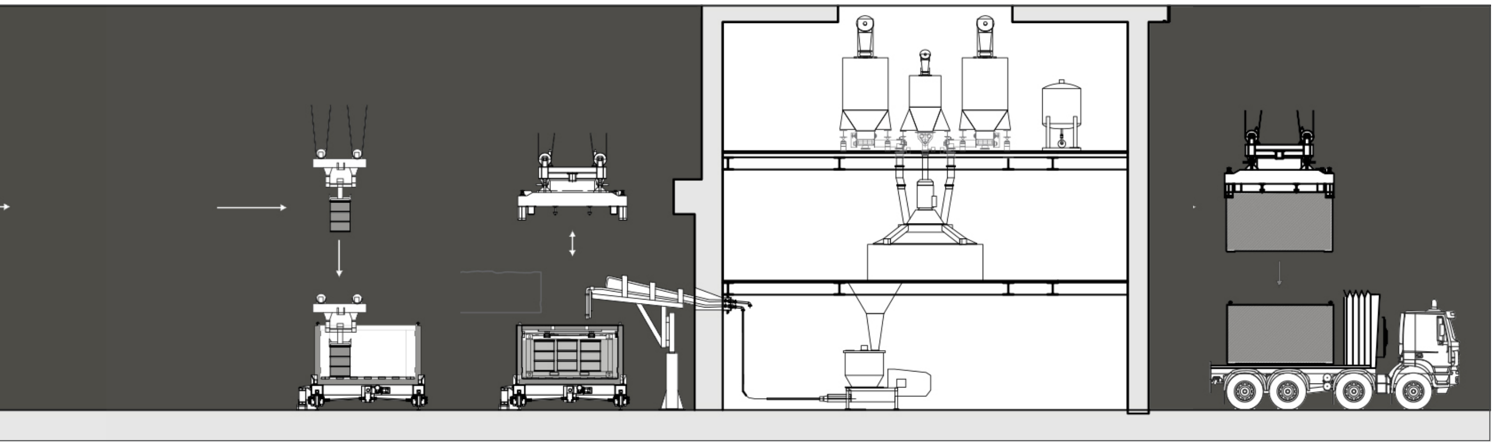


The artifacts and the modules arrive into the module packaging plant

The artifacts are transported to an area of temporary storage awaiting packaging

The Modules Packaging Plant (ICM) is the facility where the second containment barrier—the module—is formed. The plant has the capacity to produce eight modules per day, and since the incoming waste is already conditioned, no additional treatment processes are required. Operations at the ICM focus solely on the handling of pre-packaged waste, its placement into modules, and its immobilization using cement mortar (grouting).

Each batch of waste undergoes a series of quality control checks, which may include administrative verification, visual inspections, and direct measurements. Once verified, the waste packages are temporarily placed in a buffer storage area before being inserted into the modules for final grouting and sealing. The entire process is closely monitored, with each module's contents and exact position in the disposal cell fully documented. After preparation, the sealed modules are then transferred to the Module Disposal Unit (USM) for final emplacement.
(Sogin, 2020a)



The artifacts are loaded into the module

The modules are then grouted with a matrix , then are set in a area to allow for proper curing before undergoing the sealing process

The modules are then sent to the module disposal unit

4.2 ILW and HLW Radioactive Waste

The CSA or High activity Waste complex is comprised of 4 buildings dedicated to the temporary storage of intermediate and high-level waste. Furthermore, only one of the buildings contain a wing that temporary hosts spent fuel and residues that are produced after the reprocessing of this fuel. This wing is designed according to the dimensional and functional requirements of casks, including the circulation paths and management of the waste.

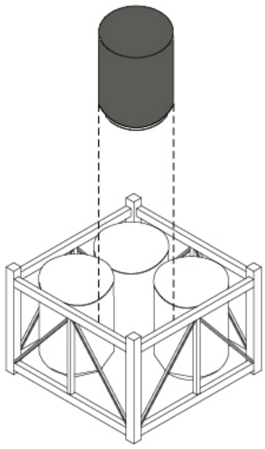
The different types of waste undergo conditioning, packaging and transportation according to their radiochemical attributes. Therefore, the structural and chemical characteristics of the matrix and the containers vary according to the type of waste, where the casks and the cylindrical containers arrive sealed and ready for storage at the CSA.
Special high integrity cylindrical containers are used for packaging of activate/contaminated high activity waste. These containers have varying thickness of walls in accordance to the need of shielding power and high structural endurance, with the possibility of applying an internal lead layer to increase the potential of inserting higher activity levels. Such containers do not require a matrix for conditioning, as it is designed to assume the role of the matrix. Cylindrical containers are arranged in vertical racks of metal HEA type profiles that contains the products; therefore, the top of rack is shaped as to support the base of that stacked above it, allowing precise centering and stability.

The casks, on the other hand, contain unprocessed spent fuel and its reprocessing residues. These containers are of dual purpose, allowing the transportation and storage of the radioactive waste. In fact, they are subject to extreme mechanical and thermal stress test after production, following the international standards. Before being inserted into the cask, the vitrified or compacted residues are enclosed in canisters, then loaded in baskets. Whereas spent fuel is capsulated in stainless steel containers or placed directly into the basket, and in turn, within the cask. Motorized hatches and heavy-duty overhead cranes allow the transport of the casks for inspection and control of the casks before transporting them into their designated spots for storage.
(SOGIN, 2018)

Stackable Containers

∅ 0.8x 1.2 m

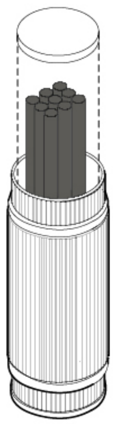
High integrity containers that don't require a matrix for conditioning due to their structural characteristics. These containers are stacked in racks inside the vaults.



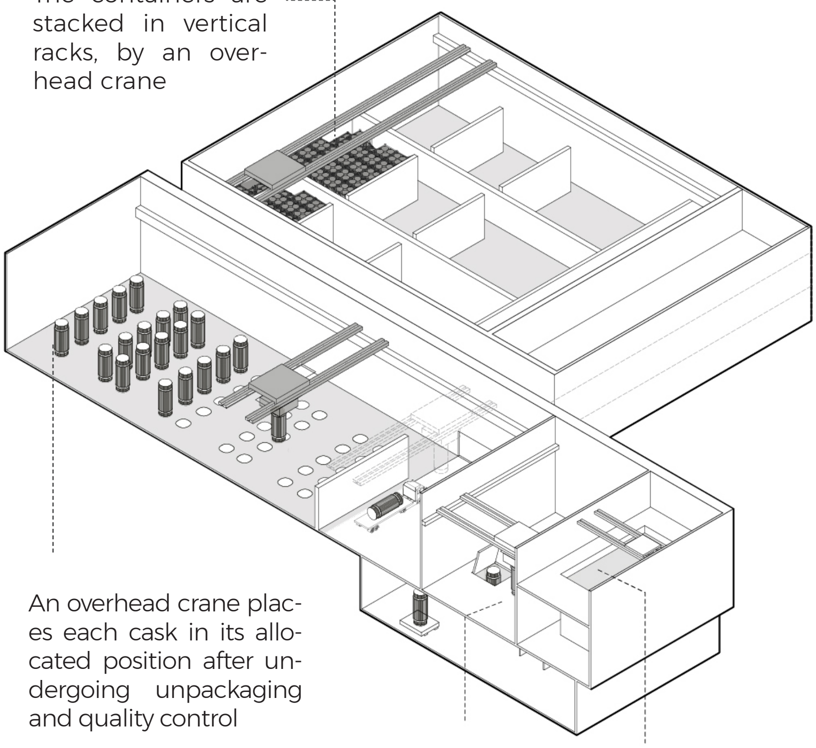
The Cask

∅ 2.7m x 6.5 m

Metal containers, comprising of spent nuclear fuel and its reprocessing residues, designed to ensure the shielding and protection from all possible occurrences that might compromise the containment of the waste, allowing safe transfer and storage.



The containers are stacked in vertical racks, by an overhead crane



An overhead crane places each cask in its allocated position after undergoing unpackaging and quality control

4

SITE LOCALIZATION

4.1 Exclusion Criteria

These criteria have been established to identify areas that ensure compliance with the safety standards, through excluding areas with the following characteristics. (ISPRA, 2014)

CE1	Area of active or quiescent volcanoes
CE2	Area of high seismic activity
CE3	Area of interest by superficial faulting
CE4	Area, characterized by geomorphological and/or hydraulic risk and/ or hazard of any grade as well as river belts
CE5	Area of holocene alluvial deposits
CE6	Area, located above 700 m a.s.l.
CE7	Area, characterized by an average slope greater than 10%
CE8	Area within 5 km from the current coast line or, if more distant, located under 20 m a.s.l.
CE9	Area, interested by morphogenetic karst processes or with the presence of sinkholes
CE10	Area, near surface piezometric levels or with piezometric levels which could anyhow interfere with the foundation of the disposal facility
CE11	Area naturalistic, protected under the legislation in force
CE12	Area at an unsuitable distance from residential zones
CE13	Area within a distance of 1 km from highways, all principal suburban roads, and the main and complementary railway lines
CE14	Area with known presence of underground resources
CE15	Area with industrial activities involving major accident hazards, dams and artificial hydraulic barriers, airports or operating military shooting ranges

Investigation Criteria

After ruling out areas as per the exclusion criteria, the identified areas are then subject to evaluation according to the investigation criteria. Detailed assessments are performed to filter out additional portions of the territories that have not been excluded and fall under “potentially suitable area” for the location of repository. The following is the investigation criteria implemented by ISIN (previously ISPRA) and that conform with the IAEA standards of site selection. (ISPRA, 2014)

CA1 Area of active or quiescent volcanoes presence of secondary volcanic activities

CA2 Presence of significant vertical movements as a result of subsidence area of high seismic activity and uplift phenomena

CA3

Geological-morphostructural setting and presence of lithotypes with vertical and lateral variation

CA4

CA5 Presence of endorheic type river basins

CA6 Presence of accelerated erosion phenomena

CA7 Weather and climatic conditions

CA8 Physical and mechanical parameters of the soil

CA9 Hydrogeological parameters

CA10 Chemical parameters of soil and groundwater

CA11 Habitats, animal and plant species of conservation importance, as well as geosites

CA12 Agricultural production of outstanding quality and places of archaeological and historical interest

CA13 Availability of primary transport infrastructures

4.2 Potentially Suitable Areas for the National Repository

The selection of one particular site for the national repository and technological park is the result of a collaborative process following the establishment of the National Map of Potentially Suitable Areas (CNAPI).

The CNAPI proposal has identified 67 sites, all of which arranged in a decreasing order of suitability, according to social, environmental, logistical and seismic parameters. Although all sites have equal safety conditions, this system of classification characterizes the areas with respect to their logistical and infrastructural efficiencies. (SOGIN, 2020c)

As seen in the map below, Piedmont region possesses a significant number of A1 Class areas out of the total 12 A1 potentially suitable sites in Italy, while the rest are located in the Region of Lazio.

Figure 3.1 :Map showing the distribution of potentially suitable area for the italian national repository .
Source: SOGIN. (2020c). Proposal for a National Map of Potentially Suitable Areas.

4.3 Italian Nuclear Cycle

The generation of nuclear waste in Italy is attributed to former nuclear power plants, fuel cycle facilities, research centers, and other producers like hospitals and industrial users". Power plants and fuel cycle facilities are equipped with temporary storage facilities for nuclear waste. However, these spaces are not structurally designed for the final disposal of nuclear waste.

The integrated service is a national system dedicated to the management of radioactive waste produced by facilities apart from to nuclear power plants- such as hospitals, research centers, and industries. This system was founded by ENEA (Italian National Agency for New Technologies, Energy and Sustainable Economic Development) in 1985, and is operated by the SOGIN group company "Nucleco" who handles the collection, transportation, treatment, conditioning and temporary storage of radioactive waste, before the eventual permanent disposal in the national repository. (SOGIN, 2020d)

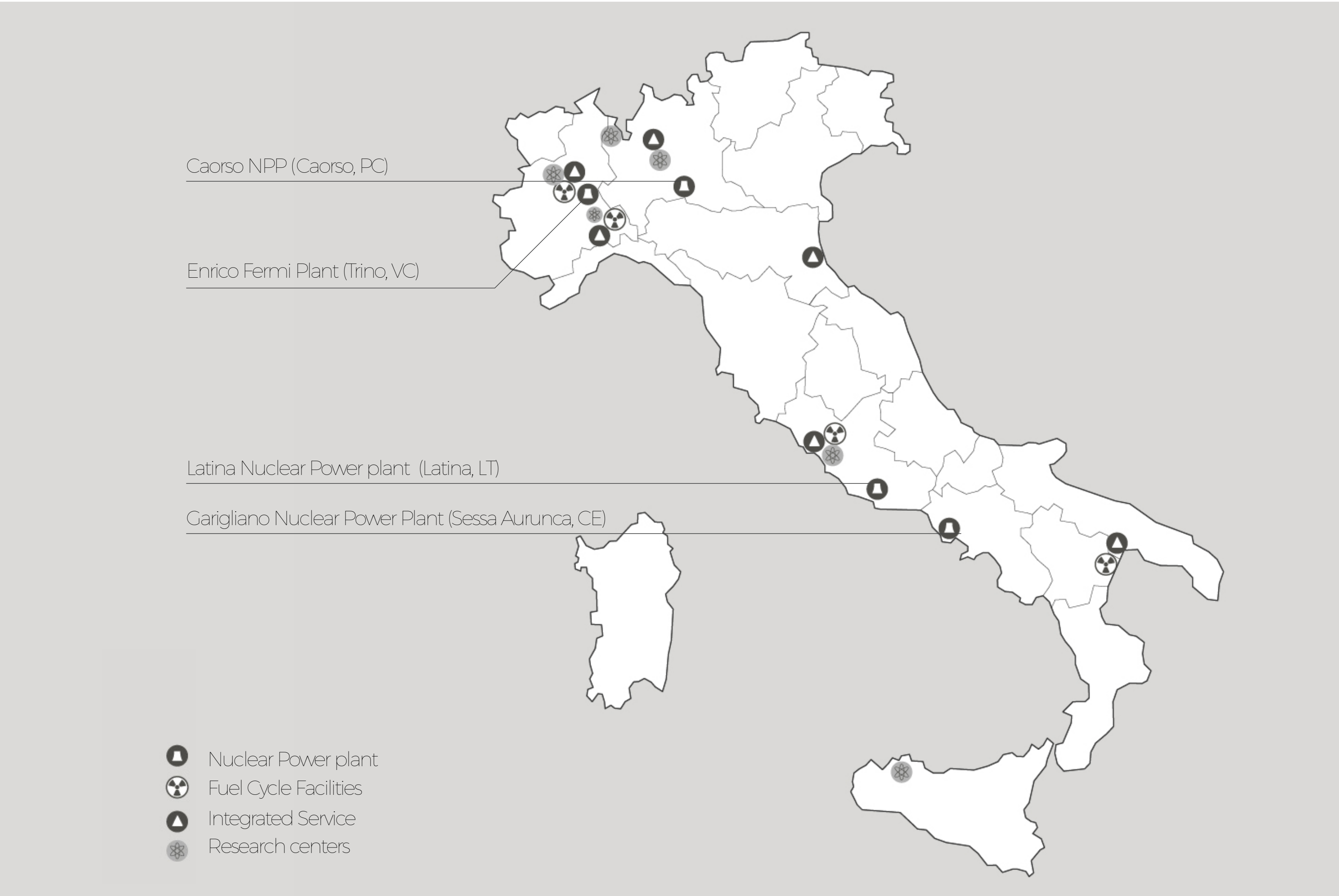


Figure 3.2 :Map showing the distribution of the facilities contributing to the italian nuclear cycle
Source: SOGIN. (2020d). Stima dei rifiuti radioattivi da conferire al Deposito Nazionale

4.4 Piedmont A1 Class Potentially Suitable Areas

This thesis selected the Piedmont region as the proposed site for the National Repository and the Technological Park. The identification is based on the results of the “Site Selection and site exclusion Criteria” established by SOGIN, along with an evaluation of the Italian nuclear cycle, both of which were discussed in earlier sections.

Within Piedmont, 7 out of 8 potentially viable locations received an A1 classification, which are then analyzed according to logistical, anthropogenic, and environmental crietria . These criteria include:

- A minimal presence of high-value agricultural land
- A low concentration of ecologically significant areas
- A sufficient distance from major railway lines
- The absence of nearby residential settlements

Nuclear Power plant
«Enrico Fermi» Nuclear Power Plant (Trino, VC)

Fuel Cycle Facilities
EUREX (Saluggia, VC)
Bosco Marengo (AL)

Integrated Service
Leva-Nova Sorin Site Mgmt (Saluggia, VC)
Avogadro (Saluggia, VC)
Campoverde S.R.L (MI)
Campoverde S.R.L (Tortona, AL)

Research centers
CeSNEF PoliMI (MI)
ISPRA - 1 CCR (VA)

Potentially Suitable Areas

Road Network

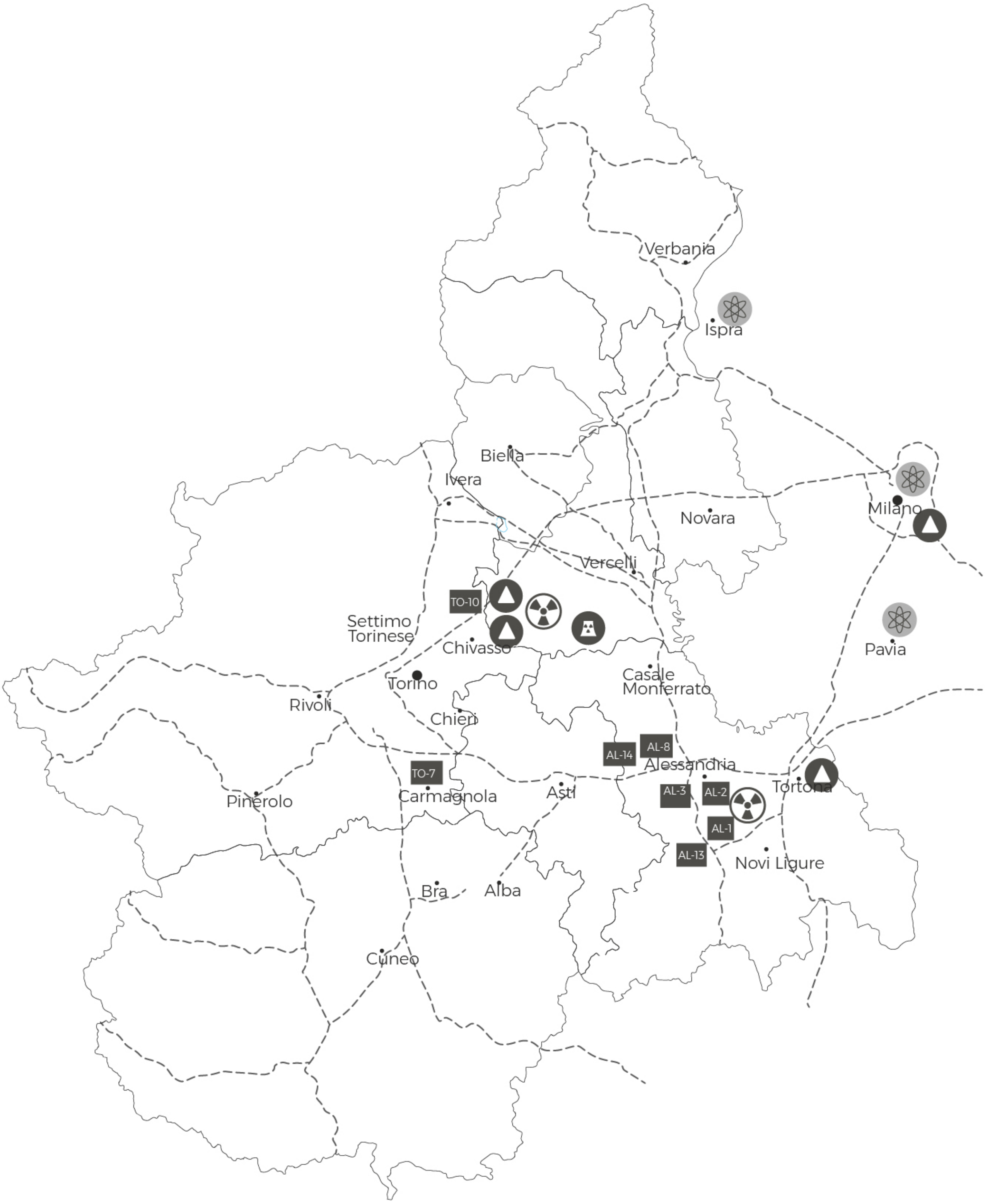
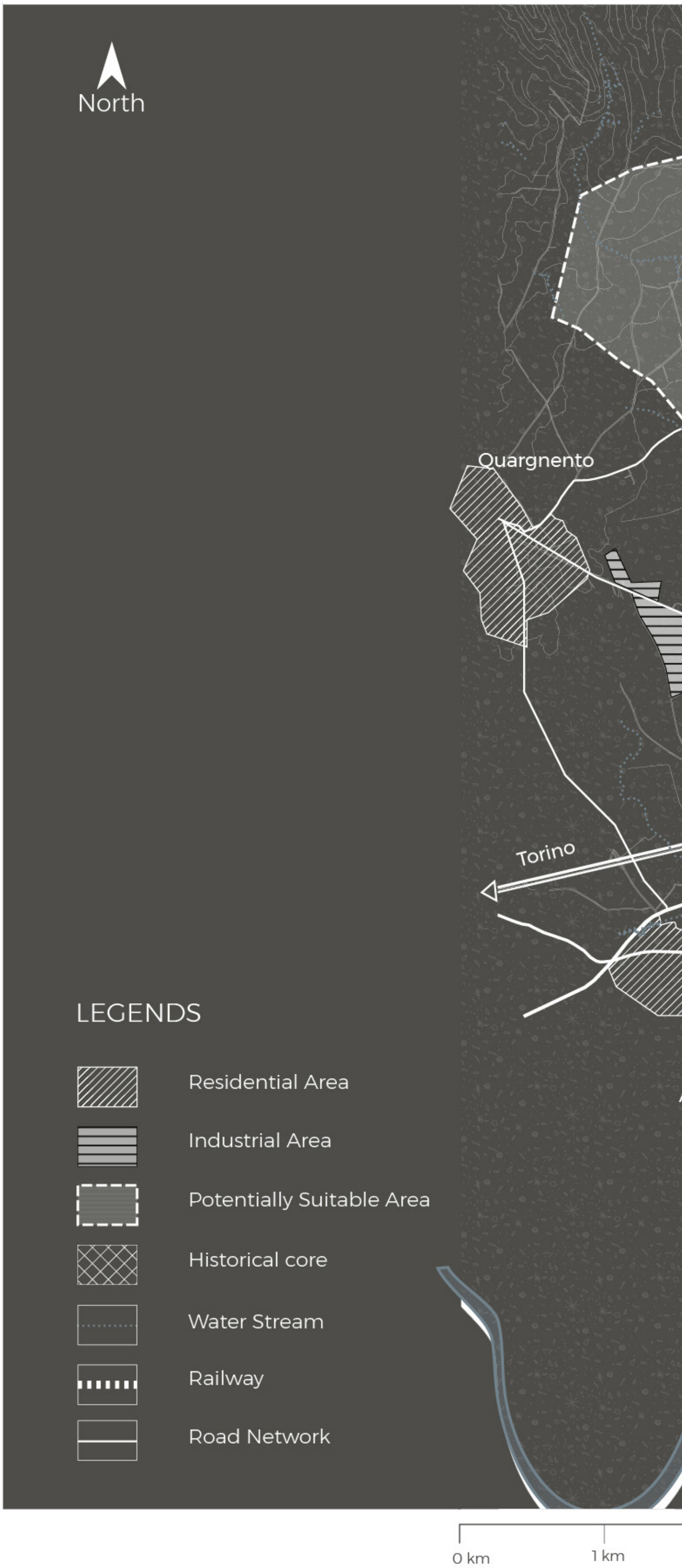


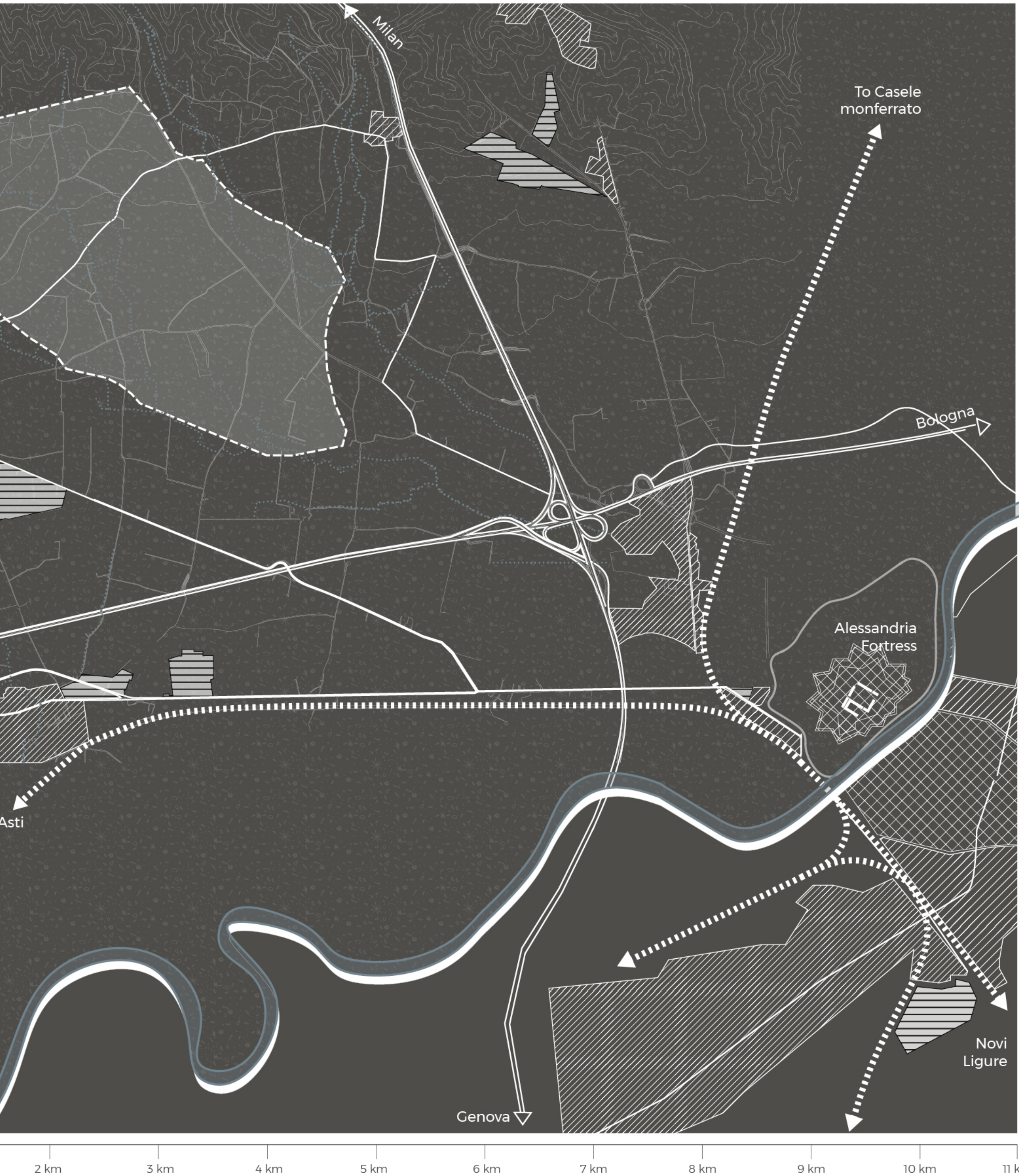
Figure 3.2 :Map showing the distribution of the fpotentially suitable areas of class A1 in Piemonte
Source: SOGIN. (2020d). Stima dei rifiuti radioattivi da conferire al Deposito Nazionale

4.5 AL-8 Area Features

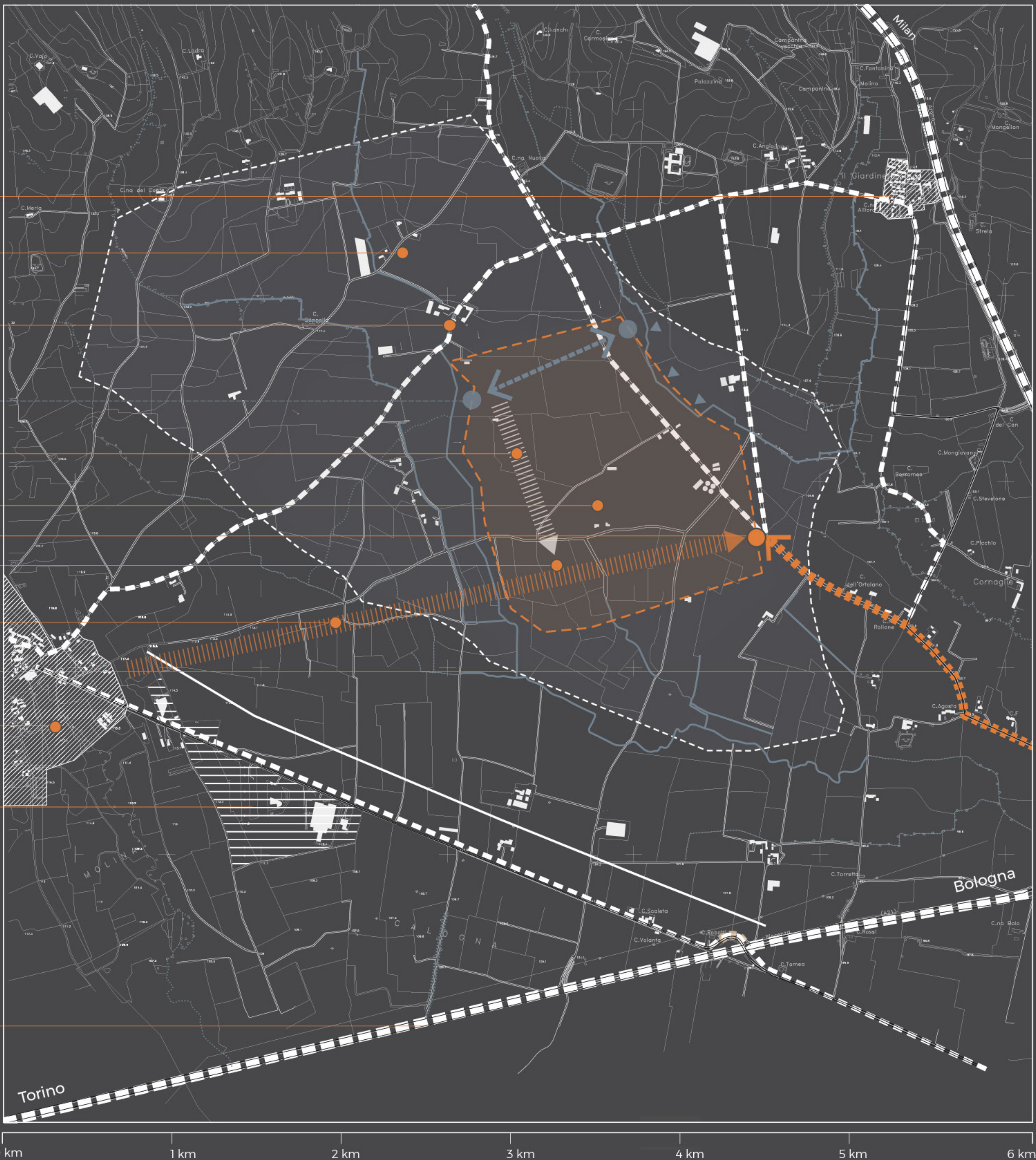
According to technical report provided by SOGIN, the potentially suitable area AL-8 is located in a Relatively flat terrain positioned between the southern slope of Monferrato reliefs and the Tanaro River. The area develops on an extensive flat surface with a weak slope towards the South and South-East (less than 1%), which allows for the localization of the project in this area, whereas the water streams confined its extents within the landscape.

The area proposed is confined by a primary road network that serves as arteries for the project, providing access to the facility from Torino, Genova, Milano and Bologna. This network layout impacts the location of entrance to the project, whether concerning the radioactive waste, or human accessibility. (SOGIN, 2020a)




Milan
To Casele monferrato
Bologna
Alessandria Fortress
Asti
Genova
Novi Ligure
2 km
3 km
4 km
5 km
6 km
7 km
8 km
9 km
10 km

As shown in the map, the existing features of the area shape the boundaries of the project and some decisions that affect the repository. Within the borders of the AL-8 area, a relatively flat surface identifies a preferred area to host the facility. Around this area exists water streams that further refine its edges. The slight natural inclination of the terrain determined the location of the disposal unit and its associated water reservoir, thus, contributing to the prevention of water infiltration.
The entrance to the repository is planned with proximity to the main motorway junction which connects the site with Alessandria, Milan, Turin, and Bologna. Another point worth mentioning, is considering the visual aspects of the facility with respect to the surrounding residential areas.



uitable area

a
ons

Existing Buildings

Water stream

High way

Principle Road

Visual Connetion to the site

Inclination Direction of terrain

5

THE THIRD LANDSCAPE

5. Entropy as Design Condition: Designing for Decay

Entropy, at its origin, is a scientific term relating to the second law of thermodynamics coined by Rudolf Clausius in 1864 to define and measure energy dispersal and the disorder of a closed system (Abalos et al., 2015). An inevitable negative movement that, when associated with daily experiences reframes our perception of waste, architecture, and decay. Robert Smithson, one of the firsts to interpret the visual disorders of life through an entropic perspective, describes the process by asking the reader to imagine an experiment: “Picture in your mind’s eye a sand box divided into half with black sand on one side and white sand on the other. We take a child and have him running hundreds of times clockwise in the box until the sand gets mixed and begins to turn grey; after that we have him running anti-clockwise, but the result will not be a restoration of the original division, but a greater degree of greyness and an increase of entropy”. Smithson implies that any closed system will eventually deteriorate, even the energy put to restore or retain a particular order will result in increased entropy, where architects are disregarding the entropic process, and building isolated and self-contained systems (Smithson, 1973). Koolhaas observed that “Junkspace” offers entropy instead of development, being in a state of constant expansion. leakage, and collapse (Koolhaas, 2002).
Among the diverse ways architecture resists entropy, the issue of nuclear waste storage is pointed out, where it is deemed necessary to include material and information entropy in the design strategy to protect the historical memory from the extreme duration of radioactive decay. Moreover, Eric Kahn and Russell Thomsen of “Idea Office” address the concentration camps of “Auschwitz and Birkenau” through targeting the visitors’ objective and instructive memory by proposing an entropic installation as solid evidence that embraces decay, and a museum as a space of curated order. This architectural proposal unravels the paradox that preservation acts may erode the remains’ authenticity. (Corbellini, 2016)

Moreover, the concept of “The Third Landscape” by Gilles Clément provides a useful framework to approach entropy in the context of landscape. In his design for Parc Henri Mattise in Lille, Clément created an inaccessible elevated forest designed to allow nature to take its course without human intervention. This paradoxical landscape compels the observers to contemplate on the inconstant evolution of biological species in an uncontrolled, isolated territory, producing entropy by design. (Gandy, 2013)

5.1 Mapping Memory

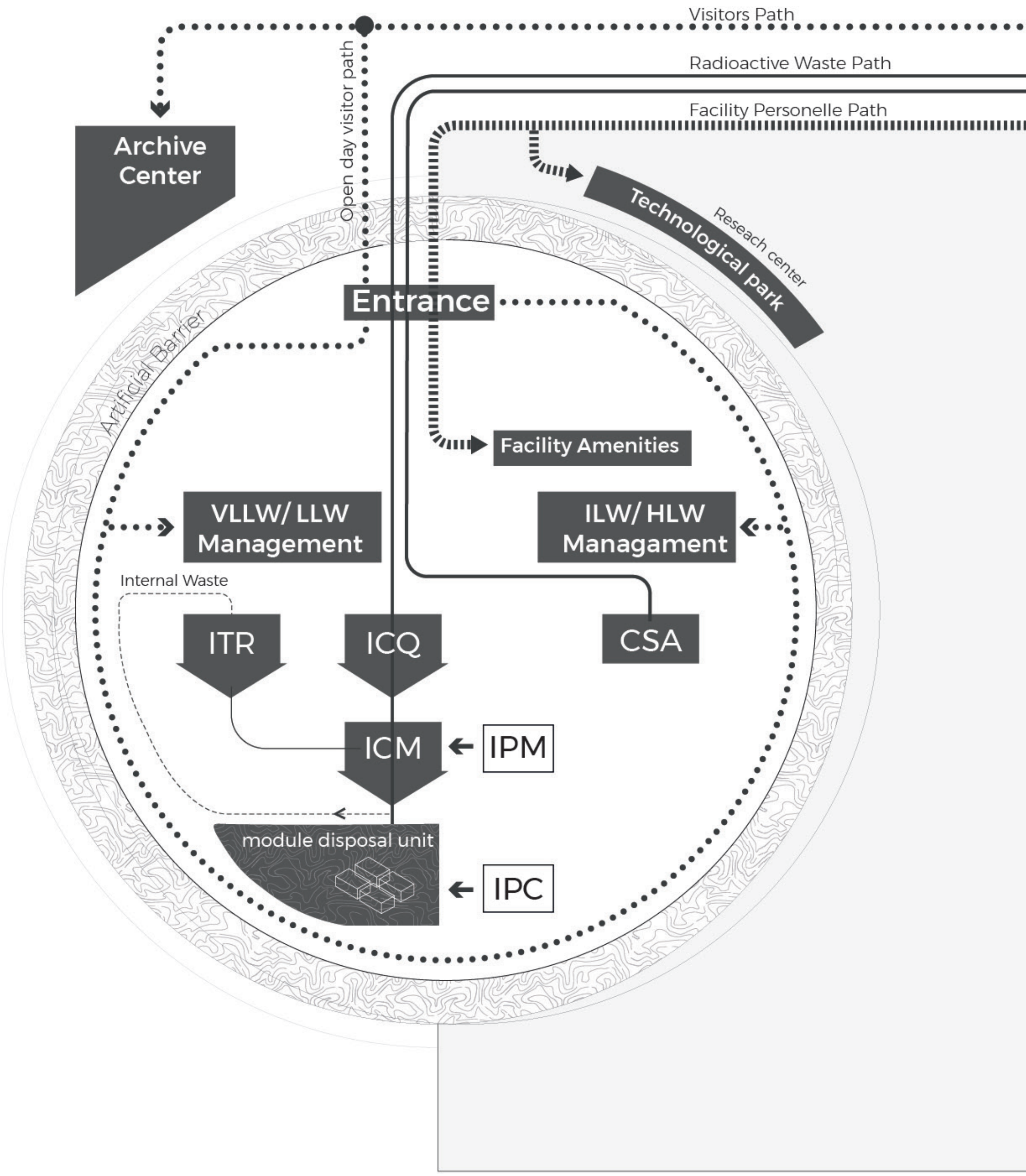
Objective and Instructive Layers

Kahn and Thomson distinguish between two regimes of memory: objective memory and instructive memory. Objective memory is embedded in the physical remnants of the past — ruins, artifacts, material traces — while instructive memory resides in subjective experience, storytelling, and reinterpretation over time. For Kahn and Thomson, memory and meaning are renewed by the arrival of unknown and every change in destination. therefore, they argue that uncomprehensible events remain elusive and beyond full understanding. Because of this, they emphasize the importance of entropy in their approach: entropy compels the continual re-examination of the subject, keeping both remembrance and forgetting active, as a necessary and living force. (Matatyaou, 2001)

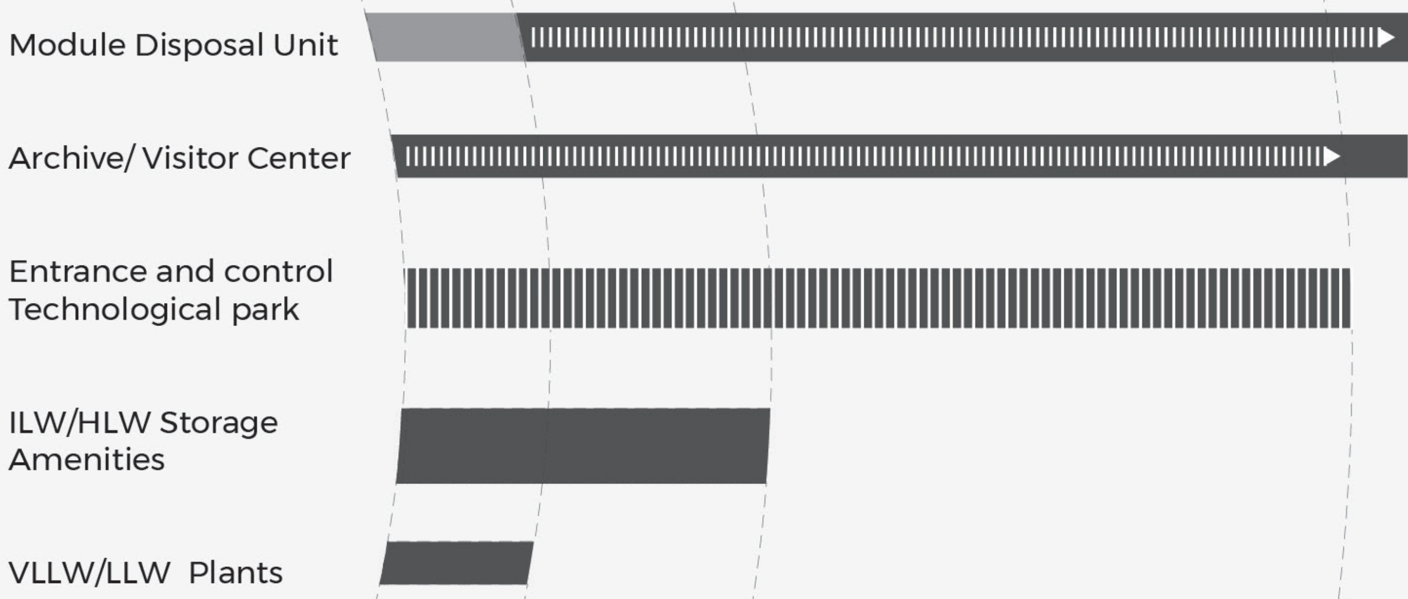
The nuclear waste repository in this project will be shaped by a system of intertwined layers of memory:
The layer of subjective memory: material witness to what the site held, through creating a third landscape that depends on entropy as a design tool. Hence, forming a subjective experience with the past in inconstant evolution.
The layer of instructive memory: by contrast, this system narrates the knowledge through deliberate means: archives, monuments, and institutional narratives that aim to partially resist time's erosion through order, control, and coherence.

Figure :the paths of visitors around the perimeter of the Tel Olam.

Source: Courtesy of IDEA Office



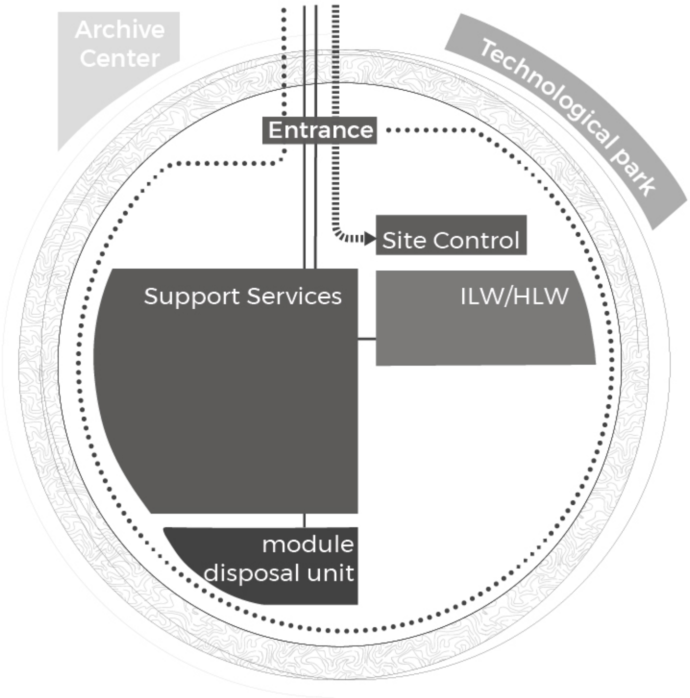
ICQ	Quality Control plant
ITR	Waste Treatment Plant
ICM	Module Packaging plant
IPM	Module Production Plant
IPC	Cell Production plant
CSA	High Activity Waste Complex

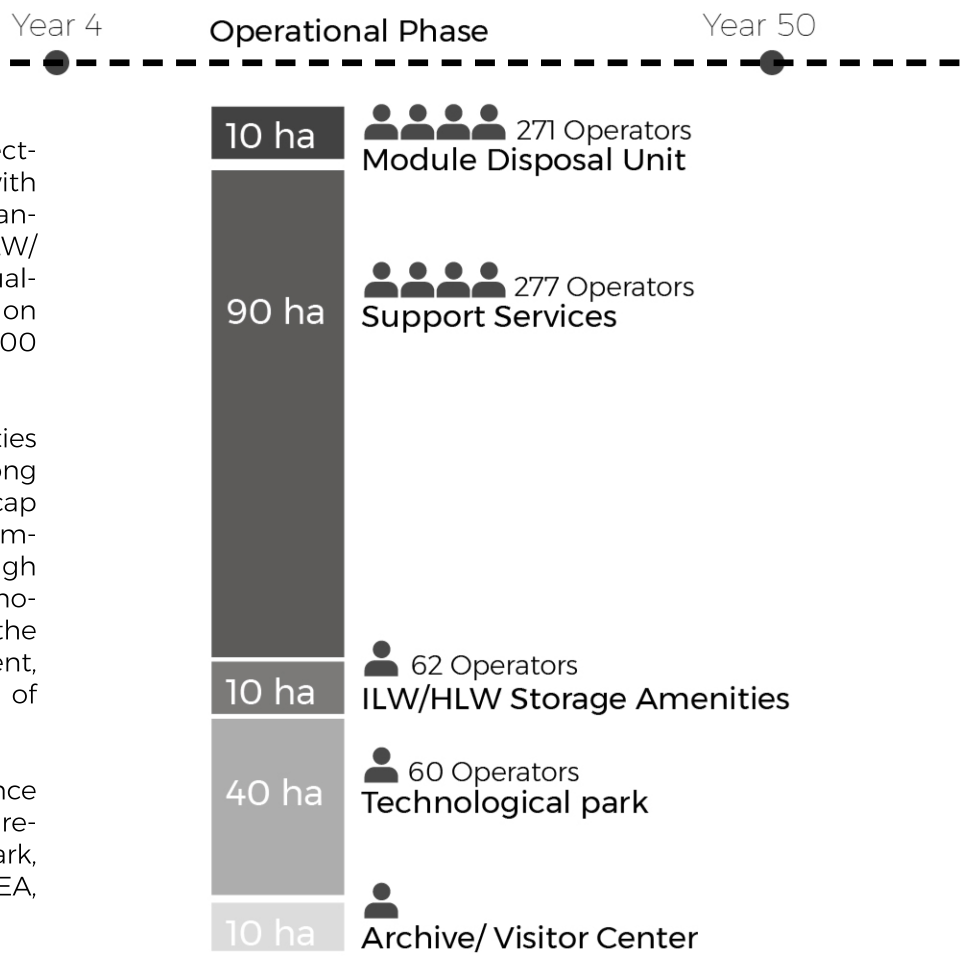


5.2 PROGRAM AS A FUNCTION OF TIME

The nuclear repository fully operates for 50 years, until 90 modules are inserted into the disposal unit and the final caps of the modules are constructed. This allows the decommissioning of the operational buildings and the burial of the waste by the mark of 100 years, confining and controlling the site for another 250 years. However, the high activity level waste facilities are decommissioned after the 100 years mark. The archive center represents the memory of the repository; thus, must operate for more than 350 years, while the Technological Park is an autonomous entity within the site. Therefore, decisions regarding its lifespan depend on its managing body. (IAEA, 2020)

The time dimension of the project components shapes the design of the facility.
The timescale of the archetypes impacts their location and level of accessibility to the public, both visually and physically, thus creating a space of different levels of administrative control.
The time dimension also affects the materiality used, where the archive must be constructed with durable material to ensure its long timeframe. The unpredictable span of the technological park calls for a lighter material, while the operational buildings require material that facilitates decommissioning.

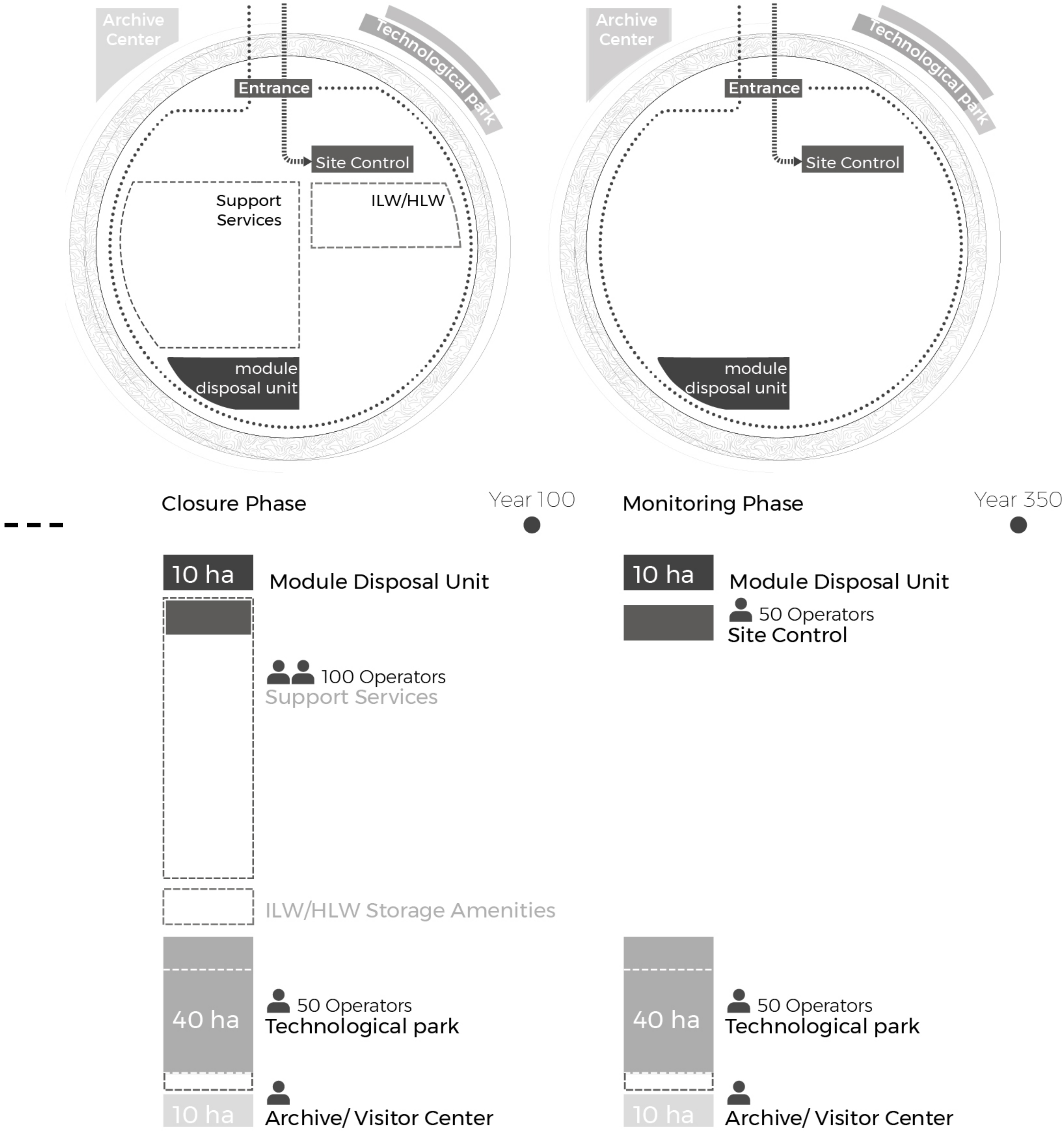




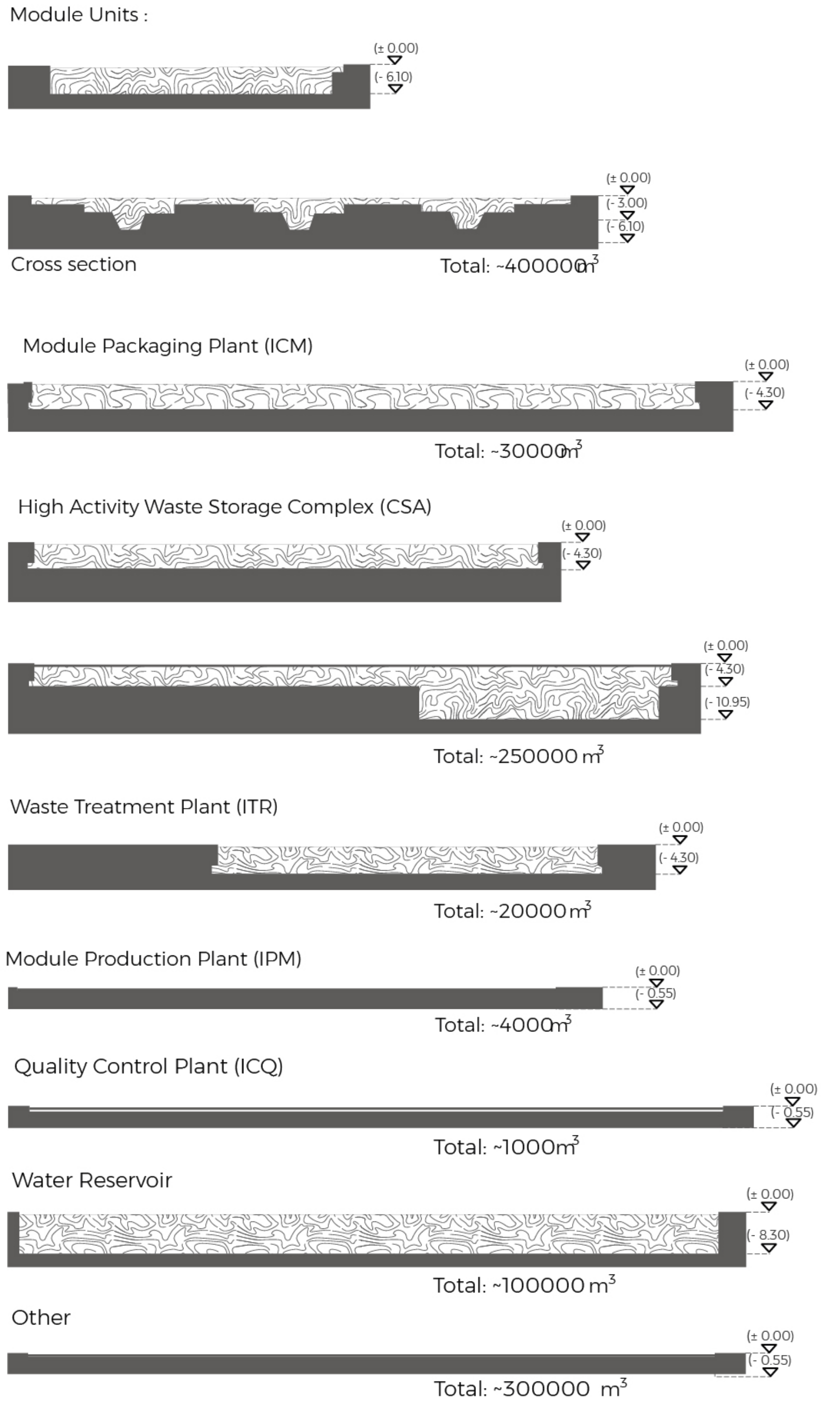
Operation Phase:
Lasts approximately 40 years, and is directed to the progressive filling of the cells with the radioactive waste modules, and managing the temporary storage of the HLW/ILW radioactive waste, while ensuring quality control and safety measurements on site, with an estimated employment of 700 operators.

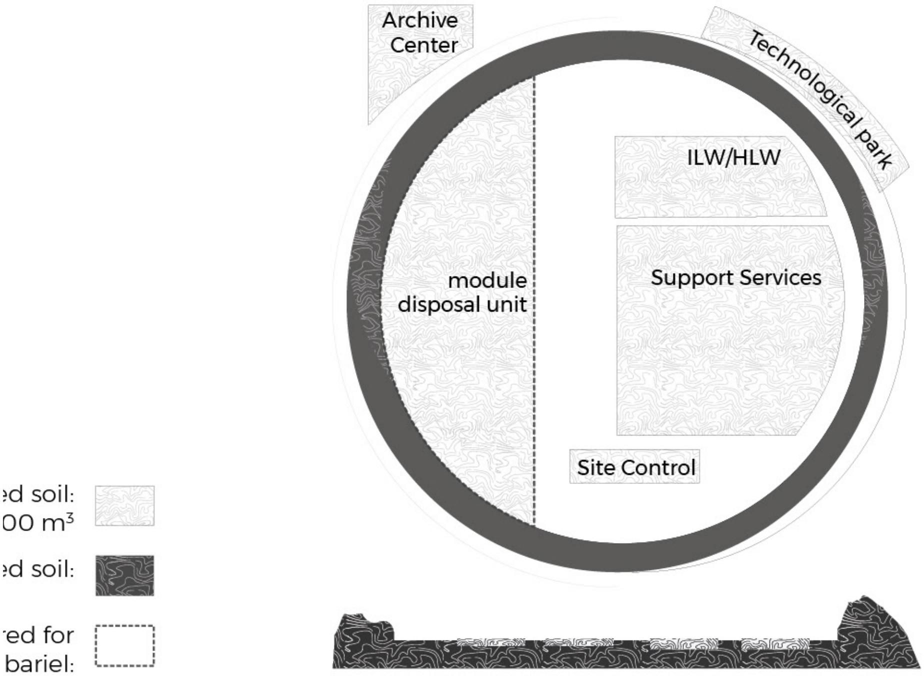
Closure Phase
Decommissioning of the support facilities and the HLW/ILW storage building, along with the construction of the multi-layer cap for the disposal unit. The estimated employment is about 250 operators, although the number of employees of the Technological Park is subject to change due to the fact that is of independent management, thus open for expansion or reduction of area and activity.

Monitoring phase:
This phase comprises facility surveillance and site control, in addition to probable research activities in the technological park, with about 100 estimated work force. (IAEA, 2014b)

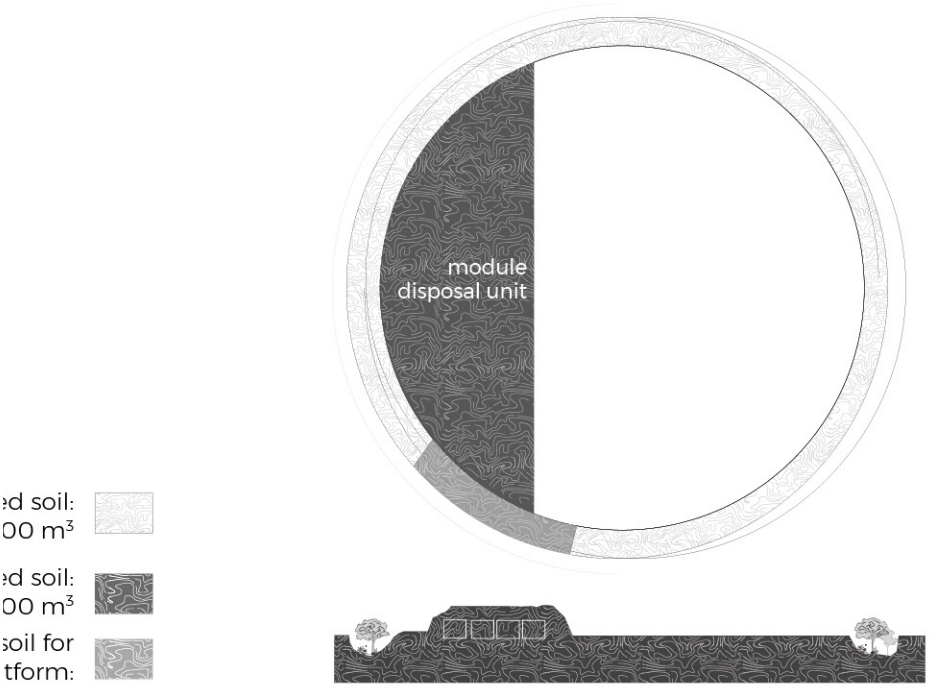

Archive Center
Technological park
Entrance
Site Control
Support Services
ILW/HLW
module disposal unit
Archive Center
Technological park
Entrance
Site Control
module disposal unit
Closure Phase
Year 100
Monitoring Phase
Year 350
10 ha
Module Disposal Unit
100 Operators
Support Services
ILW/HLW Storage Amenities
40 ha
50 Operators
Technological park
10 ha
Archive/ Visitor Center
10 ha
Module Disposal Unit
50 Operators
Site Control
40 ha
50 Operators
Technological park
10 ha
Archive/ Visitor Center

5.3 EXCAVATION PROGRAM





Operational Phase
Year 2029



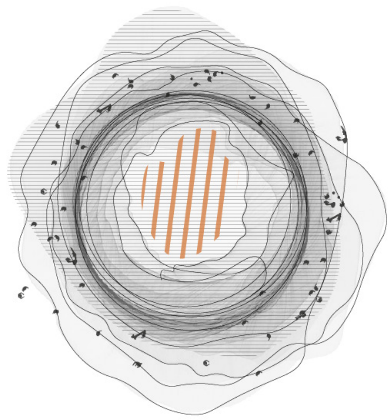
Closure Phase
Year 2129

5.4 THE THIRD LANDSCAPE: Barrier as Program

By addressing the paradoxical emotions towards waste, fear and desire, curiosity and danger, the project is designed to allow contradictory experiences, assuring both control and transparency.

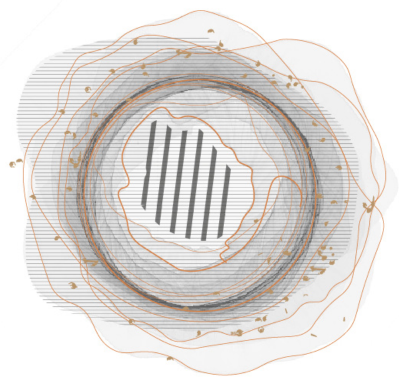
“Fear and loathing, because they access a preconscious dimension-that of the survival instinct- become powerful vectors of transformation formulating design strategies, that are just as paradoxical as they are interesting”.(Corbellini, 2010)

This is evident in the manipulation of the protective layer made of soil that surrounds the Repository, providing 3 different and sometimes contradictory functions: Confinement of the hazardous material, hiding the facility within the territory, and creating an elevated platform that allows the visitors to observe the non-reachable.



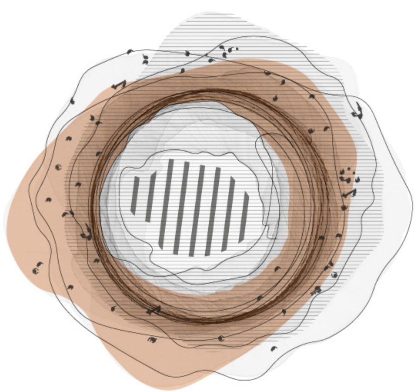
Symbolic Containment Perimeter

The soil excavated for the construction of the repository facilities forms the protective barrier in a universal and unnatural circular geometric shape. By evoking mystery and attention, this perimeter not only becomes a barricade, but also a marker for future generations.



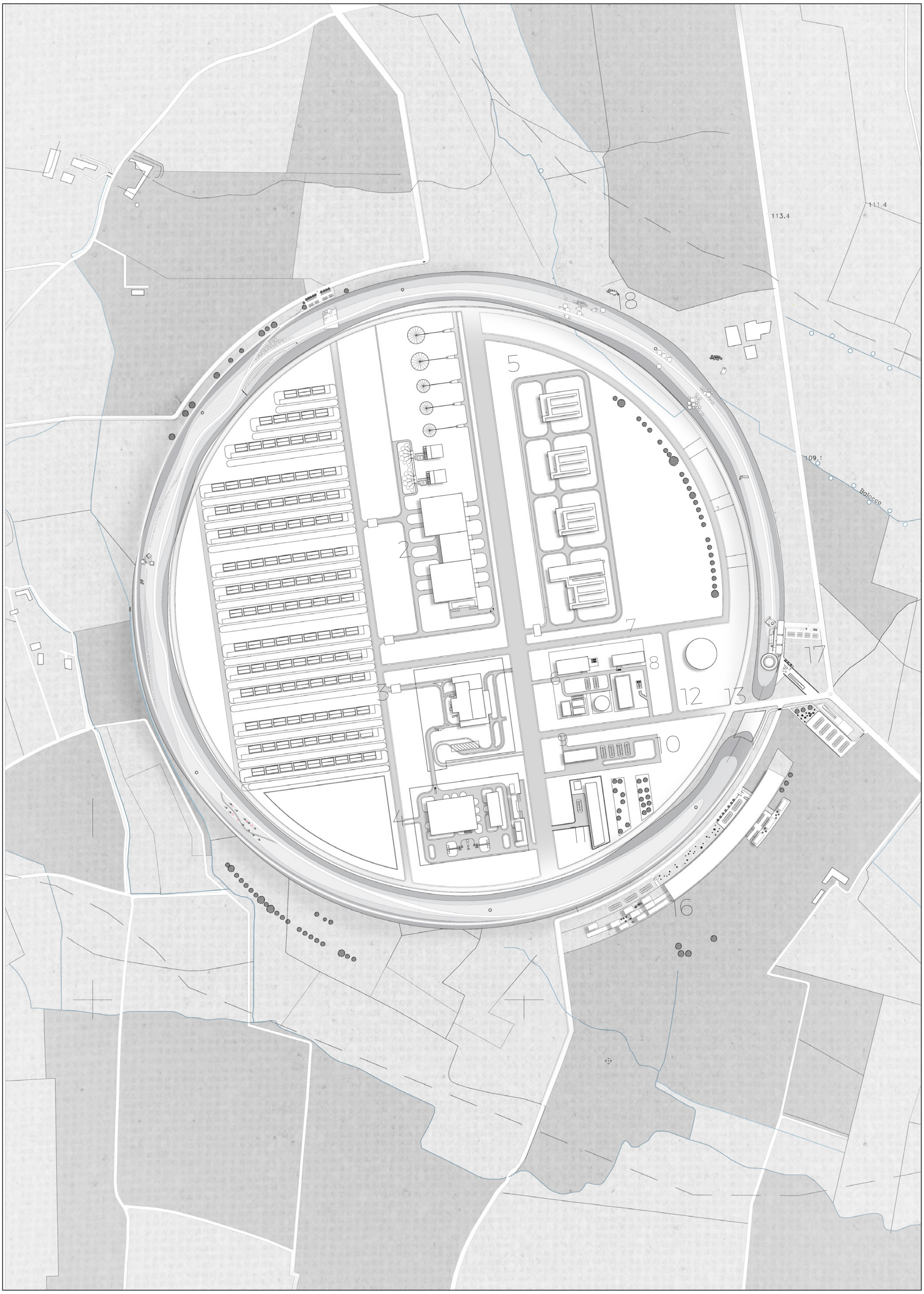
Barrier as visual obstruction

The soil barrier acts as a visual screen, concealing the industrial buildings within the repository from the agricultural landscape of the surrounding context.



Barrier as Vantage Point

Although the barrier allows a hire level of security and control, it provides the visitors with a threshold of transparency through its accessible pathways and observation platforms.


113.4
111.4
109.1
Balocco
1
2
3
4
5
6
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12
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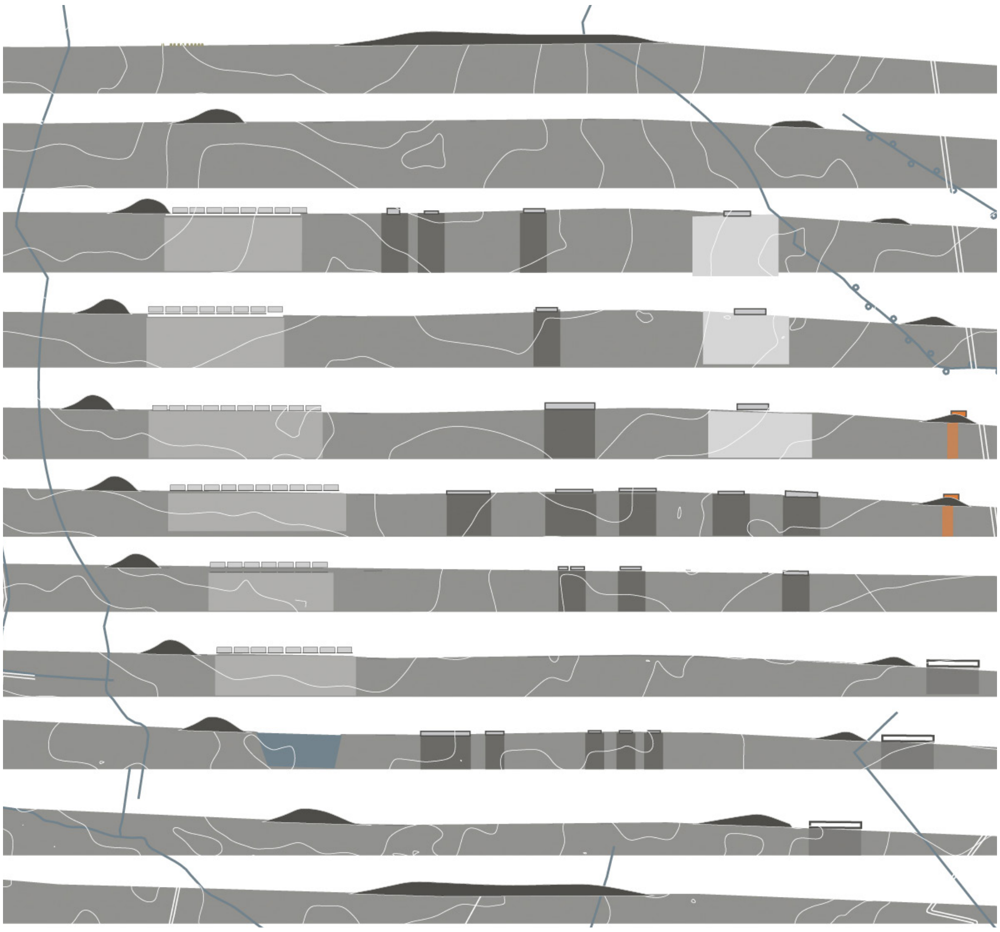
18

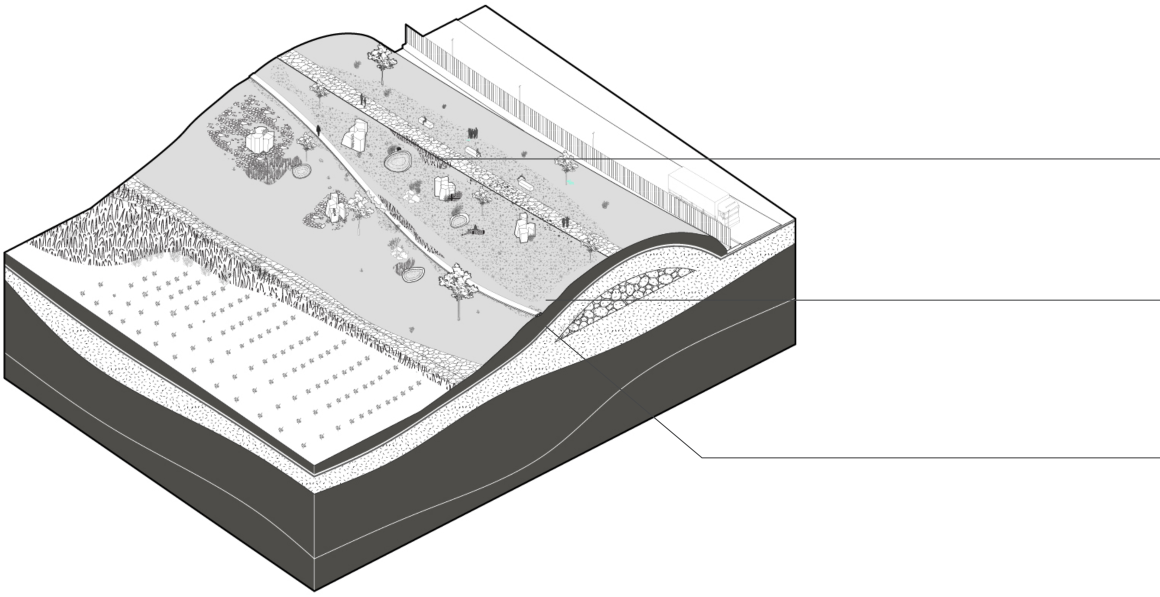
THE THIRD LANDSCAPE

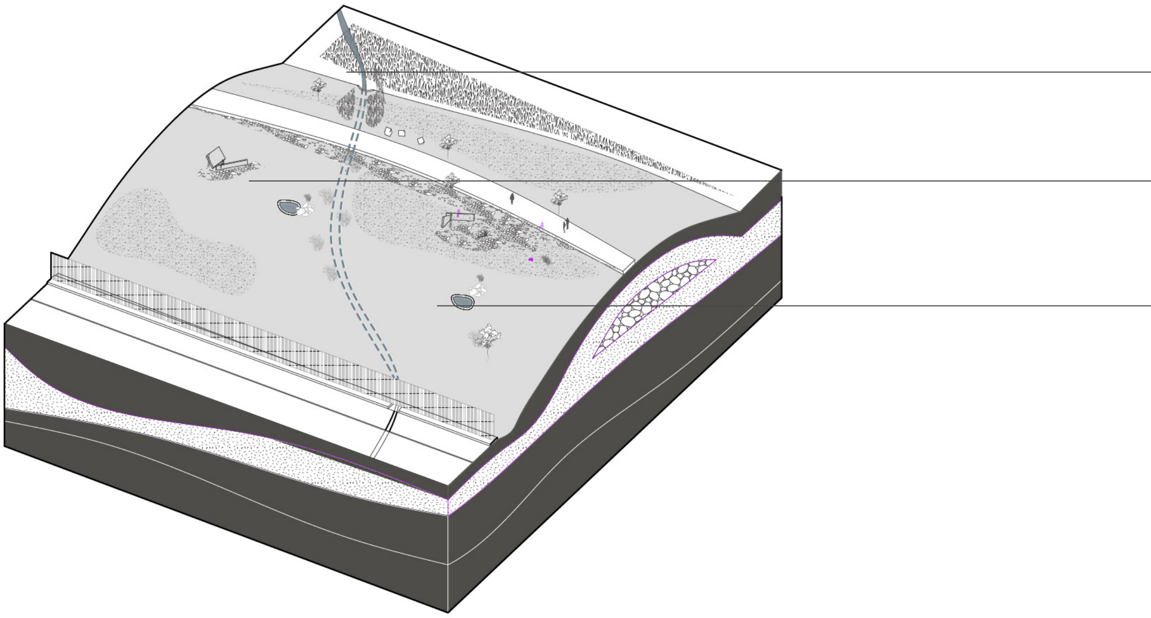
The Barrier as Temporal Infrastructure

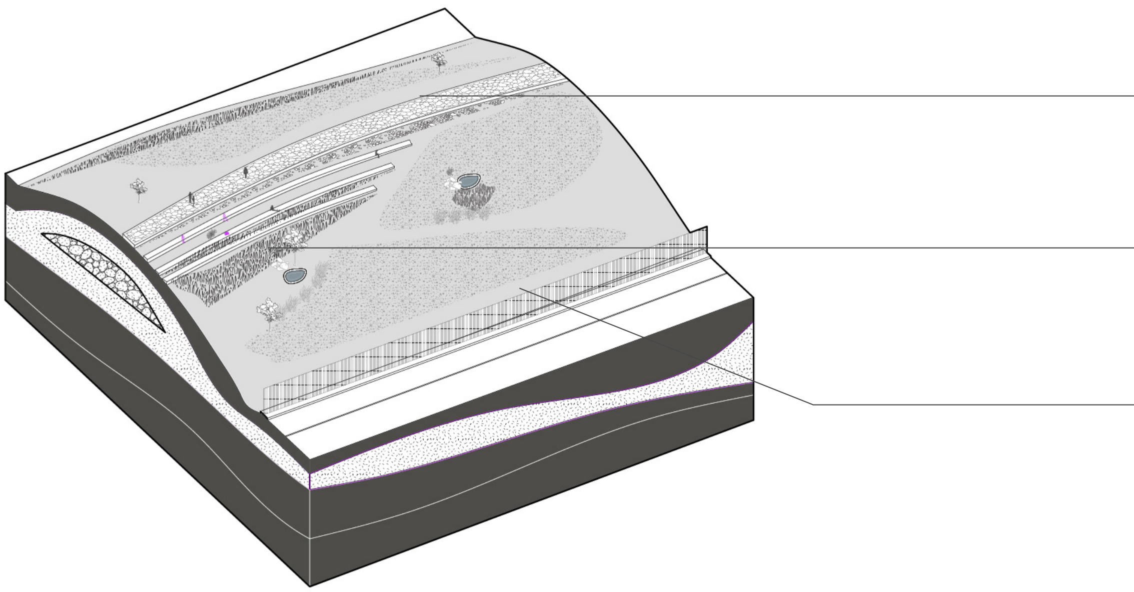


Near Surface Disposal
ILW/HLW Storage
Archive &Visitor center
Artficial Barrier
Technological park
Facility buildings
Water Streams
Water Reservoir
Research center

1-Waste Disposal Units
2-Cell Production Plant
3- Module Packaging Plant
4- Module Production plnat
5-ILW / HLW Storage
6- Waste Treatment PLant
7- Quality control plant
8- LAB
9- Health department
10-Fire department
11- Workers amenities
12- Training School
13- Entrance
15- LAB
16- Technological park
17- Archive Location
18- Artificial Hills
19- Water Reservoir







Axonometric Section of Barrier

Erosion-themed gardens are scattered across the artificial hill, providing the visitors with an entropic experience across markers of the ongoing processes of decay.

The eroding Trail
Pathways are made of locally collected, non-bonded stone, shifting and scattering with time and embracing decay and impermanence.

Geocell confinement system
To ensure stability of the artifiical barrier, a geocell confinement system was used. This also facilitates the excavation of the soil after decomissioning.

Hard Core layer
To ensure stability of the artifiical barrier, a hard core layer made of natural stone is utilized.

Water stream
Instead of de-routeing the stream, a controlled flow rail was introduced beneath the hill, preserving its original path

Residual Structures
Architectural fragments from the repository facility left to erode and decay

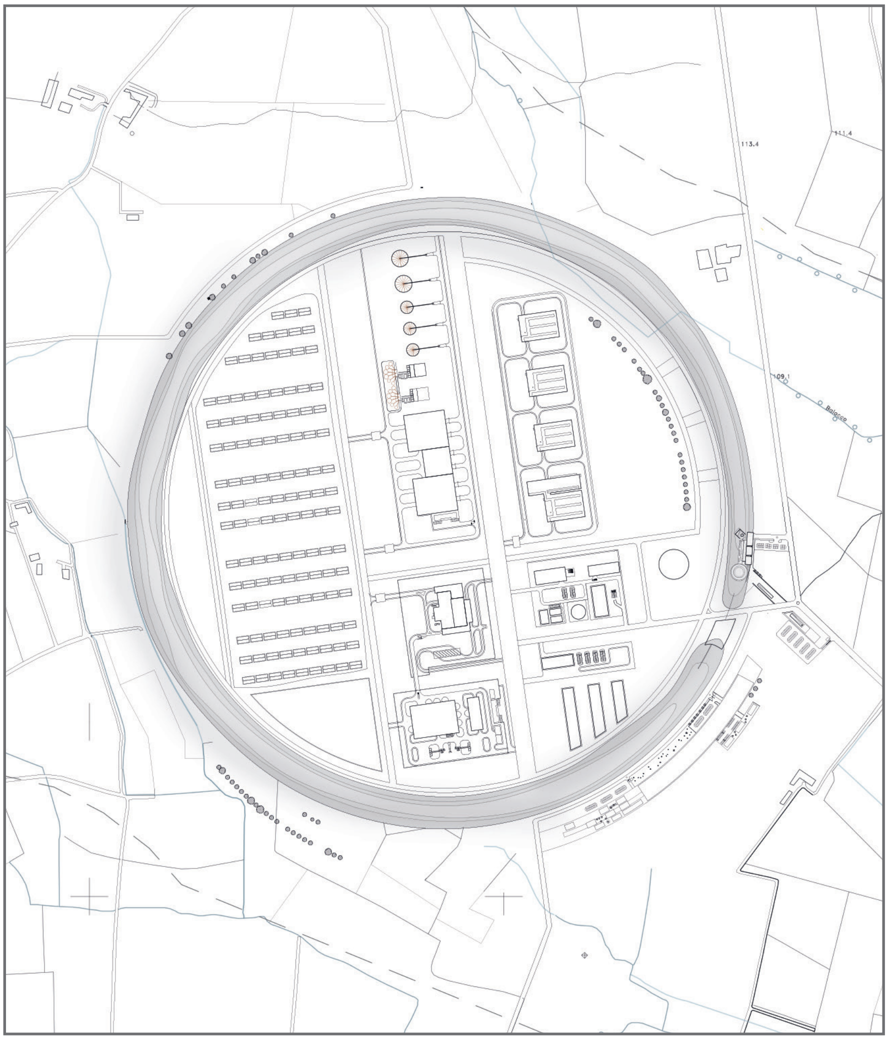
The Voids
Shallow depressions in the soil that record the passage of water, providing a condition for accumulation and evaporation.

Stone Trail
The barrier is made of natural and organic materil to allow the future use of its contents in the burial of the nuclear waste

Observation area
A stepped amphitheater that overlooks the repository encourages the engagement of the public, and enhances transparency.

Security Fence
Although the barrier allows public access, a fence is placed within the repository to prevent trespassing.

REPOSITORY TIMELINE

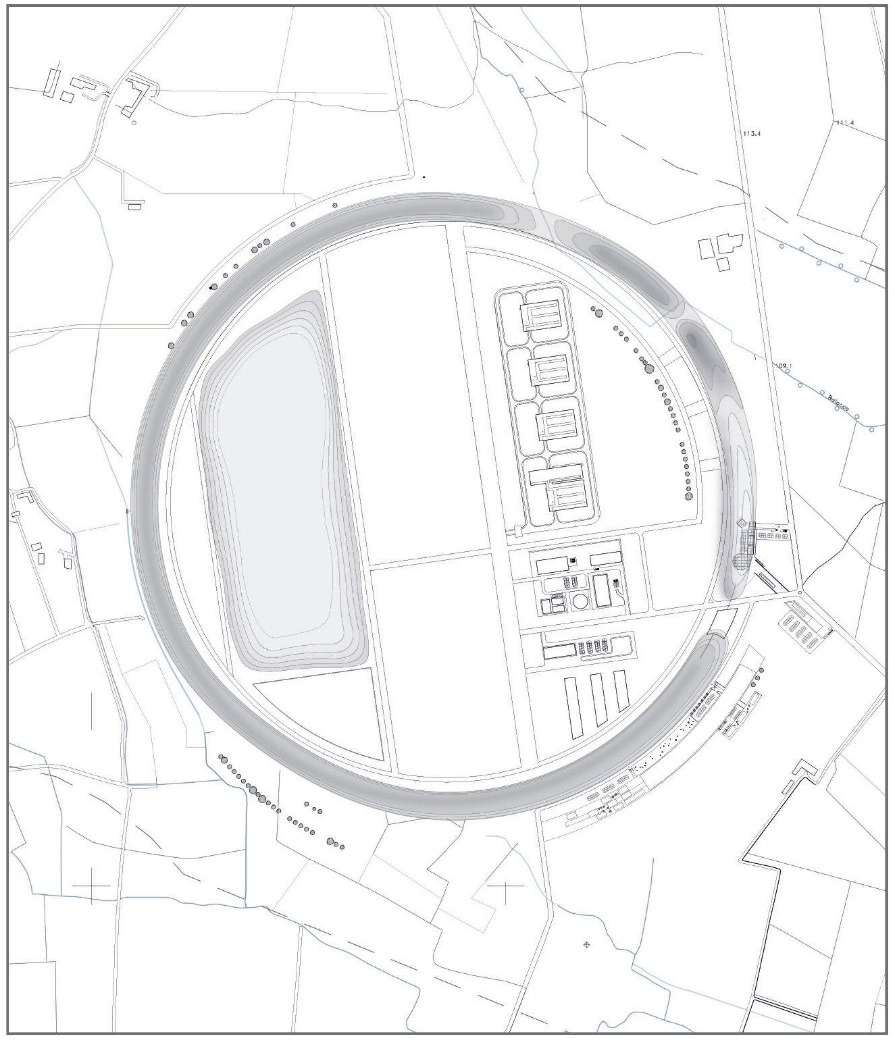


Operational Phase

-The earth from excavations is deposited in the circular barrier.
-The modules are inserted into the site and cemented, reaching 50 modules by year 20, where the rest of the modules prepared and inserted into the site reaching a total number of 90 by year 40.
-The final cap of the modules is constructed, marking the end of the operational phase

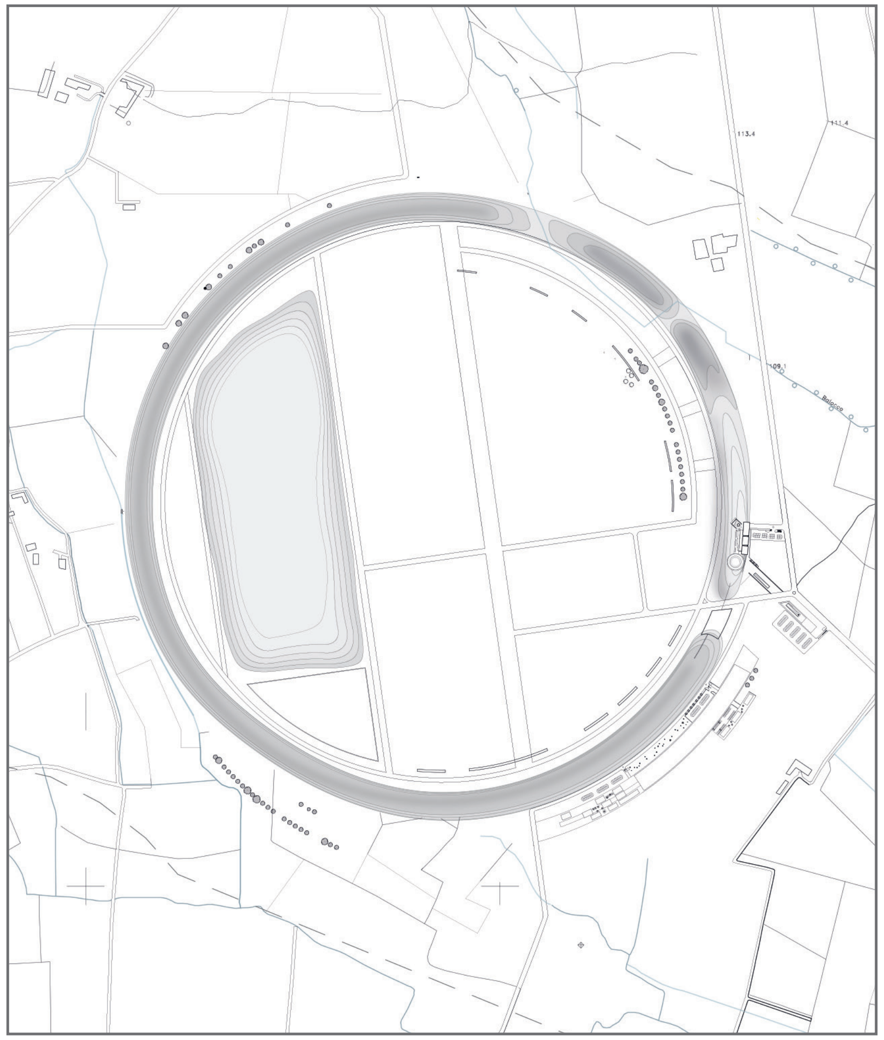
Year 4
2029

Year 50
2080



Closure Phase

- The soil of the border are starting to be collected and used
to bury the waste, including new excavations under the border, creating a negative buffer around the site.
- All the engineering features and isolation processes are
ready and put in place to guard the tomb.
- The operational buildings and services have been decomissioned.



Monitoring Phase

- The High Activity Level buildings are being decomissioned.
- The Technological Park is still active.
- The Archive’s premises are still open for visitors.
- The control points are still functioning.

Future Projection

- The site is no longer controlled
- The terrain is manipulated to form an entropic system that embraces the inevitable process of decay; where uncertainty and contradictions are design tools used to create an authentic trace to what was a nuclear waste repository.
- The visitor center still functions, marking the memory of the site, along with the subtracted circular boundary.

Year 100
2130

Year 350
2380

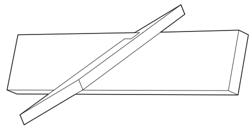

113.4
109.1

HYPOTHETICAL CONDITION 2380

Designing Conditions Rather than Form

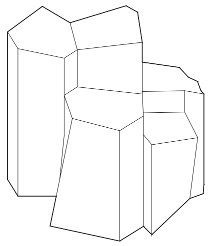
Residual Structures

Architectural fragments from the repository facility left to erode and decay — generating a disorienting terrain shaped by shifting matter and time.



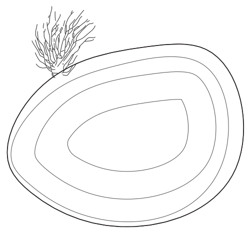
Basalt Plantations

The basalt plantations formerly located on the barrier is then moved inside of the perimeter as a monument that traces the process of time



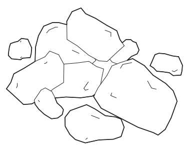
Temporal Ponds

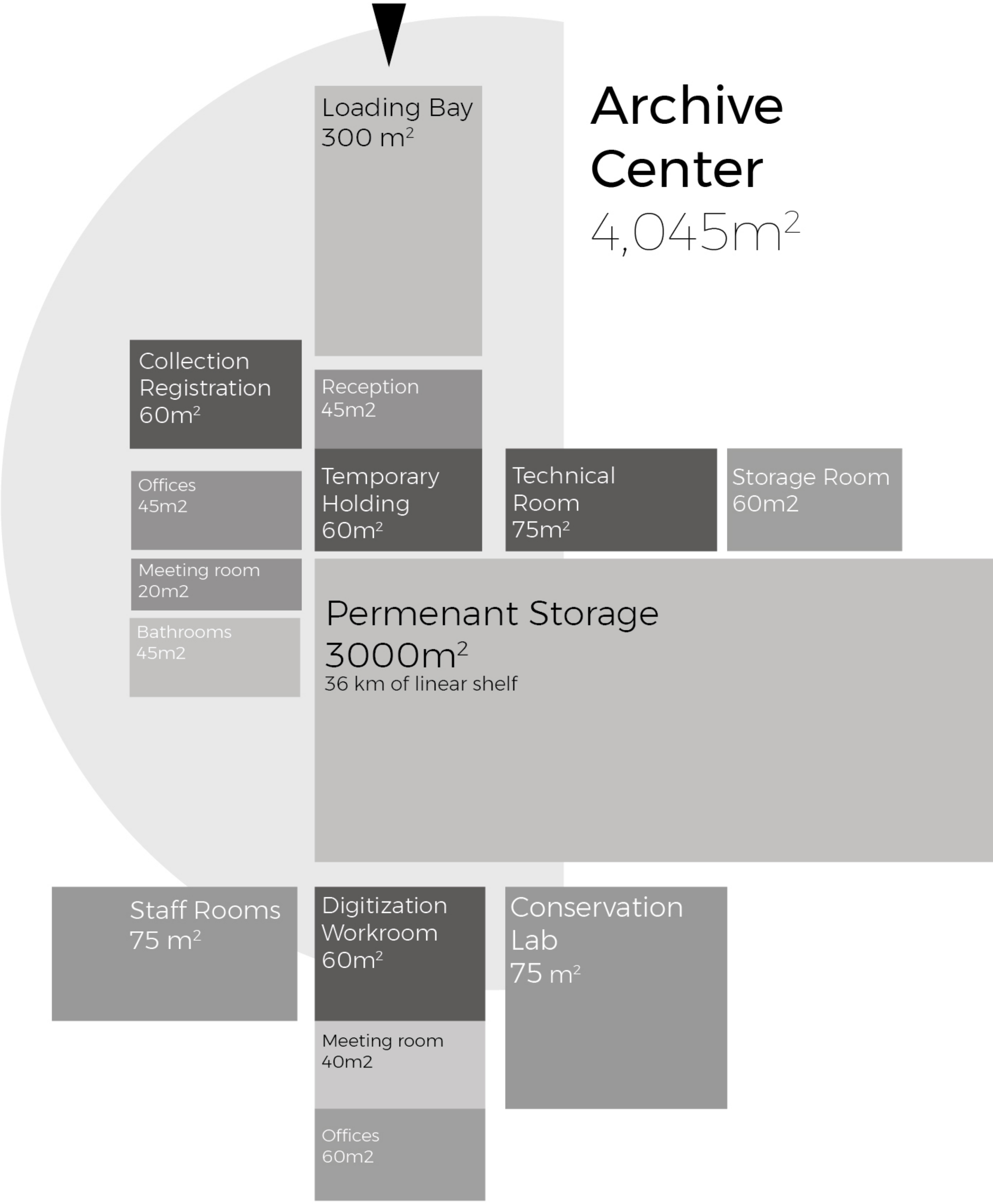
Small depressions that collect water unpredictably, thus interacting with the surrounding elements placed in the field, increasing uncertainty and entropy.



Ground in motion

Different soil types are left intentionally in the field after the decomissioning of the facility to blend over time. It represents a programmed erosion where wind, water, and movement create new ground compositions.




Archive
Center
4,045m2
Loading Bay
300 m2
Collection
Registration
60m2
Reception
45m2
Offices
45m2
Temporary
Holding
60m2
Technical
Room
75m2
Storage Room
60m2
Meeting room
20m2
Bathrooms
45m2
Permenant Storage
3000m2
36 km of linear shelf
Staff Rooms
75 m2
Digitization
Workroom
60m2
Conservation
Lab
75 m2
Meeting room
40m2
Offices
60m2

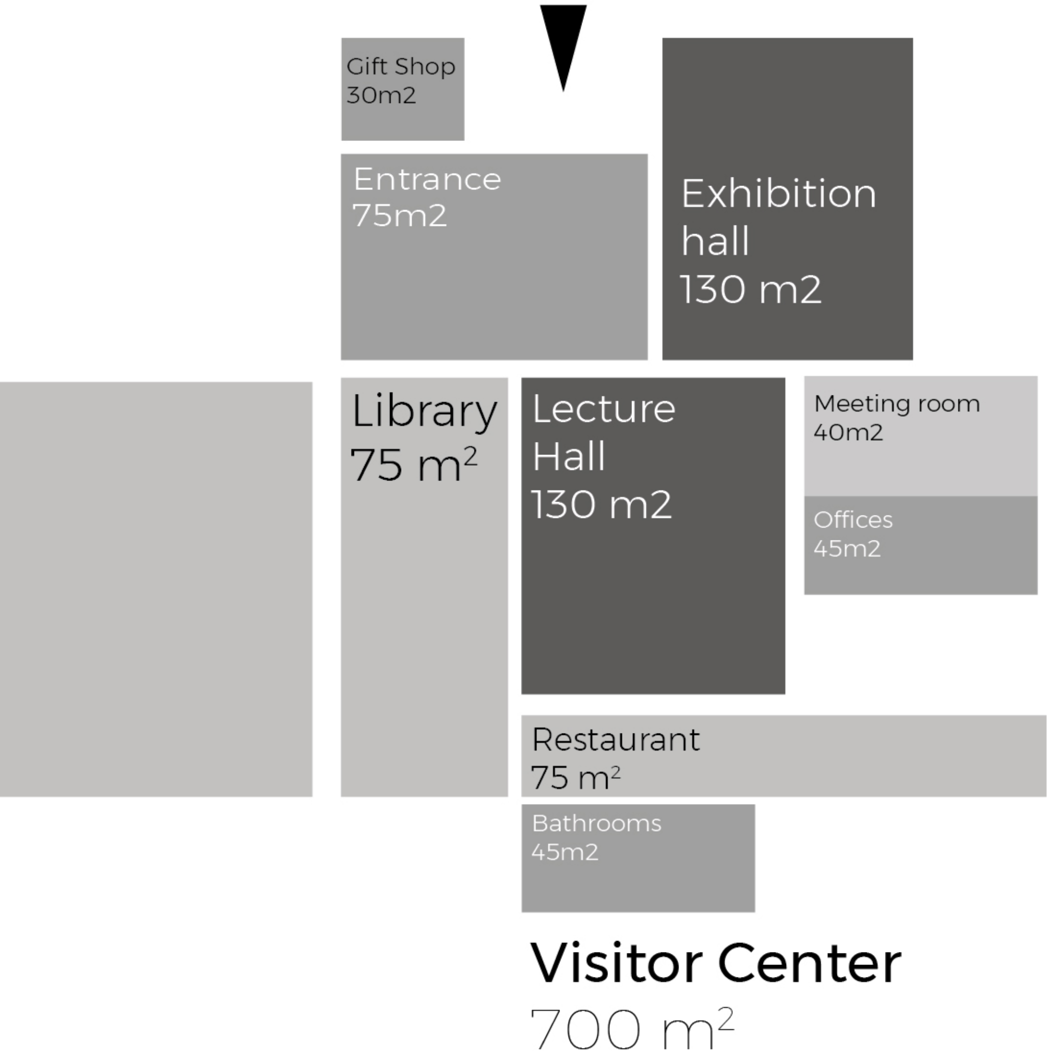


Figure 3.2 Program By area of the project, with the spaces and areas calculation derived from:

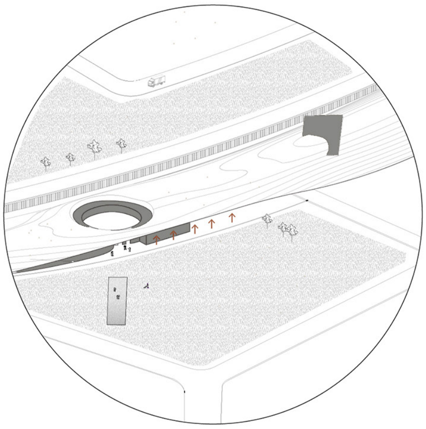
national archive of London. (2020). Planning a new repository - Archives sector. nationalarchives.gov.uk

Ling, T. (1998). Solid, Safe, Secure: Building Archives Repositories in Australia.

ARCHIVE AS AN INTERFACE BETWEEN HUMANS AND NUCLEAR WASTES

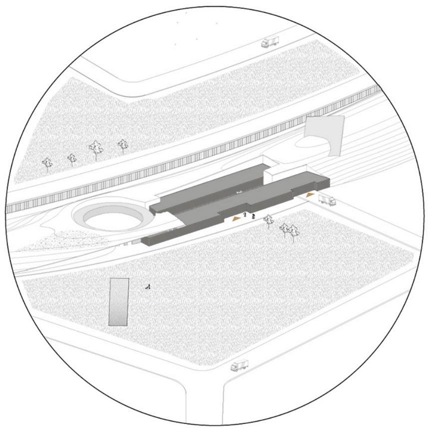
Interplay of permenance and transformation

The soil barrier serves as an authentic evidence of the nuclear repository- a physical trace of what was a protective layer from the unreachable. This entropic mass will be passively resisting the passage of time. Meanwhile, the archive represents the instructive memory that shapes the narrative of the repository in a controlled and carefully curated environment that resists the passage of time.
"Memory and information are renewed through their inevitable degeneration, in a continuous process of recycling their own meaning".(Corbellini, 2010)



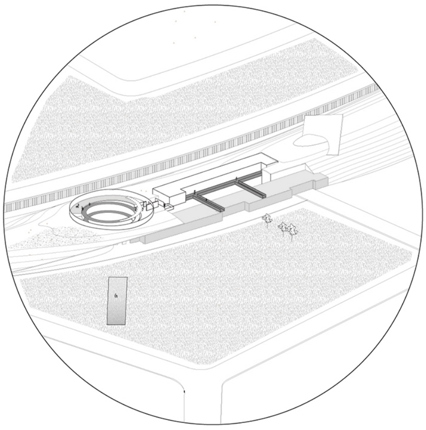
The Uplift
Entrance

The platform is an extension of the barrier, covering the archive center and providing a public space to promote the interconnectedness.



Subtraction
Archive center

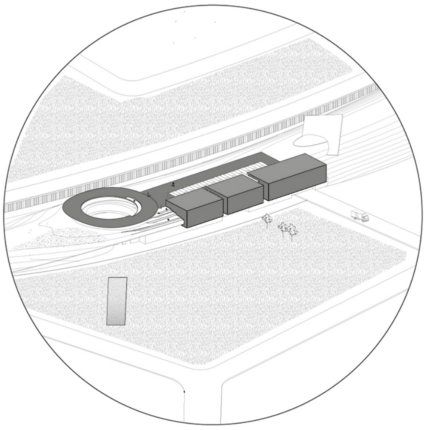
Within the barrier, the archive center amenities are embedded providing a loading bay and the workers' entrance.



The Flow

Circulation

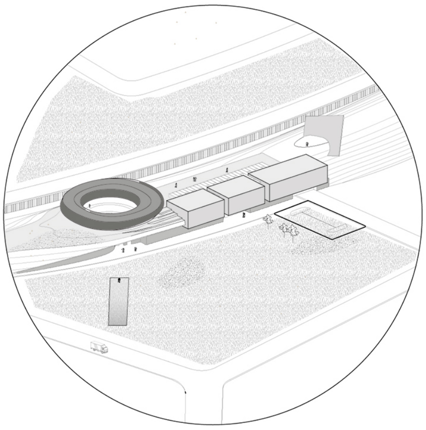
Visitors ascend through a spiral ramp passing through interlocked exhibition spaces, the first encounter with the artificial memory. Archived materials are transported to the vaults via bridges.



The Vaults

Archival Process

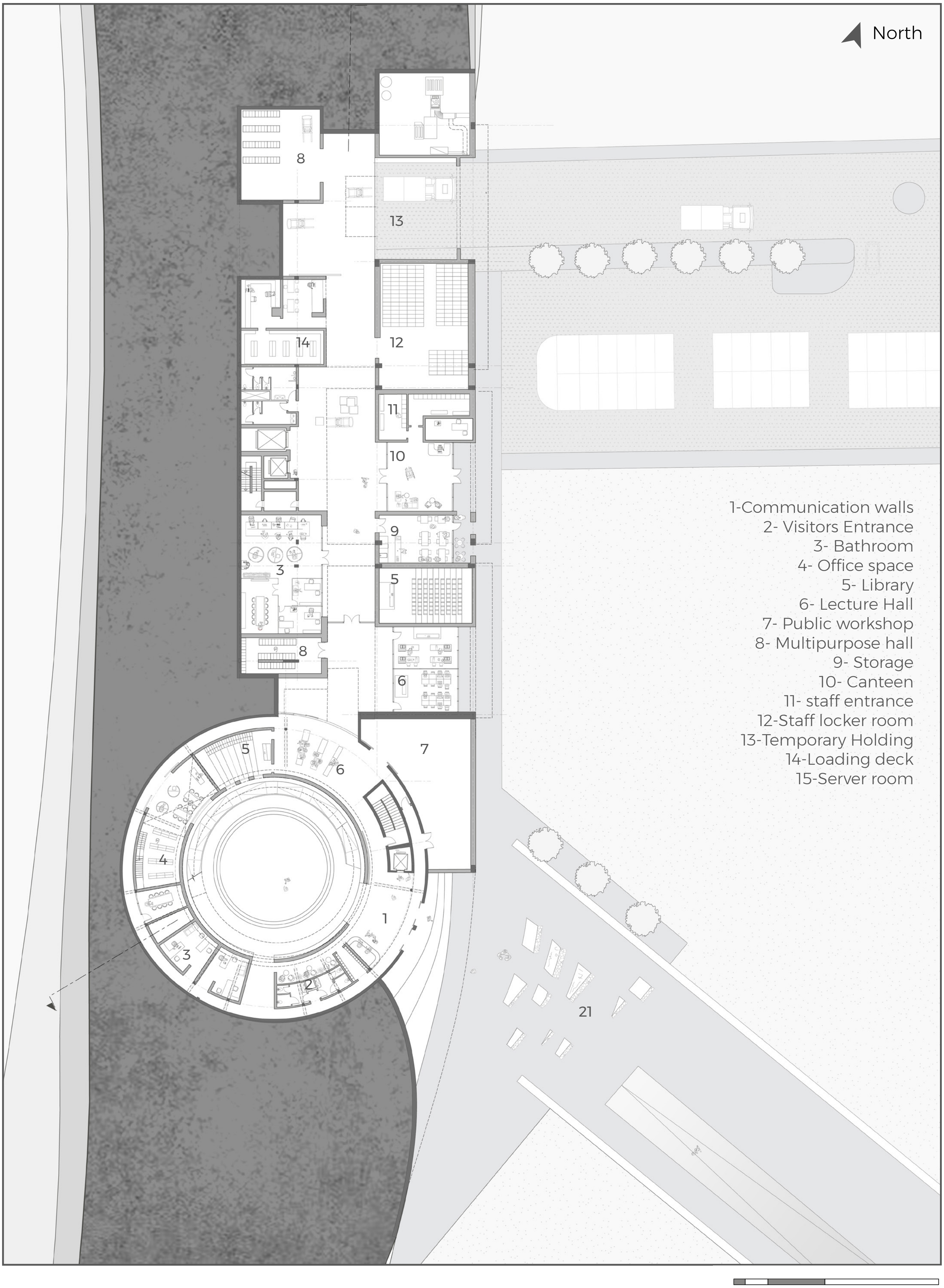
Visitors reach the observation deck which overlooks the Repository. The path leads to the model of concrete vault while visitors observe the archival process below.



The Circle

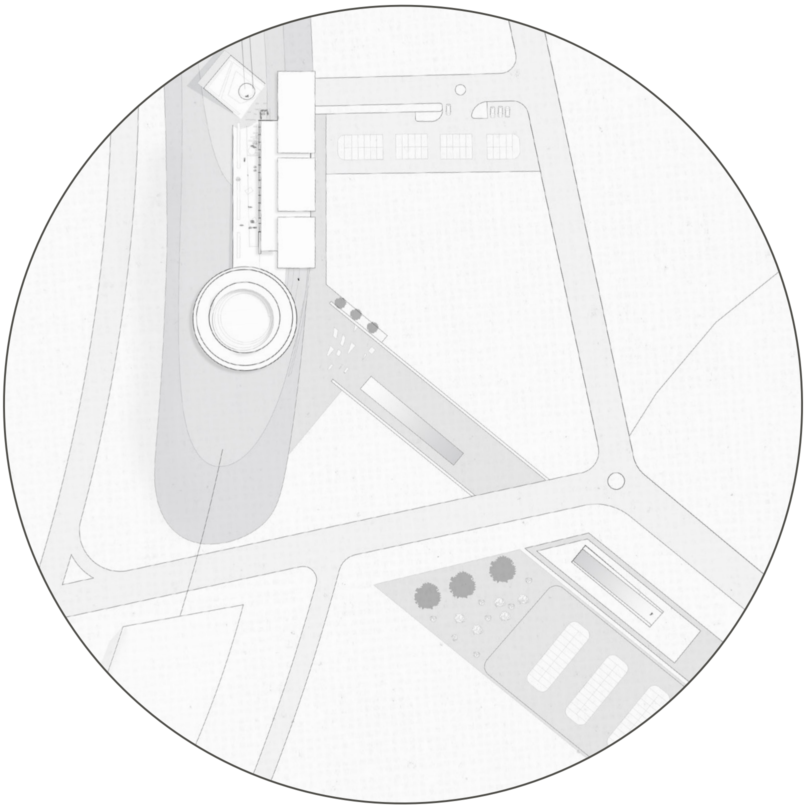
Visual marker

The visitor center serves its function not only in program, but also in its form, where the circular shape provides a marker for universality, uniqueness, and contemplation.

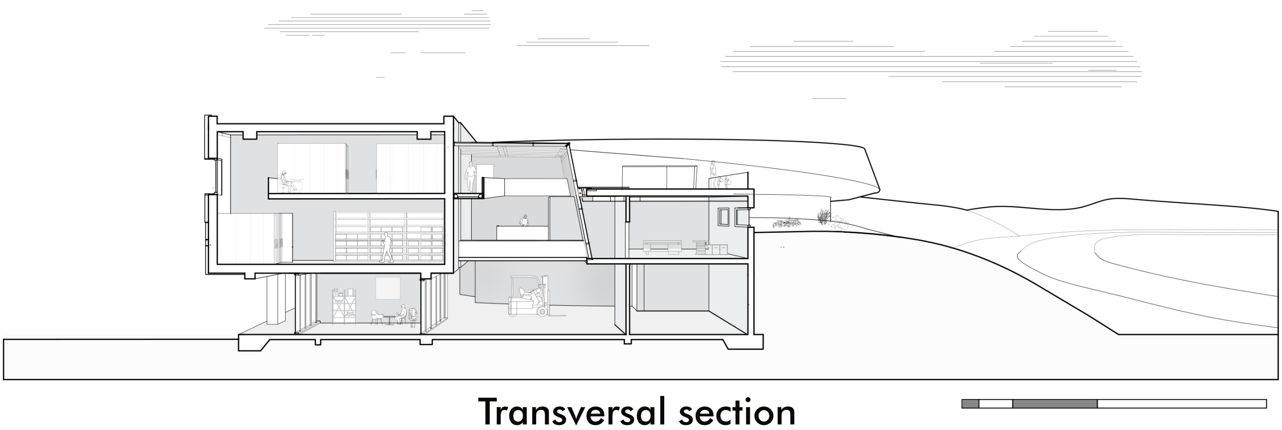


Ground Floor Plan

Visitor center entrance with public workshops
Archive center staff entrance with technical areas

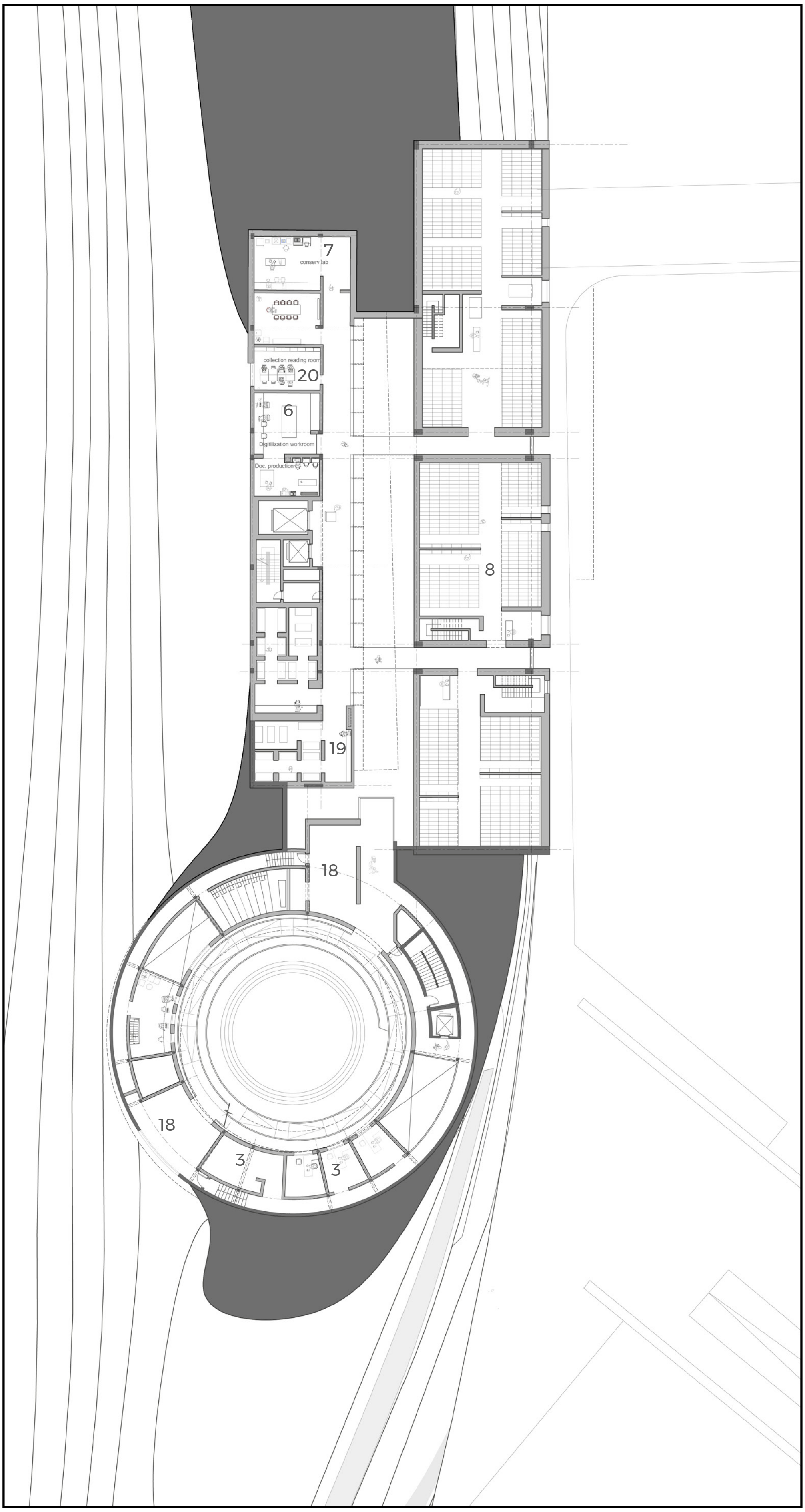


Site Plan



Transversal section

Showing the paths taken by the visitors
through the archival process

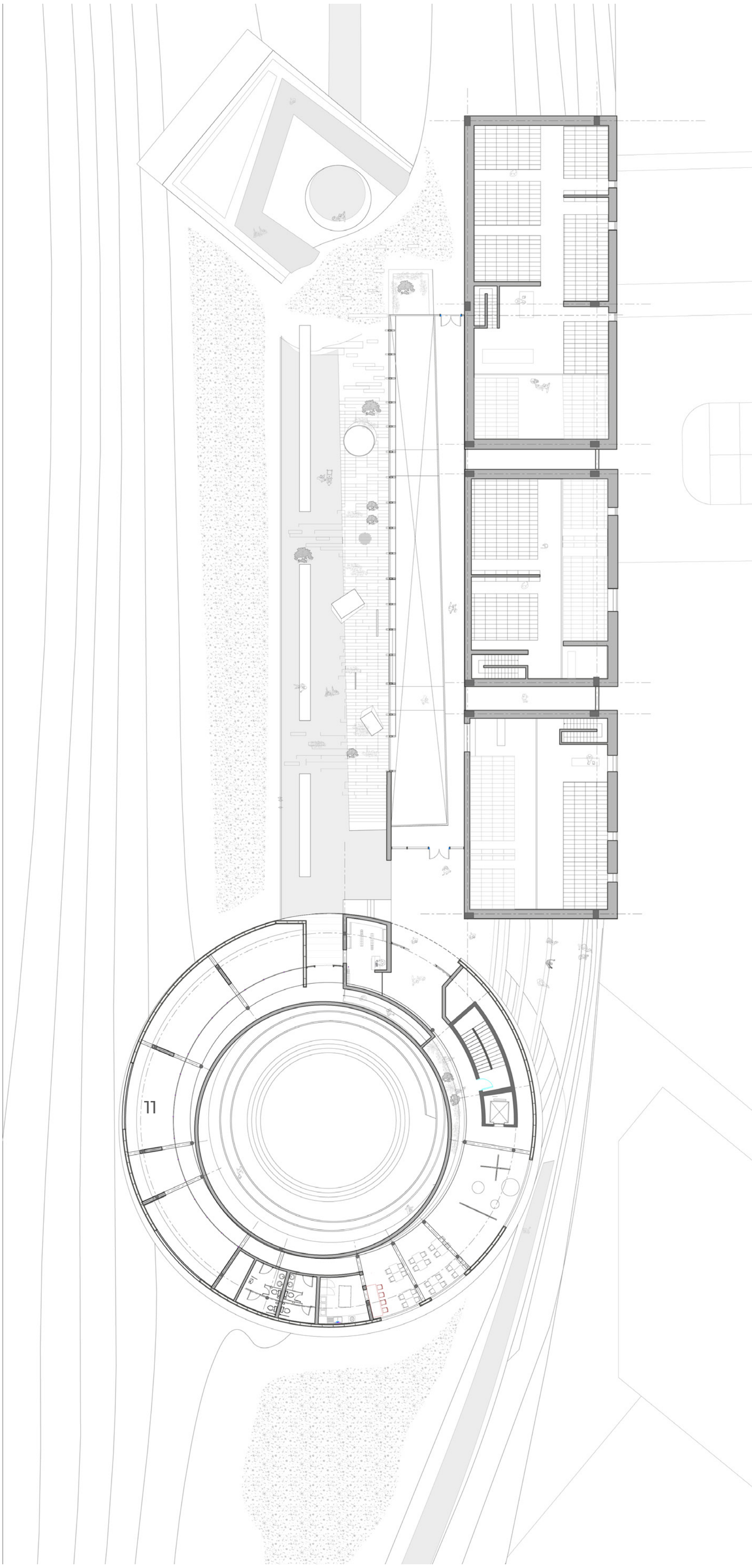


Legends

1- Entrance
2- Workshop
3- Office space
4- Bathroom
5- Technical room
6- Digital workshop
7- Conservation LAB
8- Archive storage
9- Lecture hall
10- Library
11-Exhibition gallery
12-storage
13-server room
14-staff entrance
15-temporary holding
16-Loading deck
17- Multi-purpose hall
18-observation gallery
19-disk storage
20- Reading room
21-Communication walls

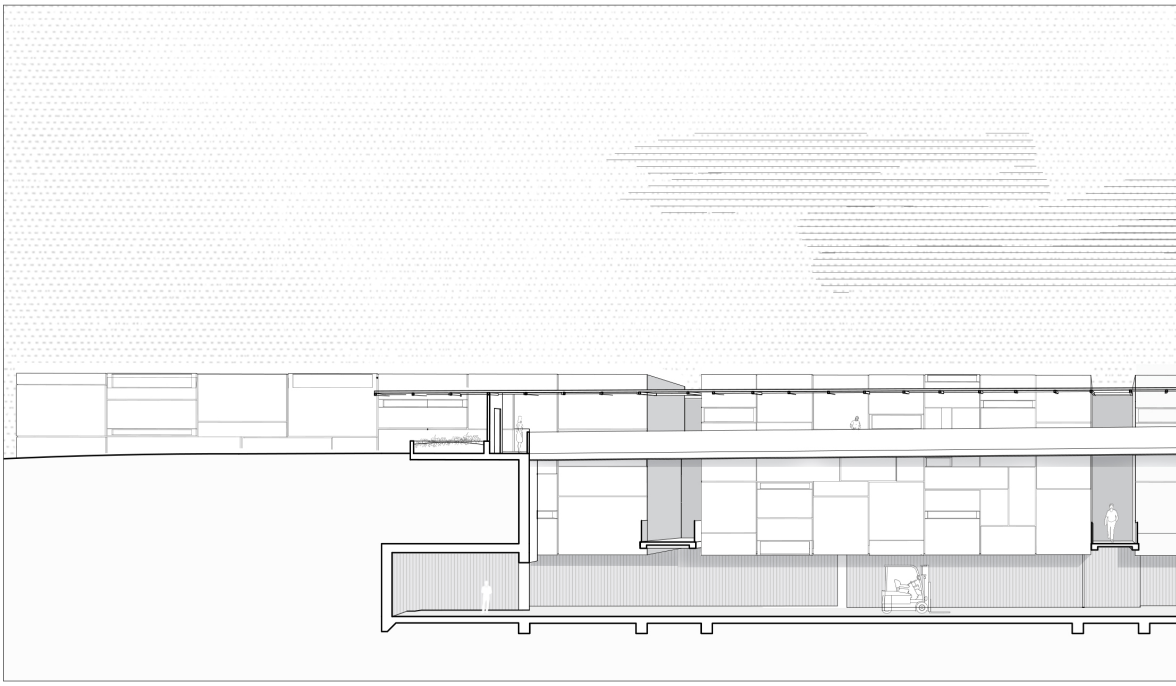
First Floor plan

Interlocking observation spaces along with archive temperory storage and conservation functions.



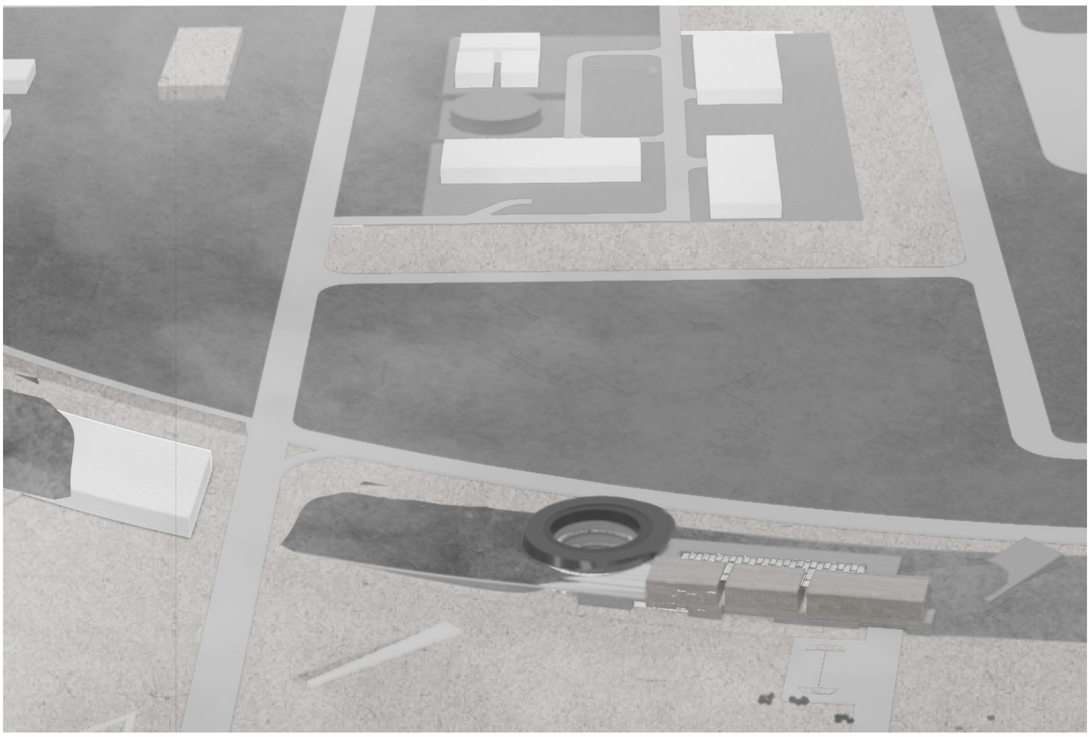
Second Floor Plan

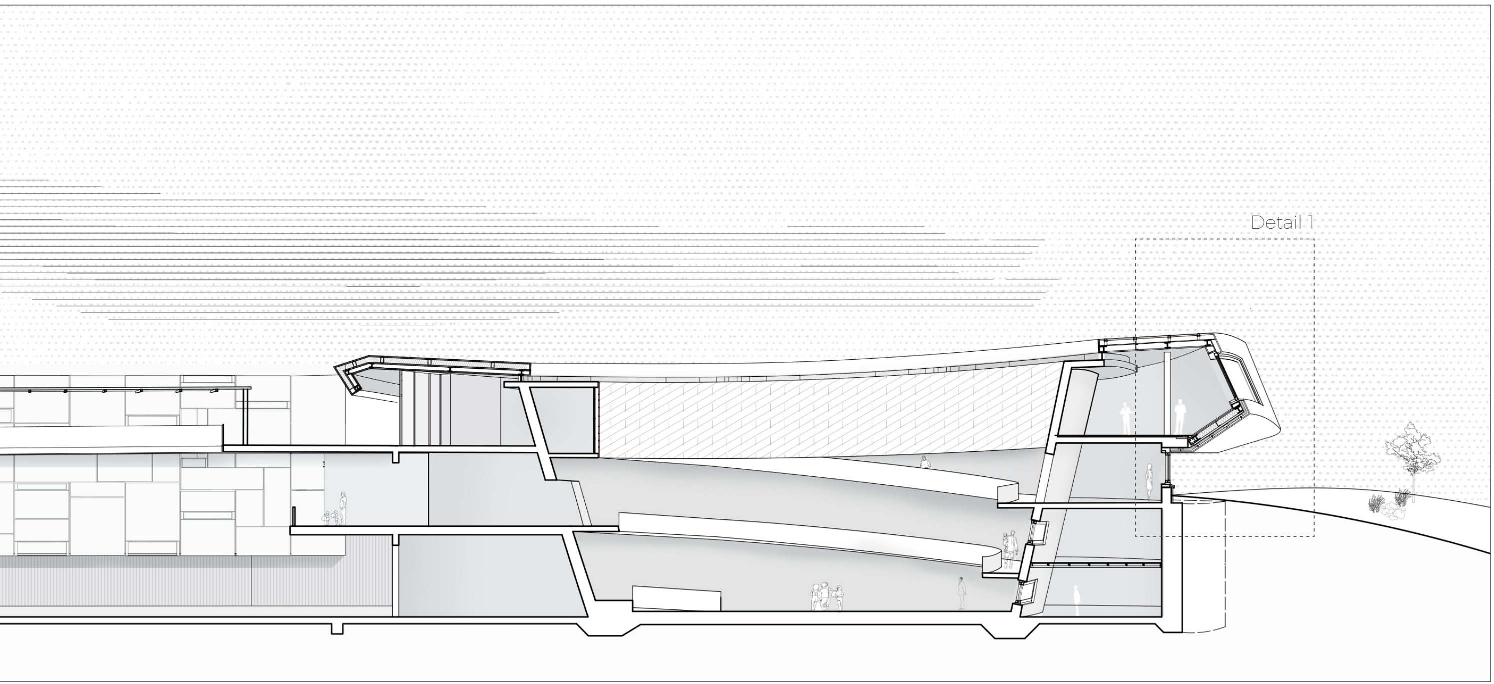
The roof acts as an observation platform leading to the 1:1 cell model

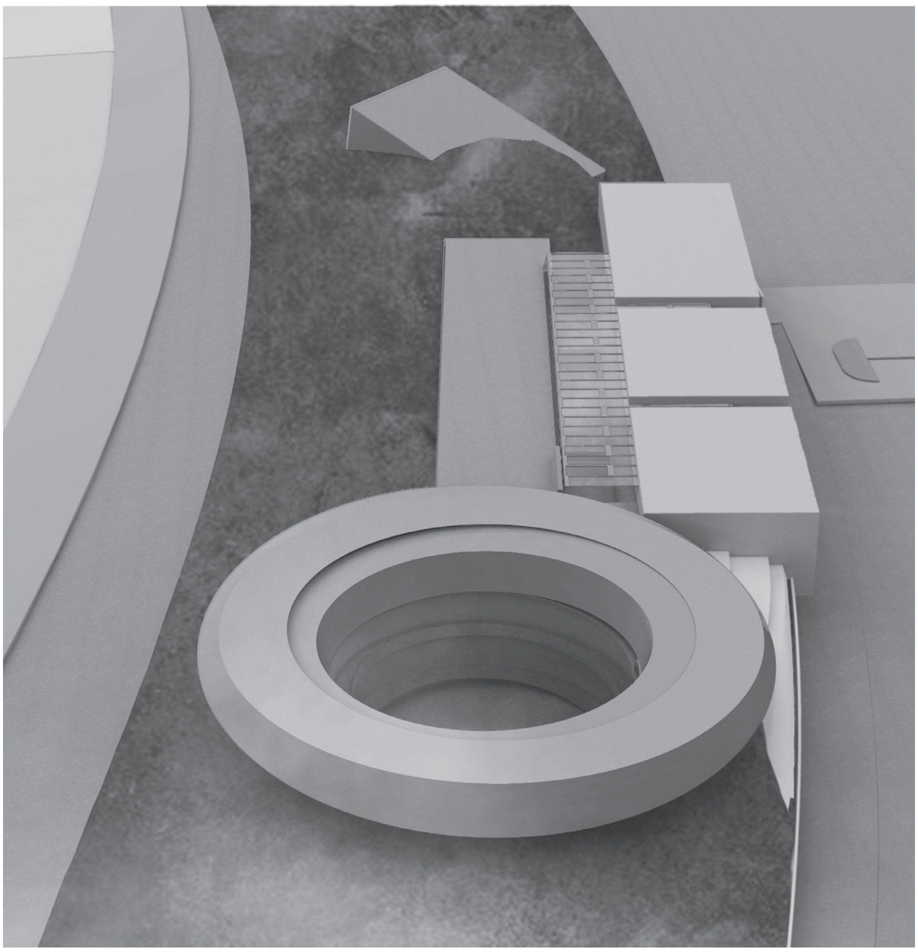


Longitudinal Section

This longitudinal section of the Archive and Visitor center shows the interlocking spaces between the two functions. It highlights the path of the visitor through the spiral ramp, implementing pockets of exhibition galleries and observatory spaces out-looking the archive center functions and the repository itself.

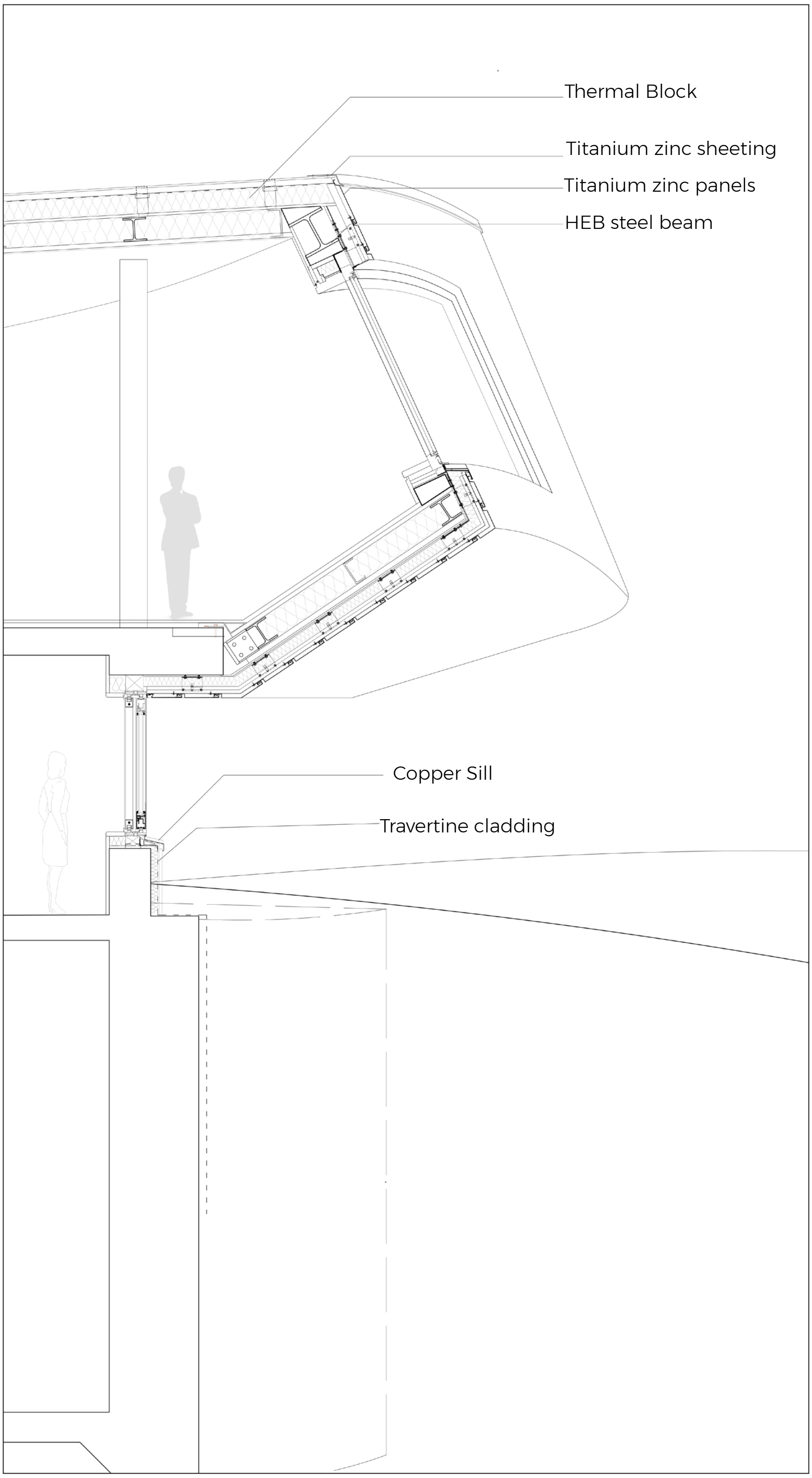






Bird's Eye view of the Archive center showing relation with sarrounding context and the repository

Titanium zink alloy consists of electrolyte primary zinc according to DIN EN 1179 with a purity grade of 99.995 % and precisely determined proportions of copper, titanium and aluminium. Alongside increasing creep strength, titanium also increases the recrystallization limit as compared to unalloyed zinc; copper increases ductility for every type of deformation. In addition to other factors.



Section detail 1: showing the structural system of the circular building, along with the connection of material of steel, titanium zinc and travertine .

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