Politecnico di Torino

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Toxic Heritage:

Italian National Repository of Radioactive Waste

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PERICOL!

DEŞEURI TOXICE
☢ RADIOACTIVE!

NU SĂPAŢI AICI!

危险！

有毒的放射性废物！☢

请勿在此地挖掘！

!סכנה

☢ פסולת רדיואקטיבית רעילה!

!החפירה אסורה

DANGEREUX!

IL Y A DES DÉCHETS
RADIOACTIFS ☢ ET TOXIQUES!

NE CREUSEZ PAS ICI!

ОСТОРОЖНО!

ТОКСИЧНЫЕ РАДИОАКТИВНЫЕ
☢ ОТХОДЫ!

ЗДЕСЬ НЕ КОПАТЬ!

TƏHLÜKƏ!

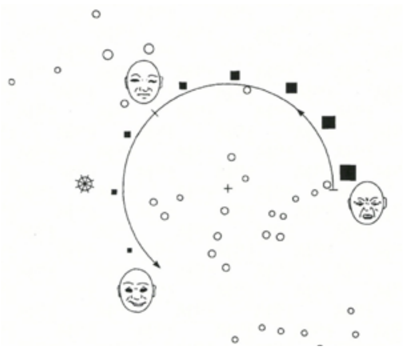
ZƏHƏRLİ RADİOAKTİV
☢ TULLANTILAR!

BURDA QAZINTI İŞLƏRİ QADAĞANDIR!

خطره!

☢ یہاں زہریلا تابکار فضلہ ہے۔

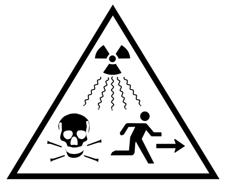
یہاں کھو دنا منع ہے



VESZÉLY!

MÉRGEZŐ RÁDIÓAKTÍV
☢ HULLADÉK!

ITT TILOS AZ ÁSÁS!



PERICOLO!

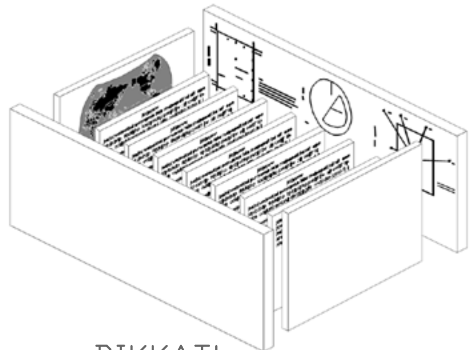
RIFIUTI TOSSICI
☢ RADIOATTIVI!

NON SCAVARE QUI!

საფრთხე!

მოწამლული რადიოაქტიური
☢ ნივთიერება!

შესვლა აკრძალულია!



КАТТЫК!

УУЛУ РАДИОАКТИВДУУ
☢ КАЛДЫКТАР!

БУЛ ЖЕРДИ КАЗМАК ТЫЙУУ!

خطر!

☢ وجود نفايات مشعّة و سامّة!

لا تحفر هنا!

GEFAHR!

GIFTIGER RADIOAKTIVER
☢ ABFALL!

HIER NICHT GRABEN!

DIKKAT!

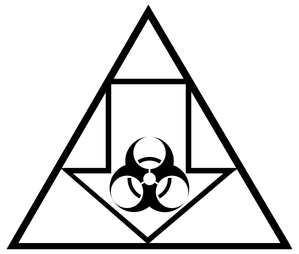
ZEHIRLI RADYOAKTIF
☢ ATIK!

BURAYI KAZMAYIN!

خطر!

☢ مواد رادیواکتیو!

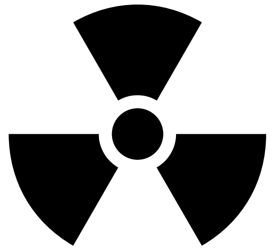
حفاری نکنید!



DANGER!

POISONOUS
RADIOACTIVE ☢ WASTE!

DO NOT DIG HERE!



НАЗАР АУДАРЫҢЫЗ!

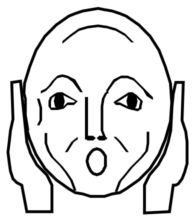
УЛЫ РАДИОАКТИВТІ
☢ ҚАЛДЫҚТАР!

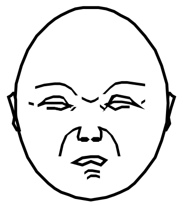
ОСЫНДА ЖЕР ҚАЗУҒА ТЫЙЫМ САЛЫНАДЫ!

PELIGRO!

¡RESIDUOS RADIACTIVOS
☢ VENENOSOS!

¡NO CAVAR AQUÍ!





GEVAAR!

GIFTIG RADIOACTIEF
☢ AFVAL!

GRAAF HIER NIET!

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LIST OF ABBREVIATIONS

AEC	Atomic Energy Commission
ANDRA	National Agency for Radioactive Waste Management (France)
ANPA	National Agency for Environment Protection (Italy)
APAT	Environmental Protection and Technical Services Agency (Italy)
a.s.l.	above sea level
BGE	Federal Company for Radioactive Waste Disposal (Germany)
CA	Investigation Criteria
CE	Exclusion Criteria
CNAI	National Charter of Suitable Areas
CNAPI	National Charter of Potentially Suitable Areas
CNEN	National Nuclear Energy Commission (Brazil)
CSA	High Activity Storage Complex
DNPT	National Repository and Technology Park
EAEC, EURATOM	European Atomic Energy Community
ENEA DISP	ENEA Department of Security and Protection (Italy)
ENRESA	National Agency for Radioactive Waste Management (Spain)
EPA	Environmental Protection Agency (USA)
EU	European Union
EW	Exempt Waste
GBq	Gigabecquerel
HLW	High-Level Waste
IAEA	International Atomic Energy Agency
ICM	Modules Packaging Plant

ILW	Intermediate-Level Waste
INES	International Nuclear Event Scale
ISIN	National Inspectorate for Nuclear Safety and Radiological Protection (Italy)
ISPRA	Italian National Institute for Environmental Protection and Research (Italy)
ISTAT	Italian National Institute of Statistics
ITR	Waste Treatment Plant
LLW	Low-Level Waste
MATTM	Ministry for Environment, Land and Sea Protection (currently Ministry for Ecological Transition)
MiSE	Ministry of Economic Development
NAGRA	National Cooperative for the Disposal of Radioactive Waste (Switzerland)
NEA	Nuclear Energy Agency
NE-SW	Northeast-Southwest
N-NW	North-Northwest
NPP	Nuclear Power Plant
NPT	Nuclear Non-Proliferation Treaty
NUMO	Nuclear Waste Management Organisation (Japan)
NWMO	Nuclear Waste Management Organization (Canada)
OCRWM, DOE	Office of Civilian Radioactive Waste Management Of the Department of Energy (USA)
ONDRAF/NIRAS	National Agency for Radioactive Waste and Enriched Fissile Material (Belgium)
rem	roentgen equivalent man
RWM	Radioactive Waste Management (UK)
SKB	Swedish Nuclear Fuel and Waste Management Company
SOGIN	Nuclear Plant Management Company (Italy)
SP75	Provincial Road 75
UK	United Kingdom

UN	United Nations
UNESCO	United Nations Educational, Scientific and Cultural Organization
UNIC	United Nations International Conference
USA	United States of America
USM	Modules Disposal Unit
USSR	Union of Soviet Socialist Republics
VSLW	Very Short-Lived Waste
VLLW	Very Low-Level Waste
WIPP	Waste Isolation Pilot Plant
WWII	World War II

AL	Alessandria (PIE)
CE	Caserta (CAM)
LT	Latina (LAZ)
MI	Milan (LOM)
PC	Piacenza (EMR)
PV	Pavia (LOM)
VA	Varese (LOM)
VC	Vercelli (PIE)

BAS	Basilicata
CAM	Campania
EMR	Emilia-Romagna
LAZ	Lazio
LOM	Lombardy
PIE	Piedmont
PUG	Apulia

INTRODUCTION

> "Since we cannot be certain what will be most relevant in the future, we have an obligation to save some characteristic evidence of every major period - to establish an environmental archive."[1]

The quotation above was taken from Kevin A. Lynch's book entitled *"What time is this place?"* It characterises the context upon which this master thesis is going to address its major issues. *'The major period'* that is revised in this study, is the Atomic Age; and *'the environmental archive'* is a Radioactive Waste Repository.

Since the beginning of the XX century, scientific and technological development in the field of nuclear has led to extensive applications in research, medicine, industry and in the generation of electricity by nuclear fission. Collectively with numerous other human activities, these practices generate hazardous waste, or, specifically, radioactive waste. The most important challenge relates to the question *"What is being done with radioactive waste?"* Apparently, this type of waste requires special management in order to guarantee the safety and protection of all living organisms and the environment.

The unique feature of radioactive waste lays in its very long isolation from humans and the environment until it no longer presents a danger and risk. The period of isolation may range from a hundred to thousands of years. Therefore, safety must be ensured not only for the present generations but also for the future ones. "This is at the same time both an impossible and necessary task."[2] Notwithstanding, the problem of radioactive waste management is not only limited to technical and engineering issues: the social, cultural and psychological ones are equally important.

The question *"Is nuclear power safe?"* is raised often. People know the score of the terrifying effects of an atomic bomb. Although they recognise that a nuclear reactor is not the same as a nuclear weapon, they associate both with horrific consequences and are suspicious because both involve fission and radioactivity. Predominantly, people perceive radiation as a mystery. When these ideas are combined with Murphy's law, which says that *"If anything can go wrong, it will"*, it is easy to understand why so many people are uncomfortable and frightened by everything related to the nuclear field.[3] This prejudgment also extends to radioactive waste. Unfortunately, the public awareness of nuclear science leaves much to be desired. Much of what is said or written is rhetoric intended either to frighten or to soothe. Debaters exaggerate in order to convince rather than to inform.[4] Subsequently, the public is often confused by conflicting statements about nuclear energy and the problem of nuclear waste. On the basis of the abovementioned, it has proven to be vitally important to build a sense of public trust in the management of radioactive waste.[5] This is not to deny or ignore real dangers posed by radioactive material but more to look at these dangers from a different perspective.

Using the exploration of the terms *'waste'* and *'nuclear'* as a point of departure, here emerges the general understanding of *'radioactive waste'* and the significance of its non-radiological aspects. This thesis is an attempt to explore radioactive waste, the ways of its management and its long-term impact from social, cultural and psychological points of view. This will create a basis to achieve the main purpose of the work, which lays in providing an architectural proposal for the Italian National Nuclear Waste Repository. The architectural proposal tries to unfold firstly, a wide range of aspects concerning different types of communication with future generations, the transmission of knowledge and memory, monumentality, and secondly, several contradictions, such as fear and desire, control and democracy.

Structurally the thesis is divided into 7 chapters organised within two domains: theoretical and architectonic. Starting by introducing waste as an inalienable part of natural and urban processes, the first chapter aims to exploit different possibilities to treat waste. The chapter sheds light on our feelings and comprehension of waste, which has been developed pursuant to our social spirit. This paves a way for a coherent conception of a tangled mix of fear and desire: *Why do we fear waste? Why do we desire it?* Moreover, the chapter straightens out the topic of hazardous waste, in particular, radioactive waste, providing a general observation and the potential scope of harm caused by it.

[1] Kevin A. Lynch, *What Time Is This Place?* (Cambridge, MA and London: The MIT Press, 1972), 49.
[2] Gustav Wollentz, Sarah May, Cornelius Holtord and Anders Högberg, "Toxic heritage: Uncertain and unsafe" in *Heritage Futures. Comparative Approaches to Natural and Cultural Heritage Practices*, eds. Rodney Harrison, Caitlin DeSilvey, Cornelius Holtorf, Sharon Macdonald, Nadia Bartolini, Esther Breithoff, Harald Fredheim, Antony Lyons, Sarah May, Jennie Morgan, Sefryn Penrose, Anders Högberg, Gustav Wollentz (London: UCL Press, 2020), 296.

[3] Raymond L. Murray, *Understanding Radioactive Waste* (Richland, WA: Battelle Press, 1981), 2.
[4] Ibid., 2.
[5] Gustav Wollentz et al., "Toxic heritage: Uncertain and unsafe" in *Heritage Futures. Comparative Approaches to Natural and Cultural Heritage Practices*, eds. Rodney Harrison et al. (London: UCL Press, 2020), 297.

Dedicated to radioactivity, the next chapter, firstly, traces the most significant historical events, as well as scientific and technological developments of The Atomic Era. Secondly, while elucidating the reasons why the words such as '*nuclear*', '*atomic*' and '*radioactive*' evoke suspicion and fear among people, the current part of the paper smoothly shifts into the investigation of the word '*radioactivity*' as an inevitable part of our daily life, from a scientific perspective and highlights the consequences caused by it.

The third part of the thesis addresses the exploration of radioactive waste. Introducing, firstly, the origins and the classification of radioactive waste, the chapter, then, analyses the ways of its management. A general historical background was followed by an investigation and comparison of currently accepted strategies on the management of each class of radioactive waste. Since this study is dedicated to the design proposal of a near-surface facility, an example of its design basis was investigated. Additionally, the chapter clarifies that a very long time - centuries or even thousands of centuries from now - are needed when it comes to contamination and security of radioactive waste. On the grounds of this, several phases of the management, or in other words, the life-cycle of the radioactive waste repository was explored. Afterwards, existing radioactive waste repositories in different countries with a nuclear programme were tracked and indicated. A comparison between total volumes of radioactive waste in those countries, including Italy, was made. This provided a basis for a summary of the Italian scenario and its resemblance with the existing repositories. Finally, as mentioned previously, since we should take into account the long-term future and the legacies concerned are toxic to the biosphere, non-radiological aspects of the nuclear waste repository were discovered. The chapter ultimately investigates different forms that *'a message'* to the future generations could take aiming to realize a *'living memory'* of this place. It discovers that "[t]he most difficult premise is that communicating the future must be a dialogue among all those who have a stake in it."[6]

Note[1]:

SOGIN is the public company responsible for locating, designing, constructing and managing the Italian National Repository and the Technological Park, based on the provisions of the Legislative Decree no. 31 of 2010.

Based on the proposal provided by SOGIN, the fourth chapter of the thesis analyses the Italian solution for the radioactive waste disposal facility. The observation of the general arrangement of the repository's site is provided. The questions on which this chapter attempts to answer are: how does the deposit operate? What is going to be constructed? What is an economic benefit? How is it going to be constructed? How each class of radioactive waste is being stored? For how long? How is

[6] Kevin A. Lynch, *What Time Is This Place?* (Cambridge, MA and London: The MIT Press, 1972), 99.

it secured? How much waste is going to be stored in the deposit? How waste produced directly on the site is going to be treated? How does waste coming from the outside is going to be treated? What is the final destination of each type of waste?

The purpose of the fifth chapter is to investigate the localization process for a radioactive waste repository in Italy, which is crucial to the definition of the technical and design solutions necessary to guarantee maximum safety for citizens and the environment. The study provides two rationales for the site selection: first, the list of criteria elaborated by the control body ISPRA (today ISIN) and the location of potentially suitable areas for the National deposit; second, deep analysis of the Italian Nuclear Cycle, which has been provided in accordance with the origins of radioactive waste present in Italy and its distribution among the regions. As an outcome, the region of Piedmont has been selected as the one to host the National Deposit and Technological Park. Later, the chapter tracks in detail the location of potentially suitable areas in the region of Piedmont and analyses in deep the selected area.

Note[2]:

The National Inspectorate for Nuclear Safety and Radiation Protection (ISIN) is today the competent regulatory authority for nuclear safety and radiation protection, independent under Directives 2009/71/ Euratom and 2011/70 / Euratom. The Inspectorate absorbs all the functions relating to nuclear safety and radiation protection already assigned in the past by national legislation to CNEN, ENEA DISP, ANPA, APAT and, finally, to the Nuclear Department, technological and industrial risk, to the National Center for Nuclear Safety and Radiation Protection, as well as to the Physics Area of the National Center for the national network of laboratories for activities in the field of radioactivity of ISPRA.

The sixth chapter is dedicated to the development of the architectural proposal on the selected area. The project, where the time issue is a starting point, is an attempt to connect the analytical framework with the design premises. The project contains the elaboration of the Master plan of the National Repository and the design of the Archive within it. The proposal was developed by answering fundamental questions: how to integrate the project with people of the present, with people of the future? How to organize a space which does not evoke a feeling of suspicion and fear? How to manage the interface between '*huge and dangerous*' (or perceived as dangerous) with fear of people? How to promote interaction between the issues of democracy (transparency) and security (control)? How to connect the existing landscape with a new one and what is the outcome? How will the 'toxic heritage' interact with nature? What is the monument from the functional, symbolic and visual point of view? How to keep a memory alive? How does time affect space?

1 | AN EXPLORATION OF WASTE

1.1 What is 'waste'?

The word *waste* derives from the Latin *vastus* (unoccupied, desolate, uncultivated), relating to the Latin *vanus* (empty, vain) and to the Sanskirt word for wanting or deficient. Its definition spreads from wilderness and uselessness to illness and reckless spending. In common terms, waste is what is unwanted, unusable and valueless; it is loss and abandonment; it is defective and of no use; it is degradation, segregation, and end. It refers to the utilized objects, materials that after production and consumption left are useless and worthless. Garbage, trash, litter, junk, dirt, rubber, lumber characterize waste. As stated by Lynch[7], there are waste things, waste lands, waste time, and wasted lives.

As it could be noticed, each meaning carries a fundamentally negative perception. The idea of waste is always referred to as something unwelcomed, inferior by its own definition: it conveys negligence or human fiasco. A bad sense appears when the whole process is frozen when it generates a useless material that cannot be occupied.

1.2 The importance of wasting process. Natural and urban wasting

Notwithstanding, the process of wasting could be witnessed all around us. As Koolhaas eloquently claims, "Junkspace is overripe and undernourishing at the same time, a colossal security blanket that covers the earth in a stranglehold of seduction."[8] It affects us in various ways every day, be it a resource or a problem. Every time we throw an object away, consciously or not, we produce waste. Since that, the object disappears from our sight, however, its life is not over.[9] Wasting, as a process, pervades the entire ecosystem, the urban and nature. Processes of wasting in nature happen so slowly that we are often unaware of its existence. For instance, cataclysms such as forest fires, earthquakes, floods, volcanoes, etc. The other ones could be perceived only through history, because they are so remote in time and space, and they cannot affect us at this exact moment. Organisms use what they need, and later dispose of what they are not able to use anymore: through the skin, the alimentary canal, the lungs, the kidney, the segregation within the body, or death. Afterwards, the wasted products become the food for other organisms, creating a cycle, a chain of wasting. Blocking of wasting will destroy life, the entire living system. Therefore, the process of wasting is as vital as water, food, or air.

The process of urban wasting is as protracted as the natural one; it is as pervasive in human society as in the living organism. The city is an operating mechanism for focusing and transforming substances.-Sewage, garbage, scrap, litter, smog, trash produce daily urban waste chain. In the current geologic epoch '*Anthropocene*'[10], man is a dominant agent in the transfer of material in this dynamic intertwined system. Human beings are distinguished from others by the quantity, multiplicity and novelty of waste they produce. Garbage-laden streets, smog-filled air, or signs that are even more revealing are in the harbours, rivers, and lakes, where human/urban waste has been thrown away for numerous generations, trying to put it out of eyeshot and carry far away. Over time, when wind, air, pollution, cold and heat mark these objects, they could become valuable and sought by photographers, preservationists. Cities are fulfilled with wastes: abandoned or demolished buildings, streets, beaches, floating wastes on the surfaces of seas, lakes, and settling on the bottom; vacant lots, rooftops, the industrial areas, the railway sidings, or spaces around highway; even entire cities may be declined, and then gradually abandoned (for instance, the ghost town of Detroit in the USA).

1.3 A tangled mix of fear and desire

Our perception of waste shifts radically from culture to culture, from one historical moment to another. For some the phenomenon of old, abandoned and lost, creates an interesting atmosphere: it makes things sentimental and emotional. These people feel a special aura from the things that are getting old. However, others are threatened by this kind of aura: they get rid of old things in no time. Besides, some people are distinguished by a sense of discipline: as soon as the commodity is not utilizable, or useless, it should be removed. Nevertheless, all people have something in common: they are troubled by the death of things. They agree that the things "pass on" and that they have some specific, distinctive power to be dealt with.

[7] Kevin A. Lynch, *Wasting Away: An Exploration of Waste: What It Is, How It Happens, Why We Fear It, How To Do It Well* (San Francisco, CA: Sierra Club Books, 1990), 146.
[8] Rem Koolhaas, "Junkspace." *October* 100 (2002): 176.
[9] Silvia Dalzero, "Rejected Landscape – Recycled Landscapes Waste Disposal and Recycling Sites Perspectives and Contemporary Architecture."*Journal of Engineering and Architecture* 3, no. 1 (2015): 62.
[10] Paul J. Crutzen and Eugene F. Stoermer, "The Anthropocene." *Global Change Newsletter* 41 (2000): 17-18.

Lynch[11] compares our perception of loss and waste with the death of people of different ages: the death of a beloved one at an advanced age is a loss, not a waste. However, when a budding junior is being killed, or for example, a place with which our best memories are strongly connected, is being demolished, then fundamentally negative feelings are strengthened by the added sense of waste. According to the author, we, humans, "are animals whose continuity lies in our genes, carried by lines of perishing individuals, but we have acquired individual consciousness."[12] We are scared of our own extinction. In short, in a human's mind the words *death, decline and waste* are interlinked. Waste is chaotic and impure. These feelings are out of our control, it is a reminder of our end, of our death. That is why all those words of waste are evil magic; they unconsciously draw our attention, it brings to us a sense of fear. Far from our "wanting to see", junk places are "sincere mirrors of the world surrounding us."[13]

Notwithstanding the above, the topic of waste has hidden gravitation, a secret temptation. Humans are mesmerized by destruction and disorder. Disorder deteriorates our (pattern makers') patterns but delivers material for new patterns. Waste is full of new forms and bears sophisticated signs of its origin and prior use. Its ambiguities are poetic, Lynch[14] claims. Waste heaps are the source of information about the past. A human being can feel nostalgic for this past, and simultaneously be pleased about its own survival. Another point of secret fascination in wasting is linked to the feeling of freedom: to the power of smashing things and seeing the effect, of defying society and proper behaviour. People feel joy in purifying themselves, in removing and eliminating waste. Reusing an old or abandoned object brings a feeling of pleasure: it is free of charge. The places of waste have their own fatal attraction: free to play, free of imagination, rich sensations. For instance, children are always drawn to empty lots, back alleys, out-of-use hillsides. People are fascinated by the possibility to act spontaneously, they are free of control in those places.[15]

These feelings run deep. The junk is a place at once fascinating, marginal, repulsive, and sociable. Waste attracts us and pushes us away simultaneously: we both enjoy and are disgusted by it. These two rational

[11] Kevin A. Lynch, *Wasting Away: An Exploration of Waste: What It Is, How It Happens, Why We Fear It, How To Do It Well* (San Francisco, CA: Sierra Club Books, 1990), 154.
[12] Ibid., 154.
[13] Silvia Dalzero, "Rejected Landscape – Recycled Landscapes Waste Disposal and Recycling Sites Perspectives and Contemporary Architecture."*Journal of Engineering and Architecture* 3, no. 1 (2015): 54.
[14] Kevin A. Lynch, *Wasting Away: An Exploration of Waste: What It Is, How It Happens, Why We Fear It, How To Do It Well* (San Francisco, CA: Sierra Club Books, 1990), 154.
[15] Ibid., 21.

judgments are entangled by our feelings and perception. This opposition is ingrained in our nature as social animals. It is rooted in biological and cultural history: it is natural, and cannot be ignored. Wasting, seen completely, is a tragic and astonishing process. It is a 'tangled mix' of good and evil, with a predominance of the latter.[16] "There is a special way of moving in Junkspace, at the same time aimless and purposeful. It is an acquired culture."[17]

1.4 Various possibilities to treat waste right

There is an Irish ritual when before leaving for a long-term journey you have to sit down in silence, at the very last moment, to think together about what was being left behind. A ritual that is enlarged in meaning and is kept in memory. According to Lynch[18], people need some kind of ritual of saying goodbye to places, to the wasted thing, something that will be preserved in memories. He provides an example of the demolition of Baker Hotel in Dallas, USA, which was a social centre for middle-class parties. Before its demolition, the ultimate party has taken place there, as a celebration of an event. If looking far beyond this, are we able to celebrate the death of an entire place, or the passing of a skill, or way of life? Lynch claims that we need customs of the re-enactment, of leave-taking, of record and memorial of sealing and sanctifying, because they can give a less traumatic association.

The problem of waste comes from ancient times; yet, it has become a crucial problem nowadays. "Junkspace will be our tomb", Koolhaas[19] claims, "[h]alf of mankind pollutes to produce, the other pollutes to consume." According to Lynch[20], we have to start looking at waste as a normal stage, a stage in itself fascinating and full of potential. The disposal of waste is the reality that we need firstly, to accept; not to battle against it or see it as a 'shame' or trying to 'hide', but rather to have the courage to perceive it as the reality; the reality to be investigated, the reality to be taken advantage of.[21]

[16] Ibid., 116.
[17] Rem Koolhaas, "Junkspace." *October* 100 (2002): 179.
[18] Kevin A. Lynch, *Wasting Away: An Exploration of Waste: What It Is, How It Happens, Why We Fear It, How To Do It Well* (San Francisco, CA: Sierra Club Books, 1990), 191.
[19] Rem Koolhaas, "Junkspace." *October* 100 (2002): 183.
[20] Kevin A. Lynch, *What Time Is This Place?* (Cambridge, MA and London: The MIT Press, 1972), 233.
[21] Silvia Dalzero, "Rejected Landscape – Recycled Landscapes Waste Disposal and Recycling Sites Perspectives and Contemporary Architecture."*Journal of Engineering and Architecture* 3, no. 1 (2015): 56.

> "If we look at waste and scars with interest, we may learn how to integrate them into a continuous cycle of use. [...] We need to look at it open-eyed, to see its present value so that it can be exploited for its own unique character. Since we expect to continue to produce waste, we must be prepared to re-use, even enjoy, that waste continuously."[22]

According to Augé[23], in the future waste is going to form the context and materials of contemporary architecture. The key is to cease distancing ourselves from the waste, but rather to use design and aesthetic tools in order to normalize wastes and bring them into our everyday environments, to turn a junk space into an efficient, modern, sanitary landfill.[24] Lynch[25] suggests that particular dumps could be preserved as historic landmarks, exactly in a way we preserve castles. A monumental representation of waste may seem satire; however, it is also a way to deal with it, making things meaningful. As already mentioned, junk usually repels us, yet it can give us the feeling of pleasure as well: it can enrich our sense of the past and can assist life itself. This noisy wasting will attract numerous tourists. Dead things could be brought back to life through art, architecture, and preservation. These proposals are aimed to extract the positive sense of waste, "[…] reintroducing it into the flow in the form of recycled materials resembling virgin materials yet even more desirable due to their ability to silence our guilty feelings."[26]

Numerous examples could be made to represent that even though waste is not usually perceived as an attractive 'thing', several artists and architects have been inspired to use it as their remedy. This kind of preservation helps in the needful change mentioned above. For example, refined Tuileries Gardens in Paris are actually the recycled garbage dump of medieval Paris. Similarly, in Berlin, a hill 110 meters high (Berlin's Mount Junk), made out of a war dump has been transformed into a public park for skiing, hiking, tobogganing. In Tonopah, Nevada, a monument dedicated to heroes of WWII, who lost their lives in a disaster at the Bombing and Gunnery, was established from the debris of that catastrophe.

Besides, "[…] there are new legal architectonic languages for management and waste disposal: an example is the thermo-plants and controlled wasted dumps. They create new architectonic scenarios,

[22] Kevin A. Lynch, *What Time Is This Place?* (Cambridge, MA and London: The MIT Press, 1972), 190-191.
[23] Marc Augé, *Le temps en ruines* (Paris: Galilée, 2003).
[24] Mark D. Bjelland, "Designing America's Waste Landscapes." *The Professional Geographer* 58, no. 1 (2006): 120.
[25] Kevin A. Lynch, *Wasting Away: An Exploration of Waste: What It Is, How It Happens, Why We Fear It, How To Do It Well* (San Francisco, CA: Sierra Club Books, 1990), 195.
[26] Giovanni Corbellini, "Residuals", in *The Landscape of Waste*, eds. Alberto Bertagna and Sara Marini (Milan: Skira, 2011), 80.

landscapes, which are always closer and closer to urban centres and sooner or later we have to learn how to live with them."[27] Such kinds of dumps will be explored later in this study.

1.5 Hazardous Waste

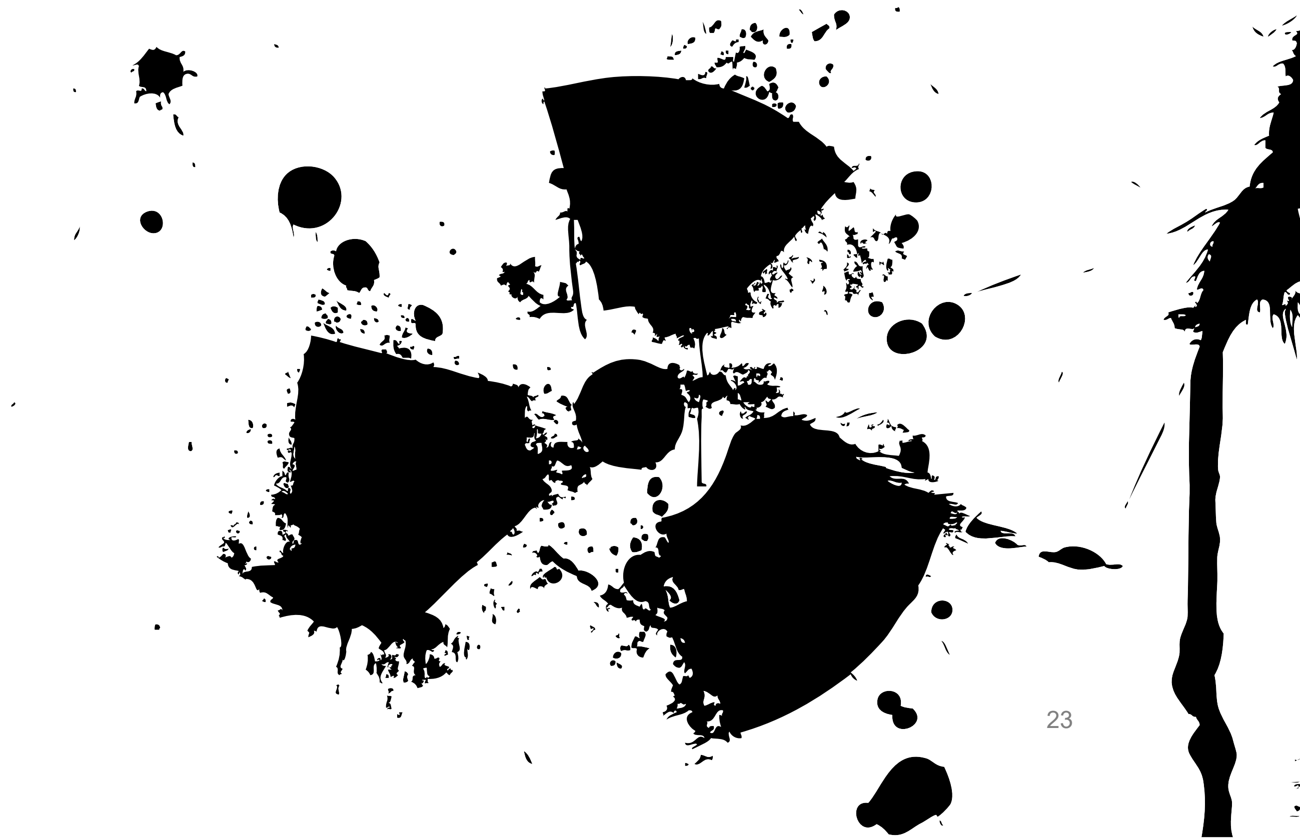
The majority of creatures produce waste that could be poisonous for themselves or even to others. A human being is unique: he produces products that are poisonous to all living organisms, including himself. Hazardous waste is corrosive, reactive, ignitable, and toxic. It is an inevitable outcome of developmental activities and industrialization; it could present pernicious consequences not only to the generation of a period it was produced but also to the future ones.

The managing of hazardous waste is an extremely sensitive topic, which started to be regulated in 1976 when the EPA[28] issued the regulations for the disposal of hazardous waste. The act included standards for waste storage, treatment and disposal management. Constant tracking and monitoring of hazardous waste from "cradle to grave" started to be mandatory. Before these regulations, most of the hazardous waste had simply been buried, dumped on the ground or spilt into sewers.

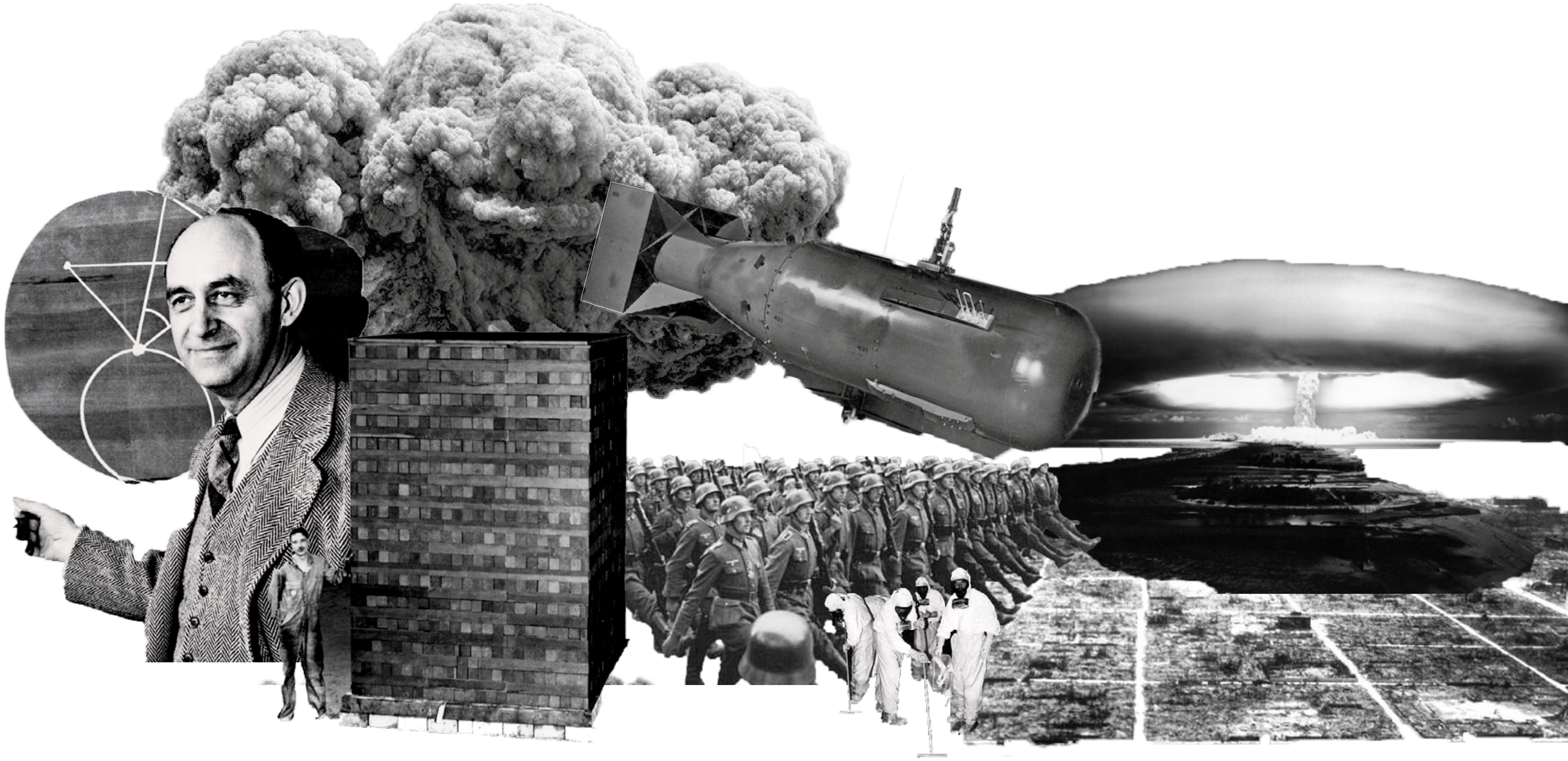
Specifically, in all the sumptuous court of hazard, radioactive waste bears the crown. The following chapters of this study are aimed to investigate in detail radioactive waste and its methods of management.

[27] Silvia Dalzero, "Rejected Landscape – Recycled Landscapes Waste Disposal and Recycling Sites Perspectives and Contemporary Architecture."*Journal of Engineering and Architecture* 3, no. 1 (2015): 60.
[28] The Resource Conservation and Recovery Act (RCRA) of 1976.

2 AN EXPLORATION OF NUCLEAR



2.1 The chronological record of the Atomic Era: Major historical events, scientific and technological development



1895-1942

/ Early nuclear science. Crucial discoveries, experiments, and investigations held by W.C. Röntgen, H. Becquerel, M. and P. Curie, E. Rutherford, J. Chadwick, E. Fermi, F. and I. Joliot-Curie, L. Szilárd, O. Hahn, F. Strassmann, L. Meitner, O. R. Frisch, W. Arnold, N. Bohr, and H. Anderson.

1939

/ The investigation of nuclear weapon.

/ **September 1** - Nazi Germany invades Poland: the beginning of WWII.

1941

/ June 22 – Nazi Germany invades the former USSR.

/ July 15 – the MAUD Committee approves a report and disbands on atomic bombs.

/ September 3 – an agreement on the development of an atomic bomb.

/ December 8, 11 – the U.S. declares war on Japan, and subsequently, on Germany and Italy.

1942

/ January 19 – U.S. President Franklin D. Roosevelt's approval of an atomic bomb production.

/ August – the initiation of the *Manhattan Project*.

/ December 1 - first nuclear reactor called *Chicago Pile – 1* in the University of Chicago, USA, by E. Fermi and L. Szilárd.

1945

/ May 9 – *Victory Day*. The former USSR government announces the victory over Nazi Germany in WWII.

/ July 16 – *the Trinity Test*. The USA tested the first nuclear weapon.

/ August 6, 9 - atomic bombings of the USA in Hiroshima and Nagasaki, which marked the ending of the WWII.

1947

/ August 25 – the abolition of the *Manhattan Project*.

/ The AEC discovers the opportunity of peaceful use of atomic energy.

1953

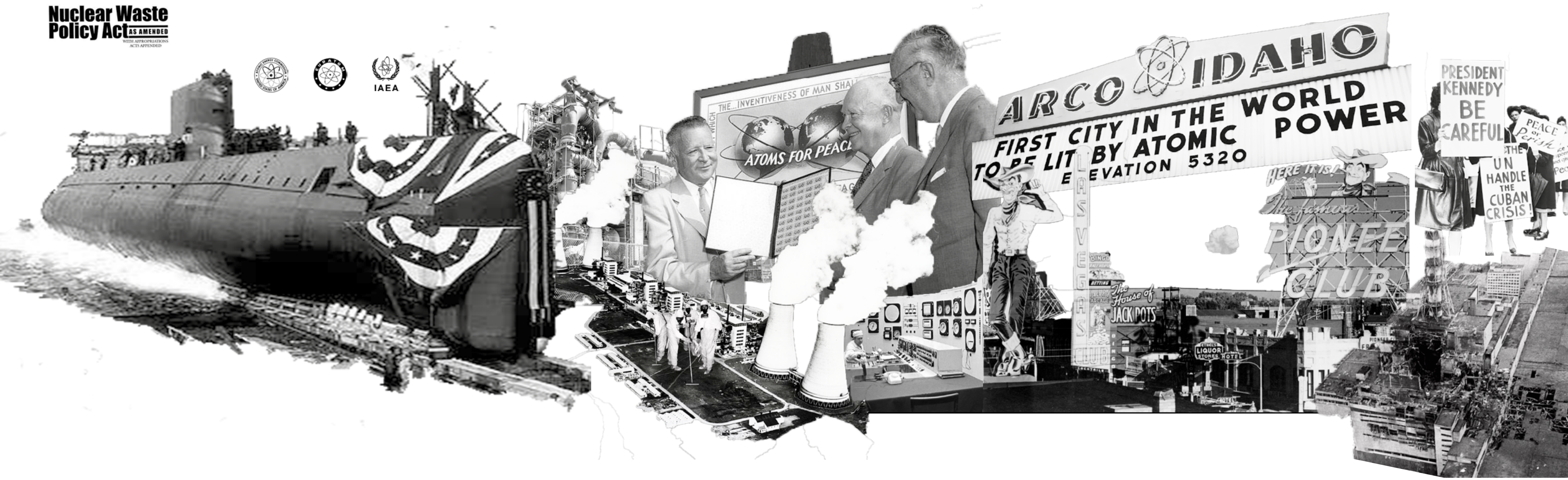
/ December 8 – U.S. President Dwight D. Eisenhower delivers his *"Atoms for Peace"* speech at the UN General Assembly in New York City.

1954

/ January 21 – launching of the world's first operational nuclear-powered submarine, *USS Nautilius (SSN-571)*.

/ June 27 – USSR's *Obnisk* NPP to become the world's first NPP to generate electricity for an electric power grid, an interconnected network to deliver electricity from producers to customers.

/ August 30 - Atomic Energy Act.



1955

/ January 10 – the AEC proclaims the Power Demonstration Reactor Programme.

/ July 17 – for the first time in the world the entire community (Arco, Idaho, the USA) was lit by electricity generated by the *Borax III* reactor.

/ August 8-20 – Geneva, Switzerland hosts the first UNIC of Peaceful Uses of Atomic Energy.

1956

/ The world's first 'commercial' nuclear power station *Calder Hall* in Windscale, England, which exported electricity in a commercial scale to a public grid.

1957

/ March 25 - the establishment of EAEC.

/ July 29 – the establishment of the IAEA with the headquarters in Vienna, Austria.

/ September 29 - the Kyshtym disaster. A radiation contamination at *Mayak* - a plutonium production site for nuclear weapons and a nuclear fuel reprocessing plant in the former USSR (INES level – 6).

1961

/ November 1 - Women Strike for Peace. Around 50,000 women in 60 cities in the USA brought together to demonstrate against nuclear weapons.

1970

/ March 5 – the USA, the UK, the former USSR and 45 other states countersign the NPT.

1979

/ March 28 - an accident at *Three Mile Island* NPP in the USA caused by human error and mechanical malfunction (INES level – 5).

1986

/ April 26 – disaster at *Chernobyl No. 4* NPP in Chernobyl, Chernobyl Raion (Now Ivankiv Raion) Kyiv, Ukrainian SSR, former USSR, causing the escape of an enormous amount of radiation. The accident leads to up to 4062 death cases (INES level – 7).

2011

/ March 11 - 3 active reactors of NPP in Fukushima, Japan, were flooded and damaged by tsunami (INES level – 7).

2.2 *What is radioactivity?*

In order to understand what does radioactive waste represent, we need to investigate the term 'radioactivity'. Radioactive waste includes two levels of scientific basis, which are often confused: atomic and nuclear. Two words refer to each other, yet they have different realms of matter. The word atomic refers to chemical processes, however, the word nuclear – to energetic ones. Nuclear physics sheds light on the radioactivity process. Both chemical and physical concepts are extremely important to comprehend the subject of radioactive waste.[29]

Numerous types of atoms named isotopes compose each chemical element. The weight of the nuclei of the isotopes, which is defined by the number of protons plus neutrons, is responsible for the difference between them. Several isotopes are persistent: they never change. However, the other ones are radioactive: they may transform into another form. There are both natural and 'man-made' radioisotopes (radioactive isotopes).

Radioactivity is a process in which the nucleus spontaneously decays or disintegrates. It is impossible to forecast the exact time of decay of a specific nucleus. It means that each isotope has its own half-life, unaffected by any kind of treatment. Half-life is the time required for a quantity to diminish to half of its primary value.[30] The half-life of a various number of radioisotopes ranges radically, from seconds to billions of years. The rate of decay or, in other words, the number of disintegrations per second is called activity.[31] In general, the safeness of the materials depends on their half-life and their activity. Radioactivity is very dangerous in terms of the ability to detect it: we are not able to see, smell, touch, taste or hear it.[32]

2.2.1 The consequences of radioactivity

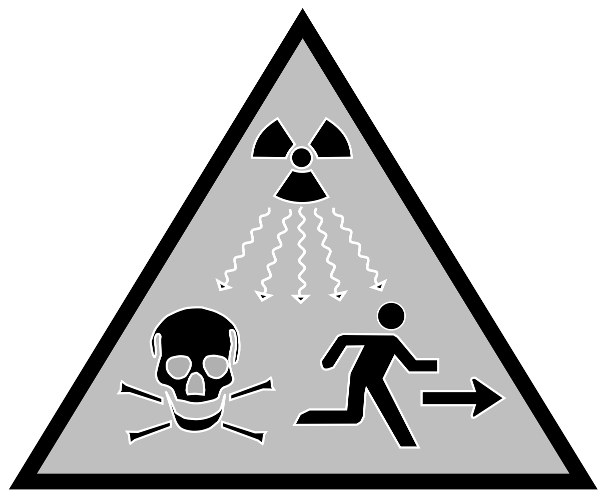
At a time when a hazard caused by nuclear activities was not well known or well understood, nuclear host communities were very positive about their status, since they felt to be a part of an advantageous and innovative industry. However, this optimism towards nuclear has changed dramatically since the late 1960s. Starting from that period

[29] Raymond L. Murray, *Understanding Radioactive Waste* (Richland, WA: Battelle Press, 1981), 5.
[30] Ibid., 9.
[31] Ibid., 10.
[32] Ibid., 24.

almost 70 nuclear research reactors and small nuclear power reactors have been decommissioned.[33]

Nowadays, human civilization is already familiar with the term radioactivity and its effects. We face it in all the steps of our life. Radiation takes many forms: it occurs both from natural and artificial sources.[34] Natural radiation, which is continuously bombarding our atmosphere, derives from the cosmos, the Earth's crust and natural radionuclides in our bodies and our homes. However, the artificial radiation that is generated out of human activities, in which radioactive materials are used (e.g. production of nuclear energy, medicine, industry, research), is strictly regulated by law.

There are two types of radiation effects namely somatic and genetic. Somatic points the damage to the body tissues, which results in, for example, cancer. Genetic refers to hereditary characteristics, which conclude impaired fertility and transmitted birth defects. The radiation effect is directly proportional to the radiation dose (the amount of radiation). This signifies that in case our body receives a miserable dosage of approximately 10 rems (the unit of dosage), there could be no essential damage; however, if the dosage is immense, of about 400 rems, the result could be fatal. Furthermore, the effect of the radiation can be revealed not immediately, but over time.[35]



[33] Morris Rosen, "Managing Radioactive Waste: Issues and Misunderstandings." *Energy & Environment* 11, no. 2 (2000): 173.
[34] Raymond L. Murray, *Understanding Radioactive Waste* (Richland, WA: Battelle Press, 1981), 17.
[35] Ibid., 18.

3 RADIOACTIVE WASTE

"Radioactive waste is terrifying. No change is completely reversible; all events leave their traces. But we are grateful for adaptability, for near-reversibility, for the chance to try again without penalty. We cannot lie still in the water, nor even sail home. Instead, we hope for a good voyage: no bad surprises, a continuous heading, and interesting destinations, from which we can leave for other ports."

— Lynch, *Wasting Away: An Exploration of Waste: What It Is, How It Happens, Why We Fear It, How To Do It Well*, 160

3.1 The origins and the classification of radioactive waste

The establishment of radwaste is the result of the activities, which involve the use of radionuclides and the production of nuclear energy. Besides, radwaste can also be a result of research, medical and industrial usage of radioisotopes and radiation sources, military programmes and mining and mineral processing, which involve elevated levels of naturally occurring radionuclides. Another example of the origins of radwaste is the intervention activities after nuclear-based accidents.[36] The waste from nuclear power production includes also the waste that originated from reactor operations, reprocessing, decontamination, decommissioning and other activities in the nuclear fuel cycle. The radwaste can be generated in diverse forms, activities, concentrations and types of generating activity. It may be solid, liquid and gaseous.[37]

As radwaste derives from several kinds of facilities, there is a different characterisation of it. Hence, the classification of radwaste is generated according to its physical, chemical and radiological properties. For different classes of radioactive waste, there is a different management solution. The classification of radwaste has been developed according to the international standards on the safety of its management. The main point for determining the classes of radwaste is long-term safeness. Therefore, the parameters used in defining the classes of radwaste are the levels of activity content and the half-lives of the radionuclides contained in the radwaste.[38] For instance, in terms of the safety and security of radwaste, a radionuclide with a half-life of less than approximately 30 years is generally accepted as short-lived.[39]

Even if these parameters are used as the basis, still there are specific types and properties of radioactive waste, which should be taken into consideration. The parameters mentioned above (e.g. half-life and activity) do not represent a precise quantitative border between the classes of radwaste, as they only indicate the potential hazard posed by a particular type of radwaste. In fact, it is impossible to develop a single classification scheme, as there are plenty of objectives to be taken into account, which sometimes even contradict each other. Hence, flexibility and adaptation are required.[40] The particular criteria vary from country to country, regarding the nature of radwaste and the ways of its management. In other words, the boundary between the classes of

[36] International Atomic Energy Agency, *Classification of Radioactive Waste*. IAEA Safety Standards Series No. GSG-1 (Vienna: IAEA, 2009), 34.
[37] Ibid., 34.
[38] Ibid., 21.
[39] Ibid., 7.
[40] Ibid., 20.

radwaste is intended to be perceived as a transition zone, where the final solution will depend on the country of origin. Specific features of radwaste at the generic level do not define the final classification. On the contrary, specific criteria for various types of radwaste is extracted from the general concept of its classification.

According to IAEA[41], six classes of radioactive waste are derived and used as the basis for the classification scheme:

- **Exempt waste (EW),** which corresponds to the criteria for clearance, exemption and exclusion from institutional control, since very small concentrations of radionuclides are present in it.

- **Very short-lived waste (VSLW)**, which could be stored for disintegration over a particular period of time, up to a few years. Afterwards, it is going to be freed from regulatory control. This class includes the radwaste with very short half-lives, predominantly coming from research activities and medical industries.

- **Very low-level waste (VLLW)**, which does not require a high level of containment and isolation. Accordingly, this type of radwaste is suitable for disposal in near surface landfill type facilities with limited regulatory control.

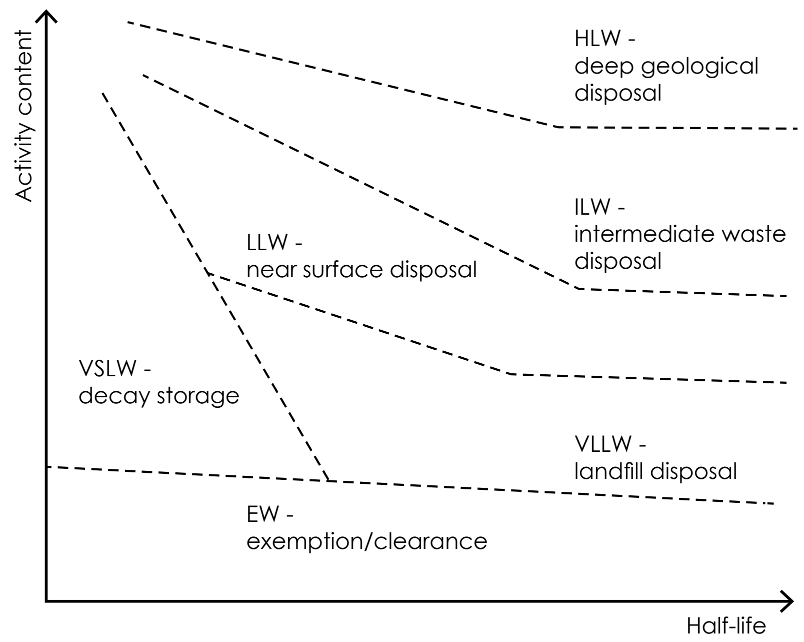
- **Low-level waste (LLW)**, which contains limited amounts of long-lived radionuclides. This class demands strong isolation and containment for up to a few hundred years. It corresponds to disposal in near-surface facilities. This class covers a very broad spectrum of activity concentrations and could contain a great variety of radionuclides. For this reason, there are different design possibilities for near-surface disposal facilities: from simple to more complex engineering solutions. Moreover, it may involve disposal at diverse depths, usually up to 30m. It may vary based on the need for institutional control over time. In multiple countries, regulatory control is expected for a period of 300 years. "The selection of a disposal option depends on many factors, both technical and administrative, such as the radioactive waste management policy; national legislative and regulatory requirements; waste origin, characteristics and inventory; climatic conditions and site characteristics; public opinion; etc."[42]

[41] Ibid., 5-6.
[42] International Atomic Energy Agency, *Disposal Aspects of Low and Intermediate Level Decommissioning Waste: Results of a coordinated research project 2002–2006*. IAEA-TEC-DOC-1572 (Vienna: IAEA, 2007), 22.

- **Intermediate-level waste (ILW)**, which, because of its long-lived radionuclides, requires a higher degree of containment, such as a disposal at a greater depth. Disposal at a depth between tens to hundreds of metres is able to provide long-term isolation from the environment if both natural and engineering barriers of the disposal system are selected and designed in a proper way. For such disposal, regulatory control is not required, as the likelihood of inadvertent human invasion is significantly decreased.

- **High-level waste (HLW)** contains a large number of radionuclides with long half-lives. Disposal in deep, stable geological formations with engineering barriers, typically several hundred metres or more, below the surface, is a commonly accepted solution for HLW. It involves two major components: spent fuel from reactors at nuclear power plants and different by-products of nuclear weapons productions. Nowadays it is estimated more than 250,000 tons of high-level nuclear waste worldwide.[43]

The classification is provided for the solid radioactive waste, however, "the fundamental approach could also be applicable to the management of liquid and gaseous waste, with appropriate consideration given to aspects including the processing of such waste to produce a solid waste form that is suitable for disposal."[44]



Conceptual illustration of radioactive waste classification scheme. The greater the level of activity content, the higher the requirement for containment and isolation of radwaste from the environment. IAEA, 2009, 7.

[43] International Atomic Energy Agency, *Status and Trends in Spent Fuel and Radioactive Waste Management*. IAEA Nuclear Energy Series No. NW-T-1.14 (Vienna: IAEA, 2018), 36.
[44] International Atomic Energy Agency, *Classification of Radioactive Waste*. IAEA Safety Standards Series No. GSG-1 (Vienna: IAEA, 2009), 3.

3.2 The management of radioactive waste

The management of radwaste is still one of the predominant issues the world faces nowadays. As the nuclear industry grows, so grows the problem of radwaste management. Nearly all the states produce insignificant quantities of radioactive waste from research, medical and industrial applications. As mentioned before, radwaste presents a potential hazard to human beings and the environment. On the grounds of this, radwaste should be managed in a way to reduce the potential risk of danger. When we talk about radwaste, we should consider a long-term future – hundreds and thousands of centuries from now.

3.2.1 Historical background

The first safety standard document on radioactive waste management titled "Radioactive Waste Disposal into the Sea" was published in 1961.[45] For more than half of a century, the nuclear industry has used the seabed as a dump. The barrels were supposed to be diluted by water, forever isolated from men and the environment, especially in a case of war. In 1951, the barrels of radioactive waste were dumped into the Atlantic Ocean, 200 km from the coast of New York City. The same operation took place in the Pacific Ocean, 40 km from San Francisco just off the Farallon Islands. In total 85,000 barrels were dumped into the seabed. The same situation was occurring on the European coast in May 1967, in the port of Emden. Nuclear waste coming from Germany, Britain and France was loaded onto the British cargo ship "Topaz". More than 100,000 tons of nuclear waste disappeared into the North Atlantic, the Irish Sea, and the English Channel. In the mid-1970s, "Greenpeace" raised awareness about these dumping activities. Nevertheless, the dumping activities continued until 1993, when they were officially forbidden in

June 1982: Greenpeace action protesting at the dumping of nuclear waste in the Atlantic by the dumpship Rijnborg. Two barrels are dropped on top of a Greenpeace inflatable, causing it to capsize.

Jan Beránek, Rianne Teule and Aslihan Tumer, *The deadly legacy of radioactive waste: Wasting our time with nuclear power*, 2.

[45] International Atomic Energy Agency, *Radioactive Waste Disposal into the Sea.* IAEA Safety Series No. 5 (Vienna: IAEA, 1961).

the London Convention. Almost three decades later, the analysis carried out by the EPA and "Greenpeace" have shown that some of the barrels had leaked, and as a result, the radioactive material had been dispersed to the sea life and in the sediment of the surrounding areas.

For many years, such international organisations as NEA, IAEA and EAEC have been in charge of the management of radioactive waste at an international level. A very long and heavy process was carried out in order to achieve international consensus on the safety principles for the management of radioactive waste. The agreement was reached and adopted in 1995.[46]

3.2.2 Nowadays scenario - storage solutions

Every year tons of radioactive materials are added to nuclear storage disposal facilities all around the world. Predominantly, nuclear waste is stored and cooled in water tanks, as water serves as a natural shield and prevents the spread of radiation into the environment. Yet, such kinds of installations are assailable to any kind of threats both natural and fabricated, such as fire, power outages, earthquakes, tsunami (the case of Fukushima Dai-ichi in Japan) or even terrorist attacks. Since the issue of radioactive materials does not just across space but also time, it is definitely not a long-term solution.

According to the latest declaration, "the preferred strategy for the management of all radioactive waste is to contain it (i.e. to confine the radionuclides within the waste matrix, the packaging and the disposal facility) and to isolate it from the accessible biosphere."[47] As the international practice has shown, the best engineering solution for radioactive waste disposal is the multiple-barrier concept[48], which will be revised in detail in the following chapters of this paper.

The disposal of radioactive waste, in which it is going to be placed forever, is aimed to guarantee that the amounts of radionuclides reaching the accessible biosphere due to any leakage from the disposal facility are such that possible radiological consequences are acceptable low at all times.[49]

[46] International Atomic Energy Agency, *The Principles of Radioactive Waste Management.* IAEA Safety Series No. 111-F (Vienna: IAEA, 1995).
[47] International Atomic Energy Agency, *Disposal of Radioactive Waste.* IAEA Safety Standards Series No. SSR-5 (Vienna: IAEA, 2011), 2.
[48] International Atomic Energy Agency, *Design Principles and Approaches for Radioactive Waste Repositories.* IAEA Nuclear Energy Series No. NW-T-1.27 (Vienna: IAEA, 2020), 15.
[49] International Atomic Energy Agency, *Disposal of Radioactive Waste.* IAEA Safety Standards Series No. SSR-5 (Vienna: IAEA, 2011), 3.

EXAMPLE OF A REPOSITORY DESIGN BASIS FOR A NEAR-SURFACE REPOSITORY FINAL CAP

High Level External Requirements

Can be mandatory (e.g. imposed by legislation, regulations and local and national authorities) or by agreement, (e.g. with local and regional communities and with agencies). They also include requirements from waste producers responsible for packaging. These entities vary according to country regulatory regimes and the extant stage of repository implementation.

System Requirements

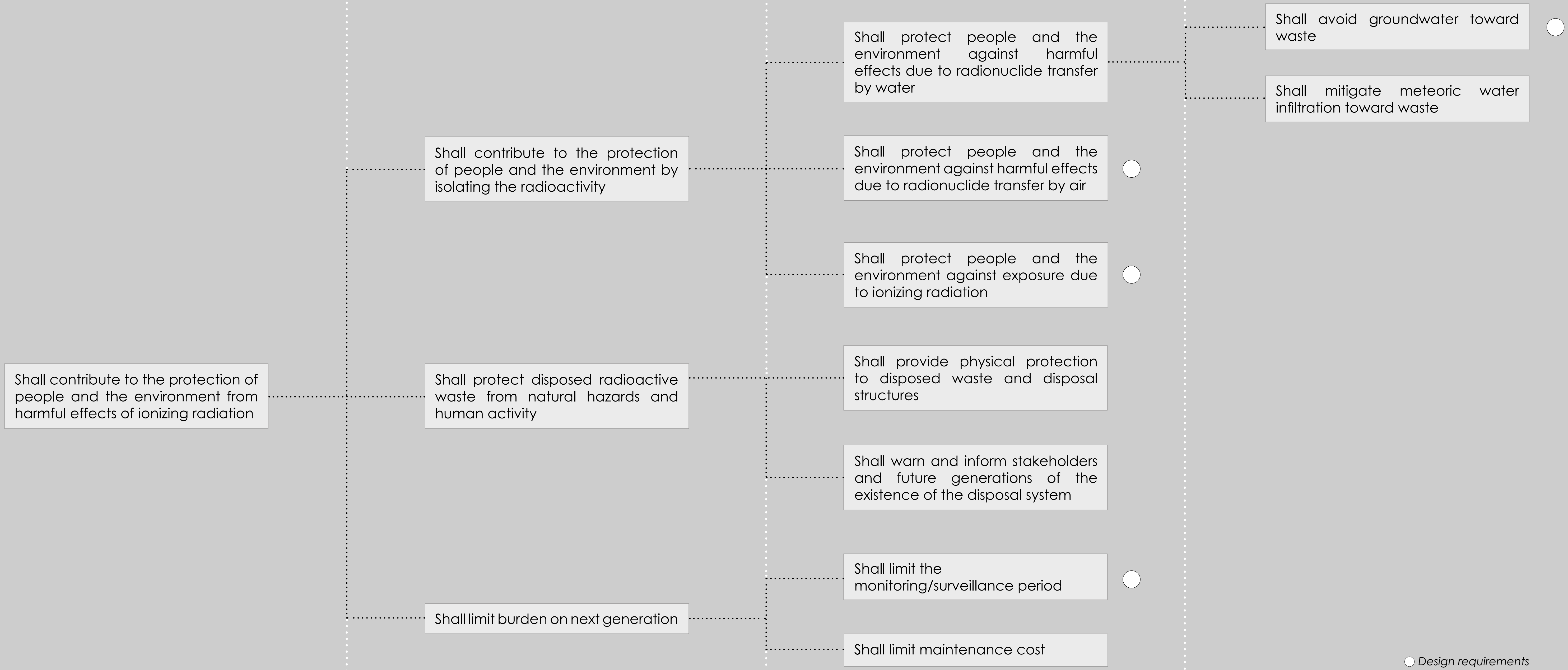
Requirements that define the total repository system and its management. These can include site specific constraints and characteristics, waste inventory, waste package types and numbers, the mode of transport for waste and construction materials to the repository, etc.

Sub-System Requirements

At this level the safety concept is specified as requirements for each of the major components, engineered (and geological) barriers and activities of the repository, where appropriate, expressed as ‘safety functions’.

Component Specification Requirements

Detailed requirements for each component, barrier and associated safety function, which cover the design, construction and manufacturing.



Referring to IAEA[50], there are several disposal facility types, which are as follows:

- **Specific landfill disposal** - could be applicable for VLLW

- **Near-surface disposal** – could be applicable for LLW

- **Disposal for ILW** – could be constructed in caverns, vaults or silos from 10 to a few hundred metres below the ground level.

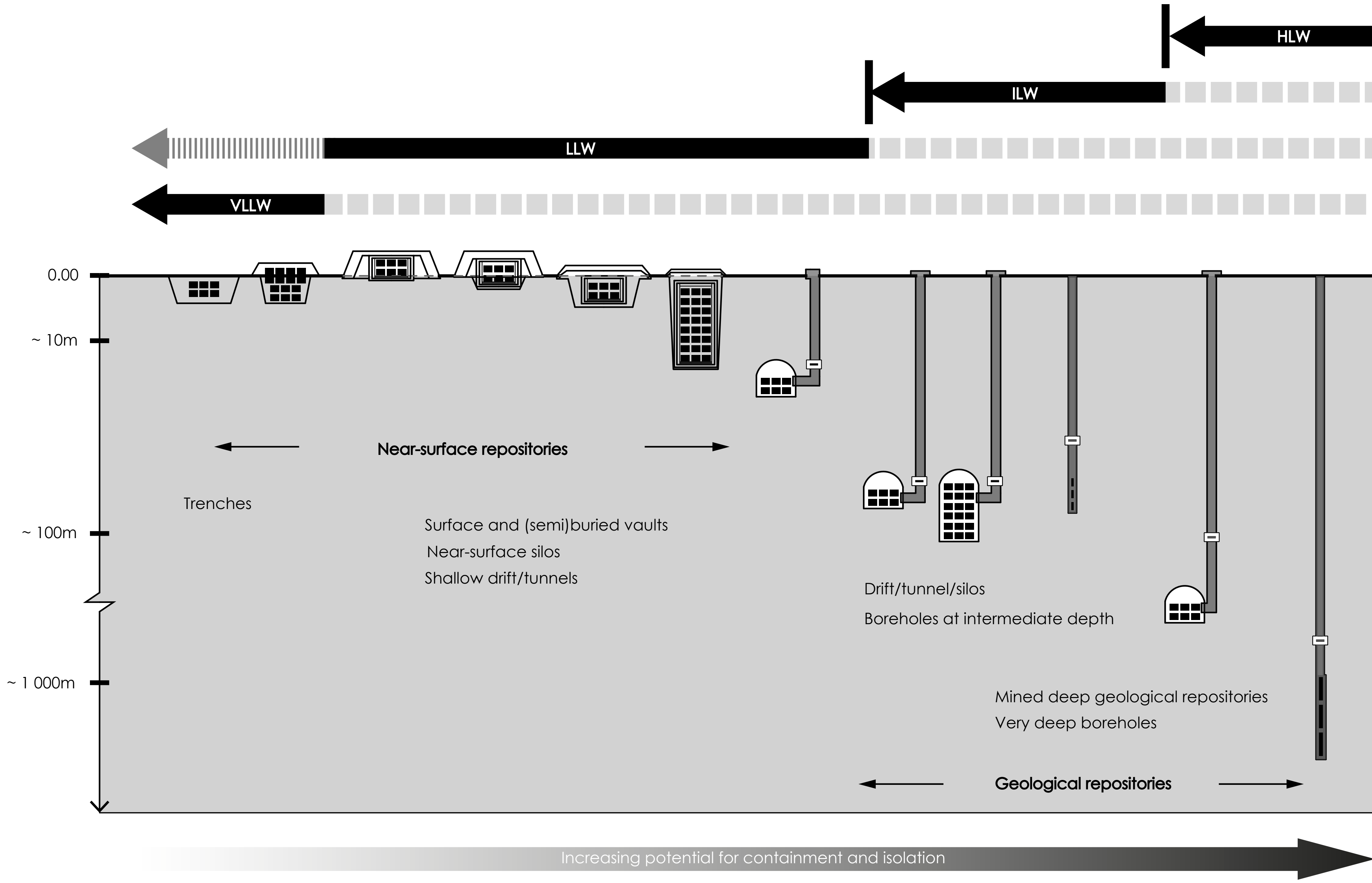
- **Geological disposal** – a facility built in tunnels, vaults or silos, in particular, geological formations (e.g. in terms of its long-term stability and its hydrogeological properties) at least a few metres below ground level. Could be applicable for HLW.

- **Borehole disposal** – a facility consisting of an array of boreholes, or a single borehole, which may be between a few tens of metres up to a few hundred metres deep. Such facility is designed for the disposal of only relatively small volumes of waste, particularly, disused sealed radioactive sources. A design option for very deep boreholes, several kilometres deep, has been examined for the disposal of solid HLW and spent fuel, but this option has not been adopted by any country.

- **Disposal of mining and mineral processing waste** – usually on or near the surface, but the manner and the large volumes in which the waste arises, its physicochemical form and its content of long-lived radionuclides of natural origin differentiate it from other radioactive waste. The waste generally stays in situ and is covered with various layers of rock and soil.

[50] Ibid., 4-5.

SCHEMATIC ILLUSTRATION OF THE RANGE OF DISPOSAL OPTIONS, FROM NEAR-SURFACE TO DEEP, CURRENTLY CONSIDERED OR IMPLEMENTED FOR DIFFERENT CLASSES OF RADIOACTIVE WASTE



3.2.3 The life cycle of the disposal facility

The development of the disposal facility includes a broad and comprehensive programme of research, design and assessment work. The programme lasts for several years and even decades. Referring to IAEA[51], the life cycle of the disposal facility consists of three periods:

- **The pre-operational period,** which includes concept definition, site investigation and confirmation, safety assessment, design studies and construction.

- **The operational period** begins with the arrival of waste to the facility. Monitoring, surveillance and testing programmes continue to take place. This phase may include activities for waste retrieval, if considered compelled, before closure, activities following the termination of waste arrangement and the final closure of the facility.

- **The post-closure period** starts at the time when all the engineering containment and isolation features have been put in place, operational buildings and supporting services have been decommissioned, and the facility is in its final configuration. Following the closure of the facility, its safety is provided through passive features inherent in the characteristics of the site, the facility and the waste packages, together with regulatory controls. Institutional control is brought in place to prevent intrusion and to confirm that the disposal system is performing as expected. Monitoring is carried out in order to provide public assurance as well. The licence is terminated after the period of active regulatory control, just as all the necessary technical, legal and financial requirements have been accomplished.

This "step by step" approach helps to adapt and correspond not only to new technical information and improvements but also to social, political and economic aspects of the disposal facility. That is to say that the management of radwaste should be politically, scientifically and publicly acceptable.

[51] International Atomic Energy Agency, *Near Surface Disposal Facilities for Radioactive Waste*. IAEA Specific Safety Guide No. SSG-29. (Vienna: IAEA, 2014), 7-9.

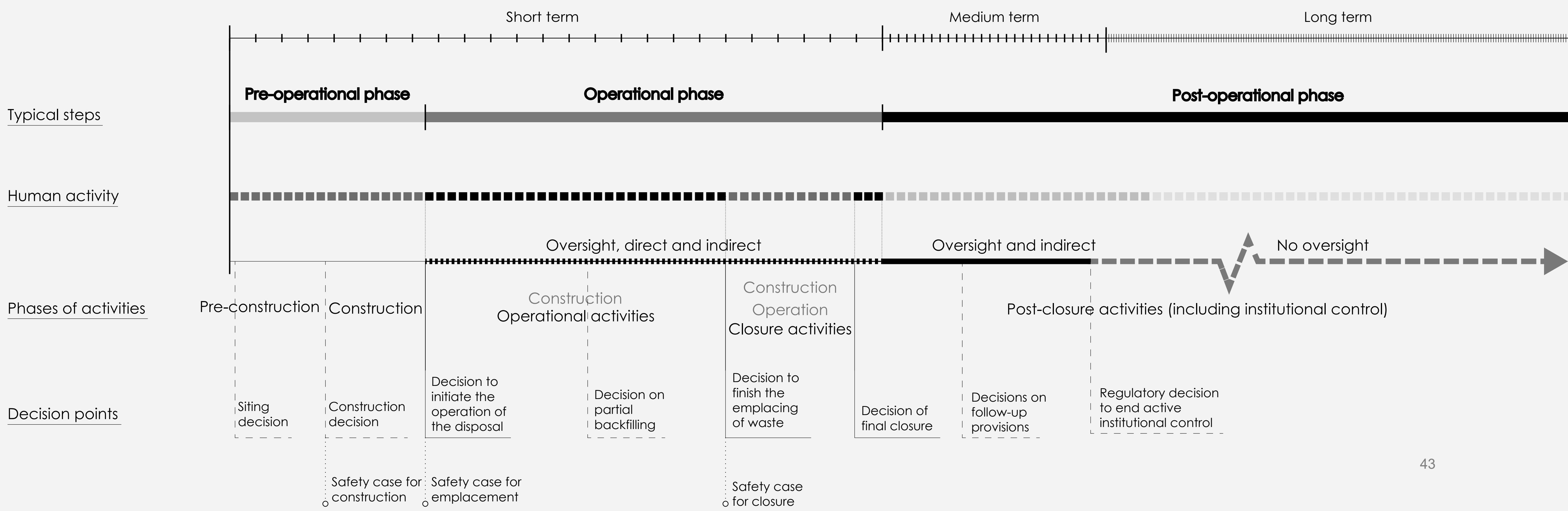
Note[1]:

Oversight is an active concept. It means 'watchful care' of the repository. It is lost when all forms of preserving have been relinquished. Oversight and memory keeping reinforce each other.

'Direct oversight' refers to the oversight of the repository when waste is accessible. 'Indirect oversight' - when the waste is no longer accessible. This will take place when sections of the repository or the whole repository are sealed.

Oversight is always exercised by people and includes regulatory supervision, institutional control, preservation of societal needs (such as archiving) and societal memory keeping the presence of the facility. After closure, and as more time goes by, oversight and preserving should become a societal endeavour.

TIMELINE TO ILLUSTRATE THE DEVELOPMENT, OPERATION AND CLOSURE OF NEAR SURFACE DISPOSAL FACILITY



3.2.4 Solutions in different countries

Considerable practice in the disposal of radioactive waste has been achieved in the last decades. The international association EDRAM, which was established with the purpose to share scientific and research results, helped in broadening the radioactive waste research field. The association consists of 11 organizations (companies or governmental agencies) responsible for radioactive waste management in each country of origin: Belgium (ONDRAF/NIRAS), Canada (NWMO), Finland (Posiva Oy), France (ANDRA), Germany (BGE), Japan (NUMO), Spain (Enresa), Sweden (SKB), Switzerland (Nagra), the UK (RWM Ltd.) and the US (OCRWM within DOE). Disposal solutions for many waste forms and classes became patent. Multiple facilities have already been constructed and nowadays are in different stages of their life cycle.

Over 60,000 tons of spent nuclear fuel and around 2.5 million m^3 of LLW and ILW has been generated across Europe (excluding Russia and Slovakia), a predominant part of which - in France, Germany and the UK.[52]

In almost all the European countries, even those, which have never produced electricity from nuclear power (for instance, Norway), permanent deposits for VLLW and LLW, were considered. Examples of operational near-surface deposits in Europe that are similar to the one which is going to be built in Italy, are El Cabril in Spain, L'Aube in France, Dukovaný in the Czech Republic, Mochovce in Slovakia, Drigg in the UK; and the ones which are under construction – Dessel in Belgium and Vrbina in Slovenia.[53]

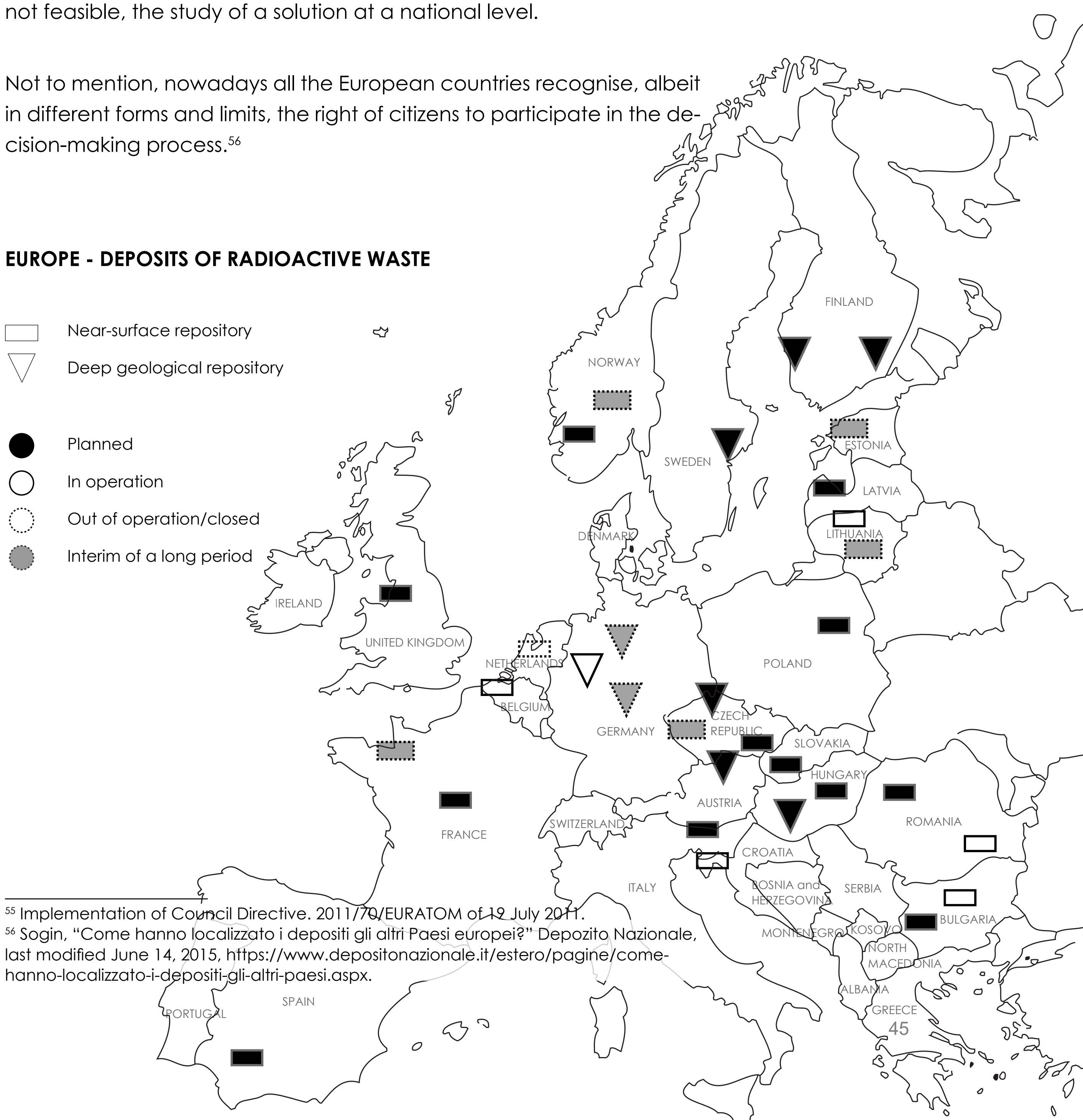
However, the scenario for ILW and HLW varies radically. The US, Finland and Sweden are the countries that have made the most progress in the development of a deep geological repository for HLW disposal. The only depot of this type, which is in operation since 1999, is the WIPP in Carlsbad, New Mexico, the US.[54] This facility houses ILW and high-level military waste, but not spent nuclear fuel from commercial reactors. In Europe, however, the spent nuclear fuel repository facilities in Finland and Sweden are anticipated to be operational in 2023 and the early 2030s respectively. Nowadays, Finland is the only country in the world that is constructing a repository for the most hazardous type of waste. Yet in Belgium, the Czech Republic, France, Germany, Hungary and Switzerland the process of localization has already been initiated. The same situation refers to Canada, Japan, South Korea and the UK.

[52] Arne Jungjohann (ed.), *The World Nuclear Waste Report 2019: Focus Europe* (Großbeeren: Arnold Group, 2019), 12
[53] Sogin, "Come hanno localizzato i depositi gli altri Paesi europei?" Depozito Nazionale, last modified June 14, 2015, https://www.depositonazionale.it/estero/pagine/come-hanno-localizzato-i-depositi-gli-altri-paesi.aspx;
Sogin, "Esistono in Europa depositi simili?" Depozito Nazionale, last modified June 14, 2015, https://www.depositonazionale.it/estero/pagine/esistono-in-europa-depositi-simili-a-quello-che-si-vuole-costruire-in-italia.aspx
[54] Arne Jungjohann (ed.), *The World Nuclear Waste Report 2019: Focus Europe* (Großbeeren: Arnold Group, 2019), 140.

In consideration of the high costs of building a repository of this type, some European countries with limited quantities of ILW and HLW are considering the opportunity to build one or more shared deep repositories.[55] To definitively settle its ILW and HLW waste, Italy pursues the strategy, referred to in the European context, of the so-called 'dual track', i.e. the feasibility analysis of a deposit to be built abroad and shared between several countries and, in parallel if the foreign hypothesis is not feasible, the study of a solution at a national level.

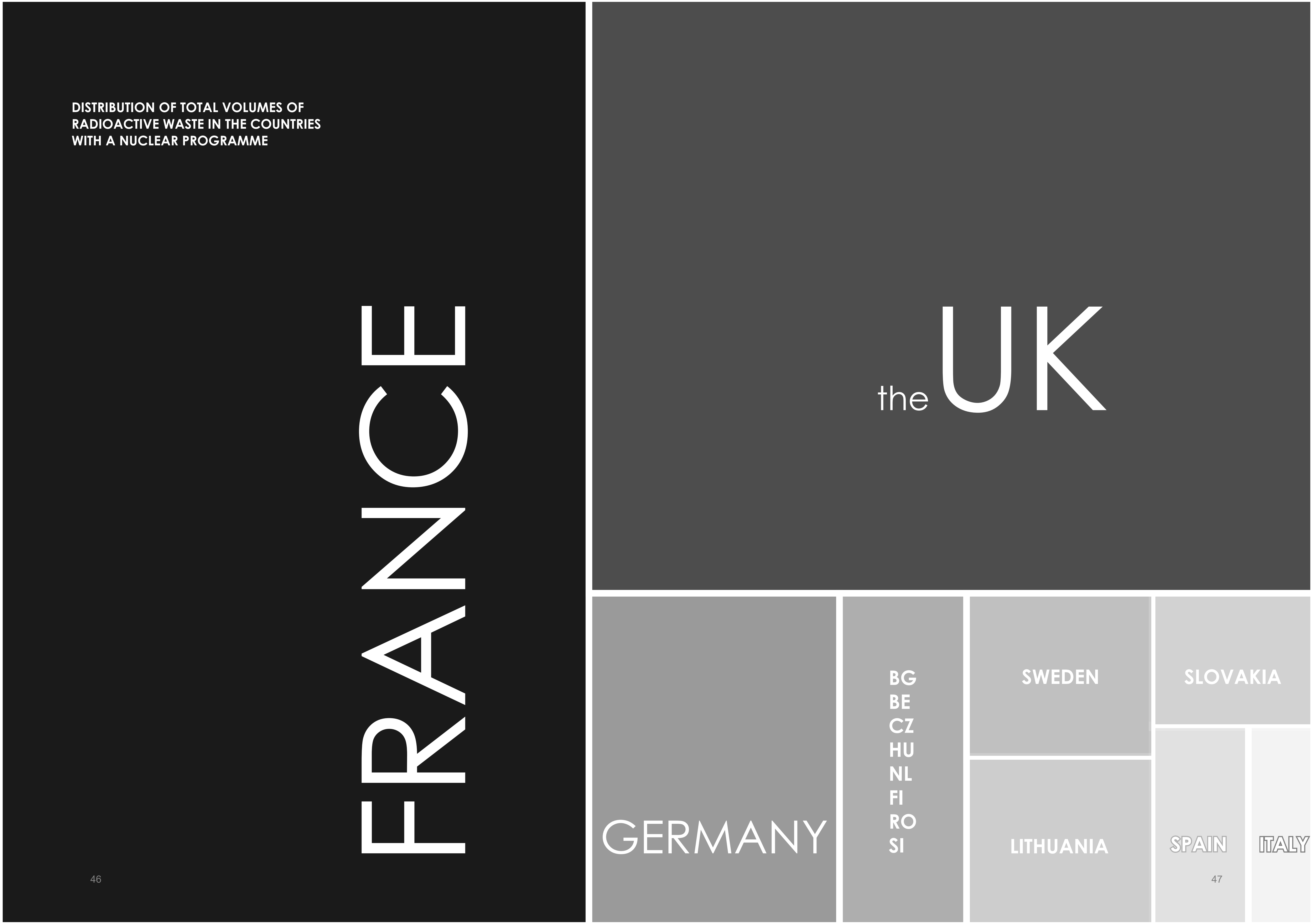
Not to mention, nowadays all the European countries recognise, albeit in different forms and limits, the right of citizens to participate in the decision-making process.[56]

EUROPE - DEPOSITS OF RADIOACTIVE WASTE



[55] Implementation of Council Directive. 2011/70/EURATOM of 19 July 2011.
[56] Sogin, "Come hanno localizzato i depositi gli altri Paesi europei?" Depozito Nazionale, last modified June 14, 2015, https://www.depositonazionale.it/estero/pagine/come-hanno-localizzato-i-depositi-gli-altri-paesi.aspx.

DISTRIBUTION OF TOTAL VOLUMES OF RADIOACTIVE WASTE IN THE COUNTRIES WITH A NUCLEAR PROGRAMME



3.3 Non-radiological aspects of the radioactive waste repository

> "Each level of the nuclear waste problem is mediated at another level by other problems and other systems. The drift of nuclear waste from a disposal facility is in one sense conceivable as a purely technical problem of containment design. But this realm is mediated at other levels by legislative design, by risk models, by social perceptions of need, by various ideas of liability and its limits, and so on. Since the formal characteristics of each of these systems are different—presupposing different ideas, different criteria for what would count as evidence - there would seem to be no way to optimize for a solution without having either an enormously elaborate model of the relevant systems and their interaction(s), or—and perhaps in any case - endeavoring to make a viable and working reduction of the complexity involved in order to consider only those interactions felt to be relevant."[57]

As stated above, radioactive waste produced nowadays is going to present a threat to all beings and the environment for many years after this generation disappears.[58] Such kind of long-term legacy (for both LLW and HLW) usually involves ethical questions. A wide range of socio-economic and other non-radiological impacts, such as equal rights, peaceful coexistence, freedom of speech, the matter of society's well-being, may arise during the life cycle of the repository.[59] "The social and institutional conflicts involved in nuclear waste disposal must be democratically resolved for the disposal programme to ultimately succeed."[60] Consequently, also justice towards future generations has become a heart of a debate because the indeterminacy of the future is especially relevant when the topic concerns a heritage, which is toxic.[61] This means that our generation owes to or projects upon future generations. Besides, "[...] this sense of responsibility is not solely concerned with keeping radioactive waste away from human beings at all costs, but also to allow future generations to make their own informed decisions and potentially create new meanings and values surrounding nuclear waste, which may be fundamentally different from our present understandings."[62]

[57] Peter C. Van Wyck, *Signs of Danger: Waste, Trauma, and Nuclear Threat* (Minneapolis and London: University of Minnesota Press, 2004), 6.
[58] Alan Marshall, "The Social and Ethical Aspects of Nuclear Waste." *Electronic Green Journal* 1, no. 21 (2005): 17.
[59] Gustav Wollentz, Sarah May, Cornelius Holtord and Anders Högberg, "Toxic heritage: Uncertain and unsafe" in *Heritage Futures. Comparative Approaches to Natural and Cultural Heritage Practices*, eds. Rodney Harrison, Caitlin DeSilvey, Cornelius Holtorf, Sharon Macdonald, Nadia Bartolini, Esther Breithoff, Harald Fredheim, Antony Lyons, Sarah May, Jennie Morgan, Sefryn Penrose, Anders Högberg, Gustav Wollentz (London: UCL Press, 2020), 299.
[60] Barry D. Solomon and Diane M. Cameron, "Nuclear waste repository siting: An alternative approach." *Energy Policy* 13, issue 6 (1985): 564-565.
[61] Gustav Wollentz et al., "Toxic heritage: Uncertain and unsafe" in *Heritage Futures. Comparative Approaches to Natural and Cultural Heritage Practices*, eds. Rodney Harrison et al. (London: UCL Press, 2020).
[62] Ibid., 306.

At the same time, there are statements regarding the issue that future generations have to undertake responsibility for their own willful actions.[63] Considering the fact that society is always developing and progressing scientifically, economically and technologically, some adepts claim that the current generation does not have to be in a hurry to invent a solution, but rather to leave the responsibility on the next generation. However, as the radioactive material by its very nature is unstable, so is the future: there is a huge uncertainty on what the future holds, especially, in terms of economy, demography and natural resources. It signifies that we should not rely on future generations but rather, take full responsibility and undertake the actions by now.

The unpredictability of the future concerns also the risks represented by the nuclear waste repository. The probability of the release of radioactive material into the environment is only one type of risk. The risk of a larger scale is an unintentional and intentional human intrusion into the repository. As Lynch pointed out "[b]esides the geological security, one must consider of the course of time the possibility of an inadvertent malicious disturbance of the deposits, by persons or creatures of nature and motives unknown."[64] Therefore, a question mark hangs over marking the territory: whether we should simply bury and forget, or whether the territory should be marked.[65]

Unintentional intrusion is possible when in search of natural resources; however, the intentional intrusion demands special attention, as we cannot foresee whether nuclear waste will be interpreted, perceived and treated as *waste* in the future: the material can be used for nuclear weapons or 'dirty bombs', etc.[66] Both scenarios can lead to fatal consequences. On the grounds of this, some experts state that probably we should just bury radwaste and forget about it. They claim: "the ancient tombs that have survived infact the longest, are the ones that have remained hidden the longest."[67] However, segregation and secrecy only work within limits, as if they fail, they fail completely. As we know from the past, it seems unlikely that future generations will be

[63] Mikael Karlsson and Johan Swahn, "Nuclear Waste, Risks and Sustainable Development." in *VALDOR 2006. VALues in Decisions on Risk. Proceedings*, ed. Kjell Andersson (Stockholm: Congrex Sweden AB/Informationsbolaget Nyberg & Co, 2006), 260.
[64] Kevin A. Lynch, *Wasting Away: An Exploration of Waste: What It Is, How It Happens, Why We Fear It, How To Do It Well* (San Francisco, CA: Sierra Club Books, 1990), 75.
[65] OECD/Nuclear Energy Agency, *Radioactive Waste Management and Constructing Memory for Future Generations. Proceedings of the International Conference and Debate, 15-17 September 2014 Verdun, France*. Radioactive Waste Management, NEA No. 7259 (Paris: OECD Publishing, 2015); Tim Maly, "A Message to the Future." *Works That Work*, issue 3 (2014).
[66] Gustav Wollentz et al., "Toxic heritage: Uncertain and unsafe" in *Heritage Futures. Comparative Approaches to Natural and Cultural Heritage Practices*, eds. Rodney Harrison et al. (London: UCL Press, 2020), 303.
[67] Tim Maly, "A Message to the Future." *Works That Work*, issue 3 (2014): 53.

ignorant if they discover such kind of operational facility. For instance, in 2011, satellite imagery of Egypt revealed 17 lost pyramids and thousands of tombs. Naturally, they became targets for excavation and scientific investigation.[68] Considering the facts stated above, the best commonly accepted solution is passing knowledge to future generations onwards through records in responsible institutions, markers and other tools.

Another principal concern is that the negligence and hubris in the history of 'nuclear' have developed suspicion rather than assurance and confidence among citizens.[69] Radioactivity, while surely being hazardous to the environment and all living organisms is not well understood by most people. Serious issues in addressing radioactive waste management at early stages paved the way for the atmosphere of fear and dread. The depth of this revulsion could be observed in studies where people were asked to describe their first association when they hear the phrase 'underground nuclear waste repository'. The most frequent answers were 'danger, death, and pollution'.[70] As a result, "it has proven to be of utmost importance to build a sense of public trust in the capability of the responsible institutions to manage the repositories and contain the nuclear waste without any additional threats to present and future generations."[71] Otherwise, people will apparently oppose the construction of the repository as in the case of Yucca Mountain Nuclear Waste Repository in Nevada, the USA.[72]

3.3.1 A message for future generations

Preservation of records, passing knowledge and memory to future generations is key factor in the management of radioactive waste. It can take different forms, such as particular designs or markers on a landscape, regular rituals (religious, seasonal, academic) and continuous story-telling.[73] The institutions specialising in heritage and memory preservation and transmission, such as national archives, museums, libraries, universities and academies will support this mission. Furthermore, art and stories most likely will also assist in this task, because such tools provide compelling metaphors for radioactive waste. As we have already learned from the past, art and stories are ancient and powerful crafts to pass on information to the future. "The link between the long-term preservation of art and the management of radioactive waste helps people to visualise and trust the concept of long-term management."[74] In this way, a real connection with the cultural heritage is developing. "The warning system must be durable enough to reach future civilizations, intelligible enough to be understood by them, and credible enough to be taken seriously."[75]

Furthermore, we should also consider the fact that the information is constantly decaying over time. Therefore, "[o]nly through approaching nuclear waste management as an ongoing and continuous process involving several actors in society, institutional and non-institutional, will there be a possibility of keeping the memory of the geological repositories alive [...]."[76] There should be different provisions with the aim to 'embed' the project into the life of society. Undeniably, communication with the public is a key and integral part of memory preservation.

Erik Van Hove claims that there are some possibilities in transmitting a living memory, such as "add[ing] value to a repository in a way that it becomes something to be proud of or has a local use. This can be at the cultural level or recreational or educational and even ecological."[77] For instance, French Radioactive Waste Management Agency (ANDRA) proposes guided visits all year long; organises exhibitions and events related to memory preservation and transmission; develops partnerships with associations and scientific societies whose missions deal with memory; has established a think tank on memory. The latter is composed of local representatives and residents, artists, as well as former employees of ANDRA and other nuclear facilities. These authorities meet several times a year and reflect on memory preservation in terms of local history, education, art and rituals.[78]

[68] Ibid., 54.
[69] Arne Jungjohann (ed.), *The World Nuclear Waste Report 2019: Focus Europe* (Großbeeren: Arnold Group, 2019), 3.
[70] James Flynn, Roger Kasperson, Howard Kunreuther And Paul Slovictime, "Time to Rethink Nuclear Waste Storage." *Issues in Science and Technology* 8, no. 4 (1992): 44.
[71] Gustav Wollentz et al., "Toxic heritage: Uncertain and unsafe" in *Heritage Futures. Comparative Approaches to Natural and Cultural Heritage Practices*, eds. Rodney Harrison et al. (London: UCL Press, 2020), 297.
[72] Paul Slavic, Mark Layman, and James H. Flynn, "Perceived Risk, Trust, and Nuclear Waste: Lessons from Yucca Mountain." *Environment: Science and Policy for Sustainable Development* 33, no. 3 (1991).
[73] OECD/Nuclear Energy Agency, *Radioactive Waste Management and Constructing Memory for Future Generations. Proceedings of the International Conference and Debate, 15-17 September 2014 Verdun, France*. Radioactive Waste Management, NEA No. 7259 (Paris: OECD Publishing, 2015), 99.
[74] Ibid., 55.
[75] Tim Maly, "A Message to the Future." *Works That Work*, issue 3 (2014): 53.
[76] Gustav Wollentz et al., "Toxic heritage: Uncertain and unsafe" in *Heritage Futures. Comparative Approaches to Natural and Cultural Heritage Practices*, eds. Rodney Harrison et al. (London: UCL Press, 2020), 306.
[77] OECD/Nuclear Energy Agency, *Radioactive Waste Management and Constructing Memory for Future Generations. Proceedings of the International Conference and Debate, 15-17 September 2014 Verdun, France*. Radioactive Waste Management, NEA No. 7259 (Paris: OECD Publishing, 2015), 106.
[78] Ibid., 18.

4

THE ITALIAN CASE:
THE PROPOSAL OF SOGIN

4.1 The general arrangement of the National Repository

The National Repository, which will house only radioactive waste produced in Italy[79], will represent a near-surface environmental infrastructure. After its construction it will be possible to definitively arrange radwaste, to decommission dozens of temporary deposits, where it is stored now; and, thus, to close the Italian nuclear cycle.

The National Repository will consist of the facilities for the disposal of VLLW and LLW and temporal storage of ILW and HLW. The latter will be transferred to a geological repository suitable for their definitive accommodation. Together with the National Repository, the Technological Park will be designed. It will represent a centre for applied research and training in the field of nuclear decommissioning, radwaste management, radiation and environmental protection. It will provide a real integration with the economic and research system, further contributing to the sustainable development of the territory in which it will arise.

Out of the assigned 150ha, 110ha are dedicated to the National Repository and 40ha - to the Technological Park. Within 110ha dedicated to the National Repository, an area of about 10ha is assigned for the disposal facility of VLLW and LLW; and an area of about 10ha – for the High Activity Storage Complex, which consists of four buildings.[80] The remaining 90ha are destined to the waste management plants and other service buildings, which will be described further in this paper. The Technological Park includes a study and experimentation centre, an environmental laboratory and a training school.[81]

The National Repository is estimated to host about 95,000m^3 of radioactive waste. VLLW and LLW occupy 78,000m^3, out of which approximately 50,000m^3 derive from the operation and decommissioning of nuclear power plants, and about 28,000m^3 - from scientific research, medical and industrial sectors. The rest 17,000m^3 are ILW and HLW, a small part of which - about 400m^3 - comes from residues left from the reprocessing of the fuel carried out abroad and from non-reprocessable fuel. Out of approximately 78,000m^3 of waste, 33,000m^3 have already been produced, while the remaining 45,000m^3 will be produced in the next 50 years (10 from today until entry into operation).[82]

Note[1]:

It must be noted that about 99% of the spent fuel used in the four decommissioned national nuclear power plants is no longer found in Italy. Over the years it has been sent to France and Great Britain, where it has undergone reprocessing. The reprocessing residues, according to what is established by the agreements stipulated in compliance with EU and international standards, will return to our country as radioactive waste.

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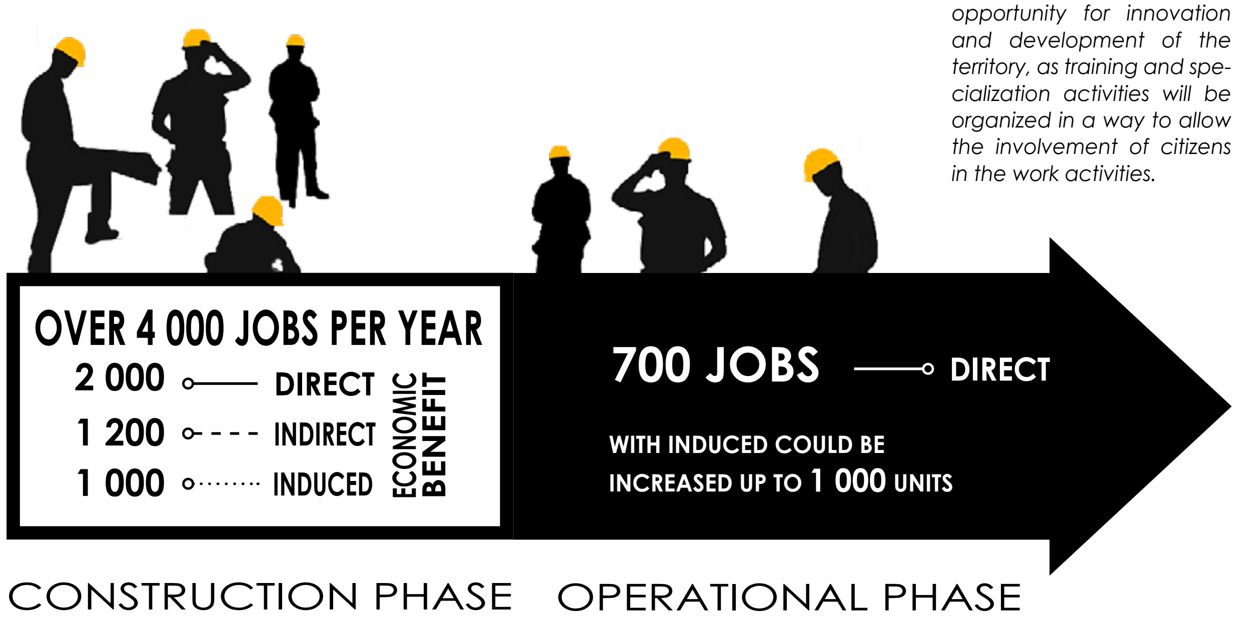
[79] Legislative decree no. 45 of 2014.
[80] Sogin, *Progetto Preliminare DNPT - Executive Summary*. Relazione Tecnica. Elaborato DN GE 00045 (2020), 11-12.
[81] Sogin, *Parco Tecnologico – Indicazioni di massima delle strutture e dei potenziali benefici al Territorio*. Relazione Tecnica. Elaborato DN PT 00089 (2020), 13.
[82] Sogin, *Stima dei rifiuti radioattivi da conferire al Deposito Nazionale*. Relazione Tecnica. Elaborato DN SM 00007 (2020).

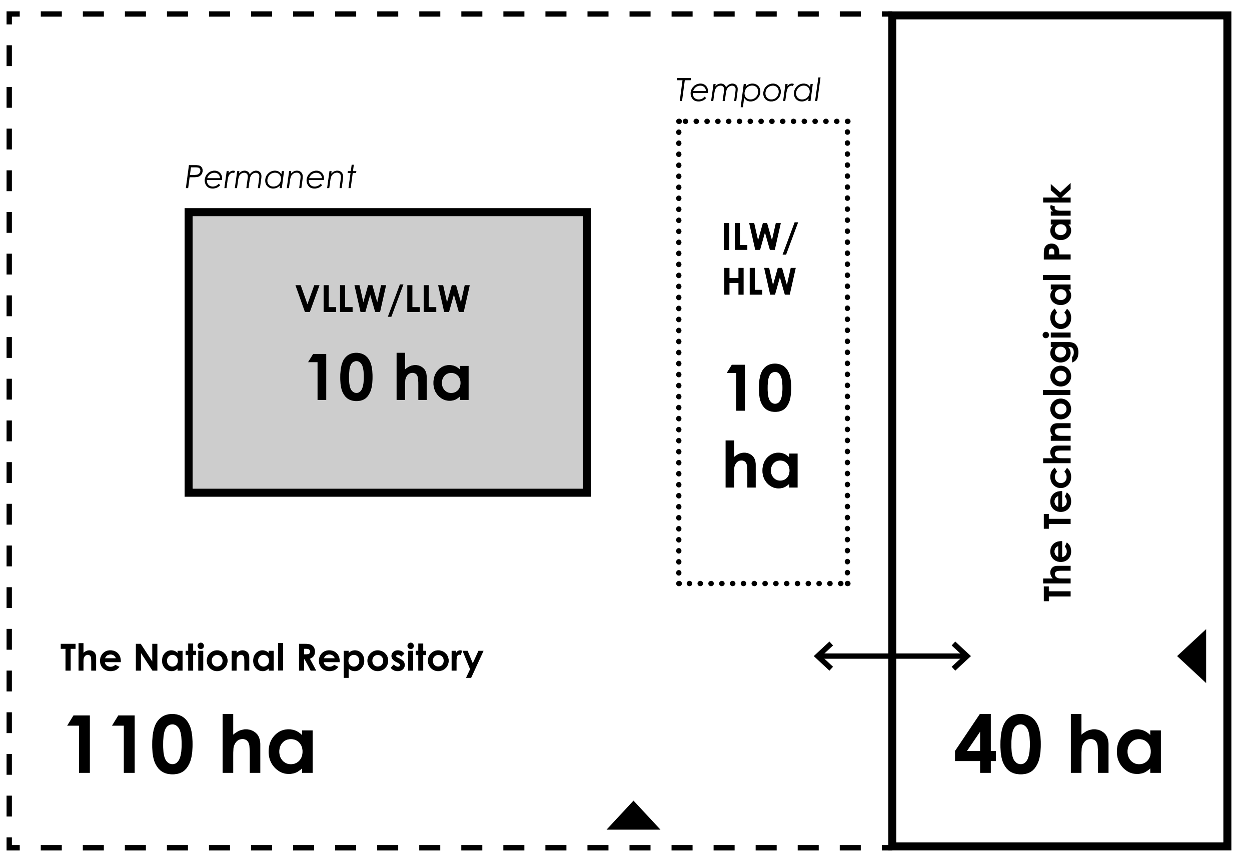
EMPLOYMENT OPPORTUNITIES / ECONOMIC BENEFIT



Note[2]:

The presence of the National Deposit will provide an opportunity for innovation and development of the territory, as training and specialization activities will be organized in a way to allow the involvement of citizens in the work activities.

GENERAL ARRANGEMENT OF THE TERRITORY, 150HA



THE NATIONAL REPOSITORY 110 ha

LOW ACTIVITY WASTE MANAGEMENT

QUALITY CONTROL PLANT
- verification of the quality standards of the products and the related radiochemical analysis.

WASTE TREATMENT PLANT
- the treatment and conditioning of solid radwaste produced during the operation of the Deposit.

MODULES PRODUCTION PLANT
- a building dedicated to construction of containers (modules) in special concrete.

MODULES PACKAGING PLANT
- the loading of artifacts inside the modules.

CELLS PRODUCTION PLANT
- a set of materials, of the premises and of the systems that permit the construction of the cells.

MODULES DISPOSAL UNIT
- a set of cells. At the end of its filling, the USM will be protected by a multilayer cover, as an additional barrier.

ARCHIVE; VISITORS CENTRE

HIGH ACTIVITY WASTE MANAGEMENT

HIGH ACTIVITY STORAGE COMPLEX - a group of buildings dedicated to the storage of medium and high activity waste pending the availability of a geological repository for their definitive accommodation

AUXILARY STRUCTURES AND SERVICES

ENTRANCE	HEALTH SECTOR	WEATHER STATION	FIRE BRIGADE
OFFICES	LABORATORIES	TRAINING CENTRE	SECURITY

4.2 A multi-barrier system for VLLW and LLW

According to SOGIN[83], the National Repository will be equipped with a structure with engineering barriers and natural barriers placed in series for the containment of radioactivity, designed on the basis of the best international experiences and according to the IAEA standards and the ISIN control body. The protective engineering barriers will be built with specific reinforced concrete conglomerates, guaranteed to confine the radioactivity of the waste for the time necessary for its decay to levels comparable to the ranges of variation of environmental radioactivity. “This general approach has been technically elaborated and adopted for all types of disposal facilities [...]. The use of multiple barriers provides reasonable assurance of adequate performance of a repository system and thus, its ability to achieve the protection of radioactive waste disposal.”[84]

The engineering barriers of the National Repository and the characteristics of the site where it will be built will guarantee the isolation of radioactive waste from the environment for over 350 years until its decay to levels that are negligible for human health and the environment.

In detail, VLLW and LLW, conditioned with cement matrix will be transported to the National Repository in metal containers called ‘the artifacts’, which represent the first barrier. Subsequently, these containers will be inserted (2.1) and cemented (2.2) in modules of special concrete - second barrier. Modules will in turn be permanently placed in cells of reinforced concrete - third barrier. Each cell is designed to host 240 modules. Once the filling is complete, in total 90 cells will be sealed and lined with a fourth barrier - an artificial hill, which will represent further protection and will allow harmonization of the infrastructure with the surrounding environment. The geological characteristics of the site, identified based on the criteria formulated by the control body ISPRA (now ISIN) in the Technical Guide n.29, and recognized by the IAEA, represent a further barrier to the possible dispersion of radionuclides and therefore a further guarantee of integrity and safety of the deposit over time. A drainage system installed under each cell will ensure the collection and treatment of water deriving from any infiltrations or condensation inside the cells.

[83] Sogin, *Progetto Preliminare DNPT - Executive Summary*. Relazione Tecnica. Elaborato DN GE 00045 (2020), 14-19.
[84] International Atomic Energy Agency, *Disposal Aspects of Low and Intermediate Level Decommissioning Waste: Results of a coordinated research project 2002–2006*. IAEA-TECDOC-1572 (Vienna: IAEA, 2007), 21.

VLLW / LLW

1 The first barrier:
THE ARTIFACT

The artifacts are the structures, cylindrical or parallelepiped in shape, made up of metal containers and the radioactive waste inside them, already conditioned in a solid form. The chemical and physical stability allows the product to be handled and transported safely. Each barrel of waste has an identity document, applied a barcode.

2 The second barrier:
THE MODULE
(3m x 2m x 1.7m)

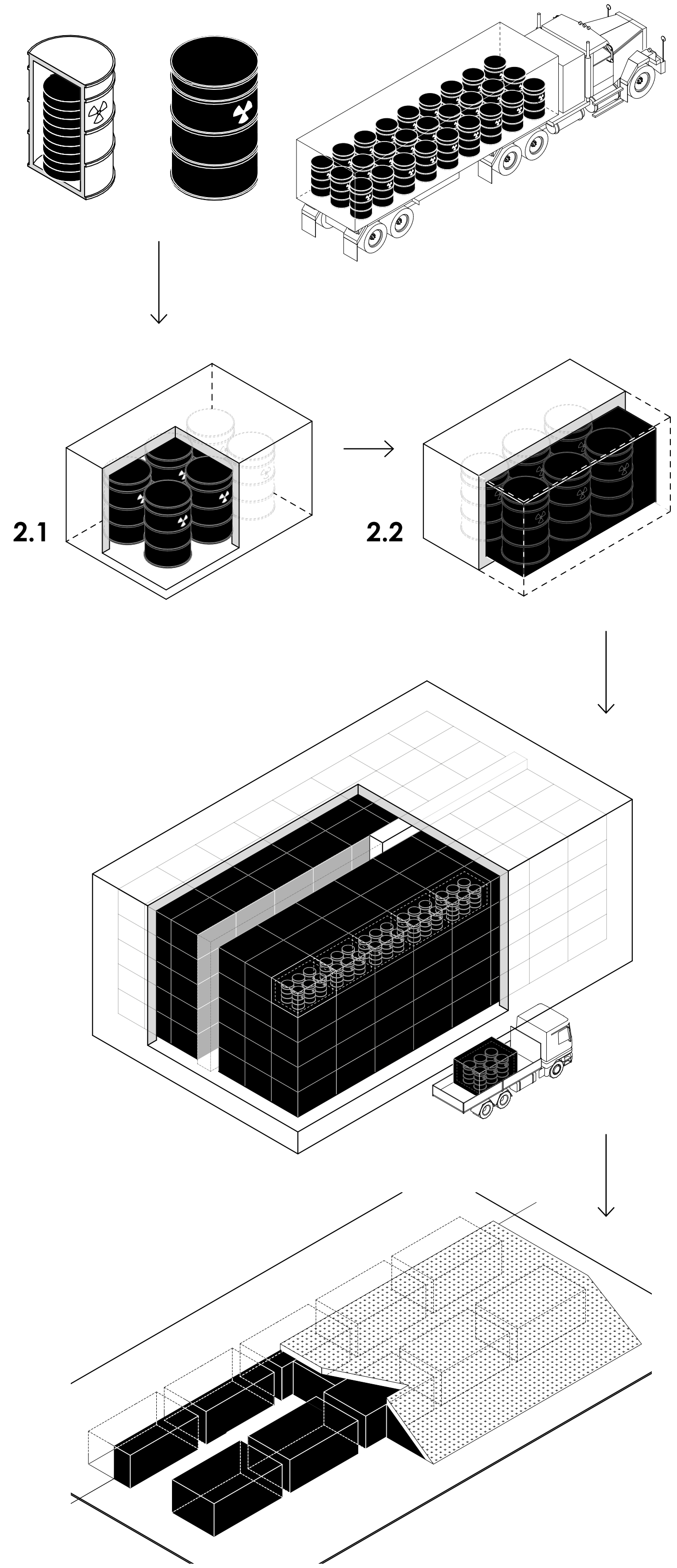
The modules, parallelepiped-shaped structures in special concrete, reinforced or fiber-reinforced, which ensure their resistance for over 350 years.

3 The third barrier:
THE CELL
(27m x 15.5m x 10 m)

The cells are the buildings in special reinforced concrete, designed to resist for at least 350 years, where the radioactive waste will be permanently placed. Within the National Repository, 90 cells will be built, organized in rows.

4 The fourth barrier:
THE MULTI-LAYER COVERAGE

The artificial hill is made with layers of different materials, for a total thickness of a few meters, in order to prevent the entry of water into the deposit, drain rainwater, isolate waste from the environment and improve the visual impact of the structure.



4.2.1 Waste Treatment Plant

In the Waste Treatment Plant (ITR)[85] the solid radioactive waste that is produced inside the Depot during its operation, such as protective clothing, gloves, and any components deriving from the maintenance of the plants are treated and conditioned. The ITR does not provide for the reception and treatment of waste produced outside the Depot.

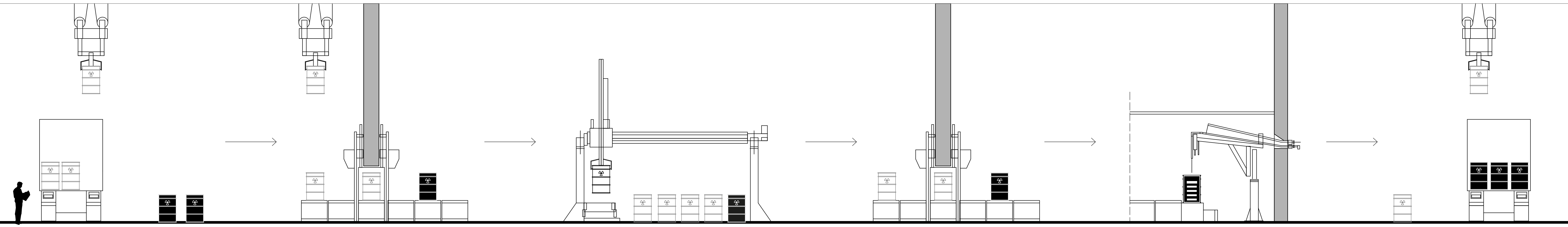
The building is organised in 5 main areas:

- 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 radioactive waste containers not yet conditioned are unloaded and subjected to physical and radiological checks before being transferred to the treatment and/or conditioning line in cement mortar.

In the treatment line, the waste is super-compacted and conditioned. In the cutting workshop, the volume reduction of large and weakly contaminated components, produced during the management and maintenance activities of the storage facilities, takes place. The parts thus obtained are subsequently packaged and immobilized with cement mortar.

The products produced by the treatment are transferred to the Modules Packaging Plant (ICM) to be incorporated into qualified reinforced concrete modules and subsequently sent to the Modules Disposal Unit (USM).



1. The arrival of the artifacts on the internal transport shuttle. Administrative control. Unloading of the compactable waste.

2. Transfer of the compactable waste to the temporary storage area.

3. The storage of compactable waste in the dedicated area.

4. Compaction of waste and selection of the compressed material for cementation. Entry of empty cylindrical containers into the storage area.

5. Incorporation of the compacted compressed material into the containers by cementation.

6. Transfer of the waste into the loading area, loading of the products on the internal transport shuttle. Transfer of the waste to the Modules Packaging Plant.

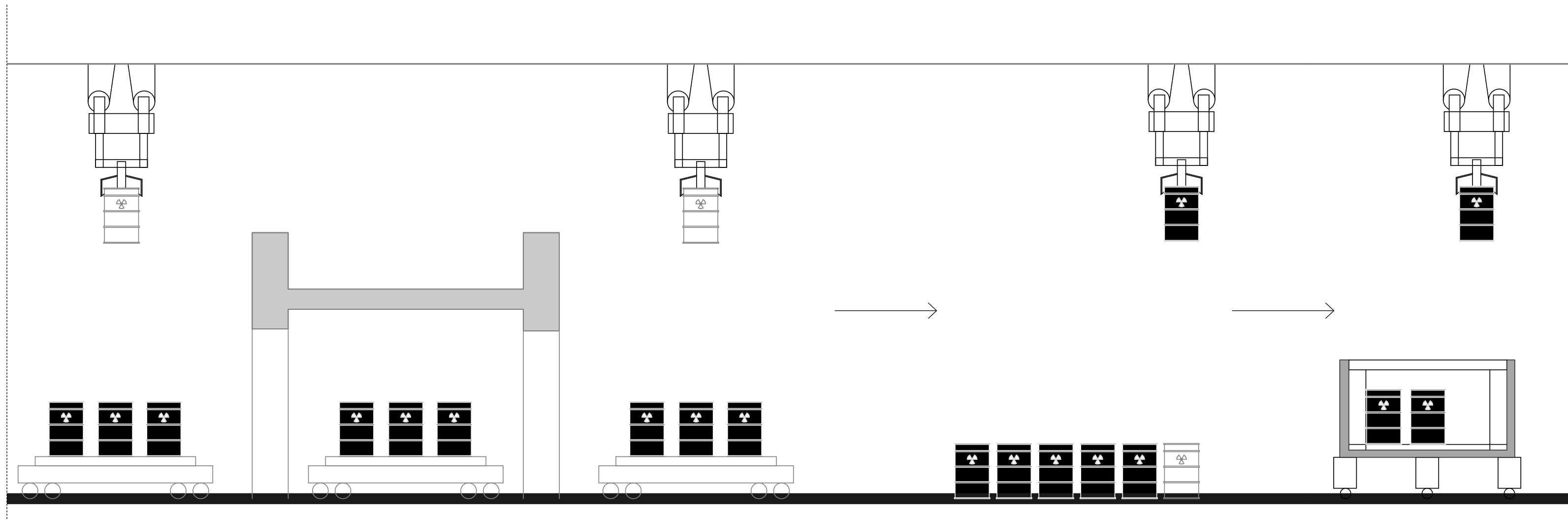
[85] Sogin, *Impianto Trattamento Rifiuti – Relazione Descrittiva Generale*. Relazione Tecnica. Elaborato DN DN 00240 (2018).

4.2.2 Modules Packaging Plant

The Modules Packaging Plant (ICM)[86] is the structure in which the artifacts of VLLW and LLW are placed in modules. The ICM fulfils 8 modules per day. No waste treatment activities are envisaged in this plant as the products arrive from the production sites ready to be packaged inside the module.

Before inserting the artifacts into the forms, the necessary checks are carried out. The checks are of three types: *administrative checks* (identification of the artifacts, verification of the data), *visual checks* (external conditions and integrity) and *direct measurements*. Once the checks have been passed, the artifacts are temporarily transferred to special areas (buffers) until they are loaded into the modules.

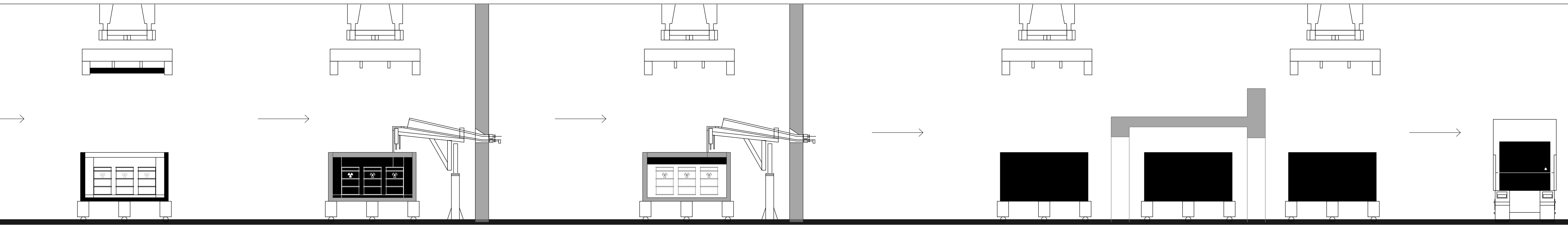
After inserting the artifacts into the modules, grouting is the next step. The modules are then closed and sealed with cement mortar and transferred to the area dedicated to the curing of the seal. Each module is registered, defining its content and position in the cell. In the end, each module is transferred to the Module Disposal Unit (USM).



1 Entry of cylindrical artifacts into the storage area

2 The buffer area.

3 The loading of the module with cylindrical artifacts.



4 Positioning of the anti floating device and the module cover

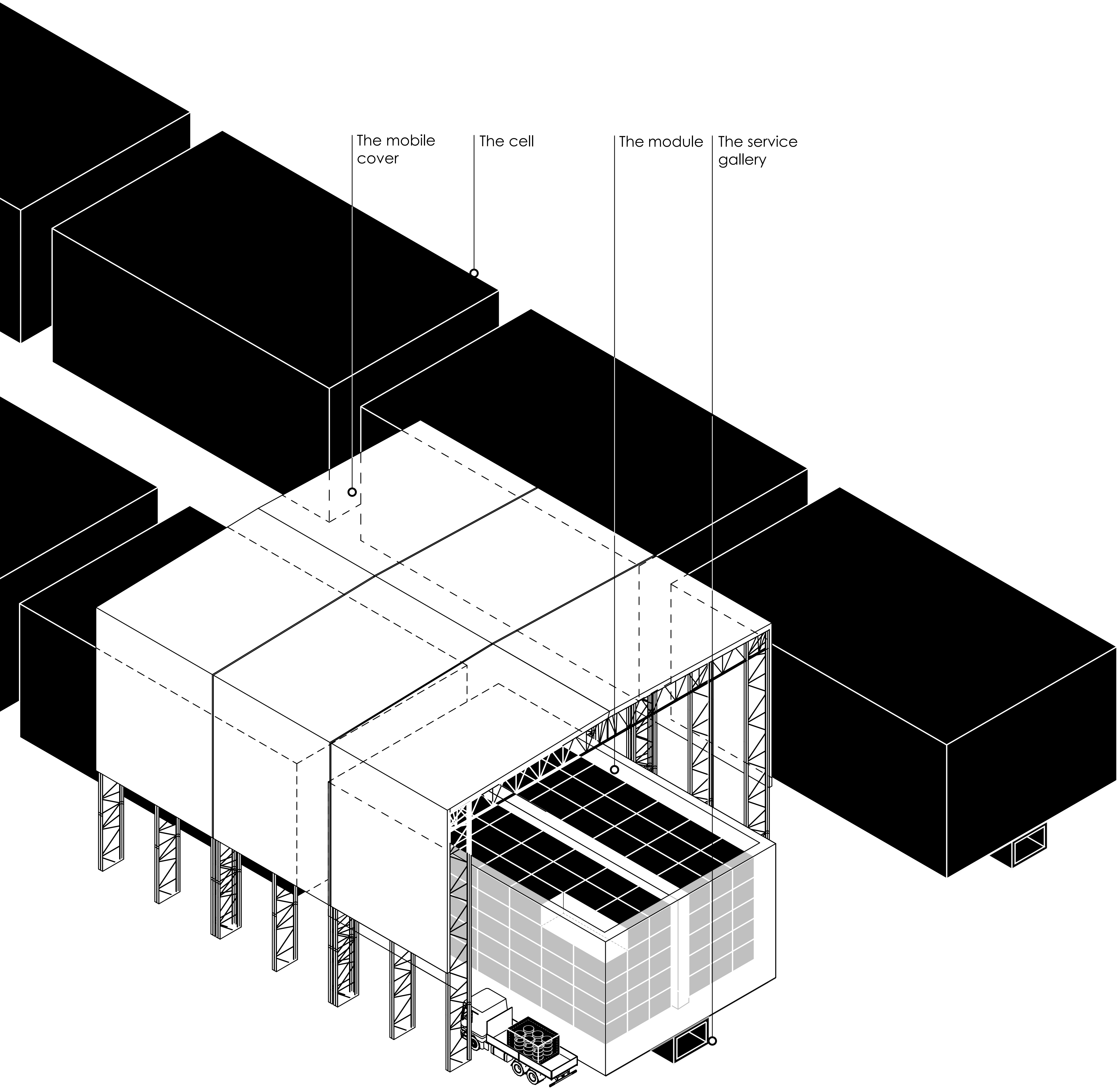
5 Grouting area (immobilization with cement mortar).

6 Sealing area

7 Modules are prepared to be transported.

8 Transportation of the module to the Module Disposal Unit (USM).

[86] Sogin, *Impianto Confezionamento Moduli – Relazione Descrittiva Generale.* Relazione Tecnica. Elaborato DN DN 00041 (2018).



4.2.3 The Modules Disposal Unit

The Modules Disposal Unit (USM)[87] is the ultimate destination for VLLW and LLW. The plant consists of a set of storage cells, which represent an independent system that can be loaded and managed without interfering with each other. Between the construction phase and the filling phase, each cell is equipped with temporary protection necessary to prevent the entry of rainwater and to protect the interior from bad weather conditions. During the filling phase, however, the temporary protection is disassembled and the cell is covered by a mobile trestle roof/crane system that can be moved on rails. It prevents the entry of rainwater and protects the entire handling and loading phase of the modules in the cells.

The structure of the mobile cover is composed of movable blocks with a length of approximately 10.5m and a width of about 31m. They represent a metal structure fixed to the ground, made of uprights and trusses with longitudinal braces. Such blocks can stay attached yet remain independent of each other. One cell is covered by 4 structural blocks, of an overall length of about 43m. The modules are lifted and arranged inside the cell on 5 levels (6 x 8 x 5) through the gantry crane. Once the filling of a single cell has been completed, the inert material of suitable particle size (backfill) is inserted into the space between the modules. Then it is closed with prefabricated reinforced concrete elements, the sealing is cast and finally, the cell is made waterproof. After the filling of a cell is finished, the same blocks of mobile structure can move in the longitudinal direction along special tracks and position themselves on the next cell.

Below each row of cells, there is a technical service gallery, which can be inspected, used for housing the collectors for collecting any infiltration water in the cells and the rainwater drainage collector collected by the cells still empty during the pre-operational phase (empty cells). The galleries are connected to each other through a back gallery that houses the pipes for sending water to the tanks of collection from which it is then downloaded. The tunnels are ventilated to allow for replacement air before an inspection.

[87] Sogin, *Unità Smaltimento Moduli – Relazione Descrittiva Generale*. Relazione Tecnica. Elaborato DN DN 00068 (2018).

4.3 A temporary storage solution for ILW / HLW

As mentioned previously in this paper, HLW, and in particular, long-lived waste, requires hundreds of thousands of years for the radioactivity contained in them to decay naturally at levels no longer dangerous for humans and the environment. Accordingly, disposal cannot be relied upon, as in the case of VLLW and LLW, to artificial engineering barriers that can last for centuries. Alternatively, it is mandatory to consider deep geological formations, stability of which can be guaranteed for such a long period.

Different types of ILW/HLW produced in the nuclear sector, undergo different conditioning and packaging processes according to their physical, chemical and radiological characteristics. Therefore, the final containers differ in both geometric and functional characteristics. For the conditioning of solid waste with greater radioactive content, special, prismatic and cylindrical containers named “high integrity” are used. They ensure high resistance and sealing characteristics. Liquid and other types of waste with similar characteristics, which are conditioned through solidification processes, arrive in cylindrical containers.

HLW consisting of irradiated fuel and residues of reprocessing of the fuel will be delivered to the CSA within the *cask*. It is a metal container made of special materials and has specific structural characteristics that ensure shielding and confinement in all possible normal and accidental scenarios. During transportation, the cask will be equipped with impact absorbers on the top, at the base and on the coupling pins in order to protect all the components necessary to guarantee strength, sealing and handling requirements. Such equipment will only be removed after the cask is transferred by the transport carrier to the reception area in the High Activity Storage Complex.[88]

[88] Sogin, *Complesso Stoccaggio Alta attività - Relazione descrittiva generale.* Relazione Tecnica. Elaborato DN DI 00018 (2018).

ILW / HLW

THE CASK

(3m x 2m x 1.7m)

Vitrified and compacted waste is conditioned inside canisters (cylindrical stainless steel containers of about 180l) inserted and stacked inside the cask. It guarantees high safety standards both for its storage and transportation. It is capable of withstanding extreme mechanical and thermal stresses.

STACKABLE METAL RACKS

(1.9m x 1.9m x 1.4/1.5.m)

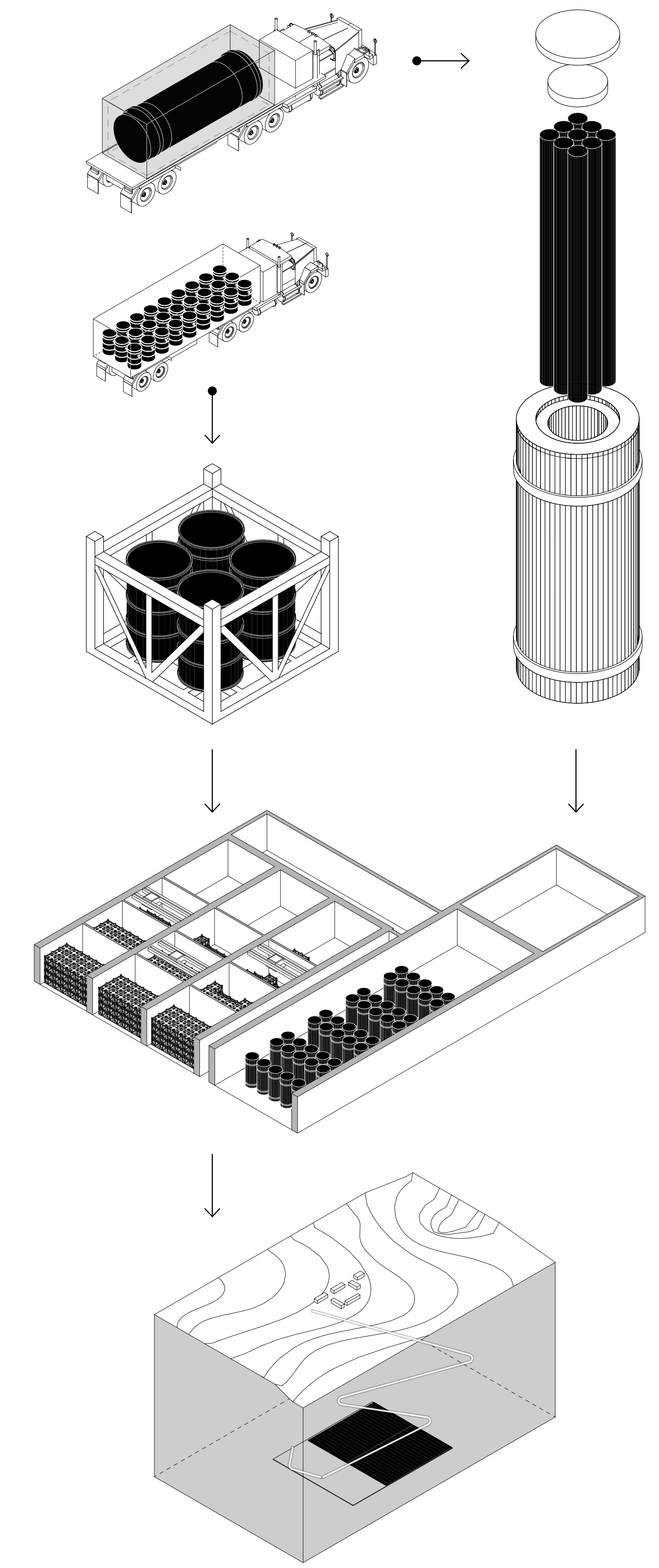
The non-shielding cylindrical containers are stored at the CSA in special stackable racks that can contain all types of containers. These racks can hold 4 containers. They are stored in the naves of maximum 5 stacking levels. The shape of the rack guarantees the stability of the stack against overturning.

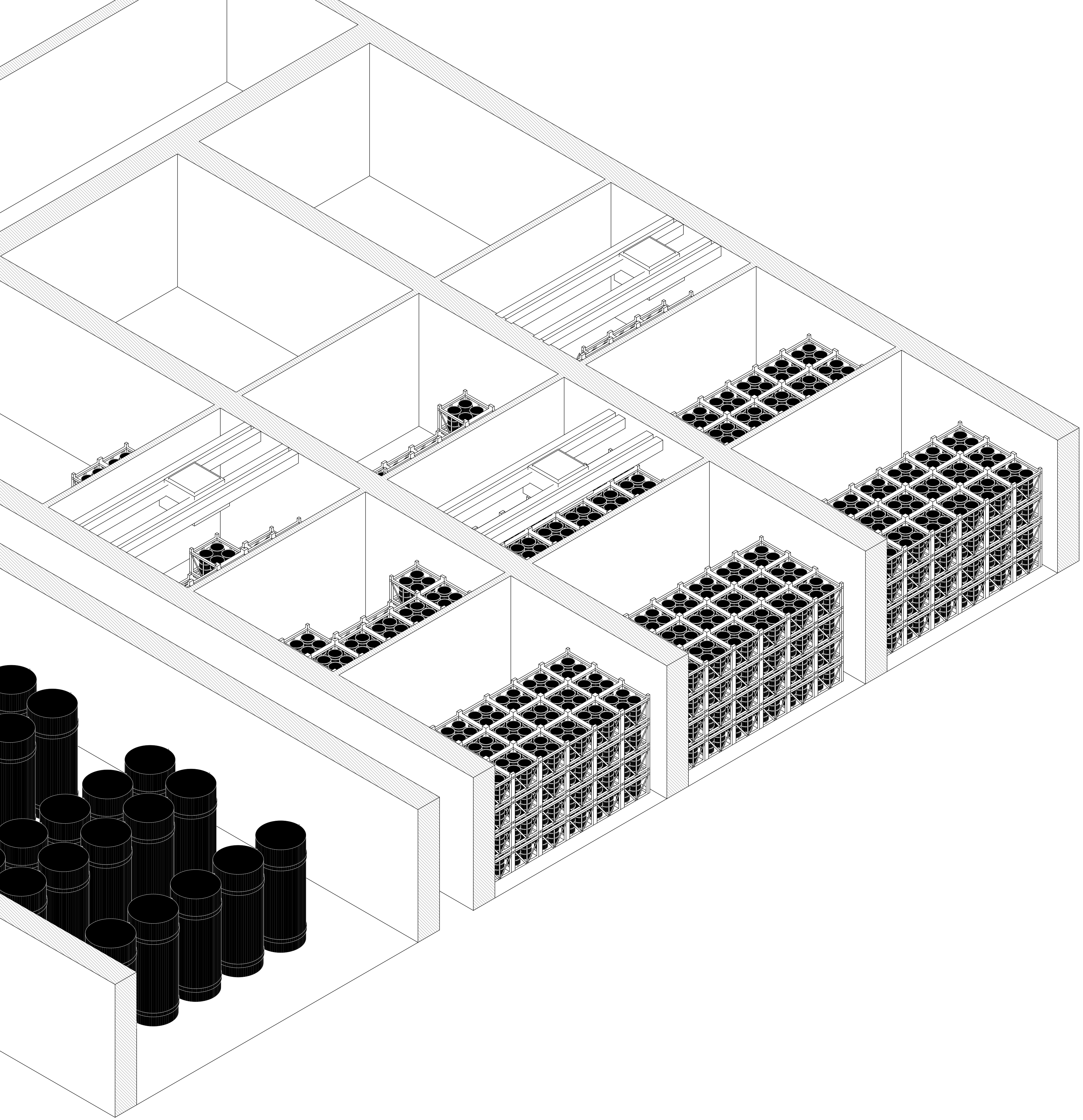
THE TEMPORAL STORAGE

The containers/cask having successfully passed all the required checks, are transferred to the areas for temporary storage. The CSA is a structure designed for ILW/HLW storage for a period of 50 years. Afterwards it will be transferred to a deep geological deposit for permanent disposal.

DEEP GEOLOGICAL DISPOSAL

The geological disposal is a structure for the final settlement of high activity waste. It is built underground at a considerable depth (several hundred meters), in a stable geological formation (clays, granites, rock salt).





4.3.1 High Activity Storage Complex

High Activity Storage Complex (CSA)[89] is estimated to accommodate the entire Italian inventory of ILW and HLW. The waste comes in conditional form (with or without matrix), in prismatic and cylindrical containers, qualified for an appropriate duration of storage. The structures, systems and components of the CSA are designed to withstand a series of natural and anthropogenic accidents, such as earthquakes, extreme climatic conditions, air impact, fires, explosions. The preliminary design of the CSA takes into account all the technical and operational requirements linked to different types of waste to be stored and related artifact/cask to be managed for temporary storage. The complex is spread over four separate buildings, each of which is structured on three operational and functionally separate naves. Only one of the buildings has a fourth aisle dedicated to the temporary storage of cask. Storage aisles are connected to each other by an access corridor for the entrance of the artifacts. Each nave is equipped with different systems according to the artifacts it houses. Each aisle can accommodate several types of containers, however, in order to optimize storage volumes, the types considered at most are two per nave. The naves are designed in a way to ensure compliance with the following criteria:

- handling the artifacts through remote systems (e.g. overhead cranes)
- inspection of the artifacts through specific remote systems or with the presence of the operator near the building, of allowed.
- screening of the radiation towards the outside of the building

The cask nave consists of a room (65m x 28m) that is non divided by any septum. The height of the room is the same as the typical nave, equal to 16m. The casks are positioned vertically at a sufficient distance to allow thermal dissipation by natural convection. The distribution includes 5 rows each consisting of 9 casks. Furthermore, the nave is equipped with openings at the roof for natural air expulsion.

[89] Ibid.

5 THE LOCALIZATION

5.1 Siting criteria of a near-surface disposal facility for VLLW and LLW

The localization of the National Repository and the Technological Park ensures the integration of technical and scientific aspects, as well as involvement and citizen participation.[90] From a technical point of view, localization, or siting, is the process of selecting a site based on eligibility assessments that consider site characteristics, the design solutions and the socio-territorial context. The siting process for a radioactive waste repository is crucial to the definition of the technical and design choices necessary to guarantee maximum safety for citizens and the environment.

The criteria elaborated by the control body ISPRA (today ISIN) in line with IAEA standards, represent a set of fundamental requirements and evaluation elements to arrive, with a progressive level of detail, in identifying the potentially suitable areas for hosting the National Repository.[91] The criteria have been formulated to identify areas where the integrity and safety of the National Repository are guaranteed within time.

The criteria developed by the control body are divided into:

- **15 Exclusion Criteria (CE) -** to exclude areas of the national territory whose characteristics do not allow to guarantee full compliance with safety requirements. The application of the exclusion criteria leads to the identification of 'potentially suitable areas.' It is carried out through checks based on regulations, data and technical knowledge available for the entire national territory, also through the use of GIS-Geographic Information Systems and, in some cases, databases managed by entities public.

- **13 Investigation Criteria (CA) -** to evaluate the areas identified following the application of the exclusion criteria. Their application can lead to the exclusion of further portions of territory within the 'potentially suitable areas' and the identification of the sites of interest. It is carried out through specific investigations and assessments on the areas that have not been excluded.

[90] Legislative Decree no. 31 of 2010.
[91] Technical Guide no. 29

Exclusion Criteria:
The following areas shall be excluded:

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:
In the siting phase the following aspects shall be assessed:

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 (tectonic and/or isostatic)
CA3	Geological-morphostructural setting and presence of lithotypes with vertical and lateral variation
CA4	Presence of endorheic type river basins
CA5	Presence of accelerated erosion phenomena
CA6	Weather and climatic conditions
CA7	Physical and mechanical parameters of the soil
CA8	Hydrogeological parameters
CA9	Chemical parameters of soil and groundwater
CA10	Habitats, animal and plant species of conservation importance, as well as geosites
CA11	Agricultural production of outstanding quality and places of archaeological and historical interest
CA12	Availability of primary transport infrastructures
CA13	Presence of relevant or strategic critical infrastructures

5.1.2 The map of potentially suitable areas for the Italian National Deposit

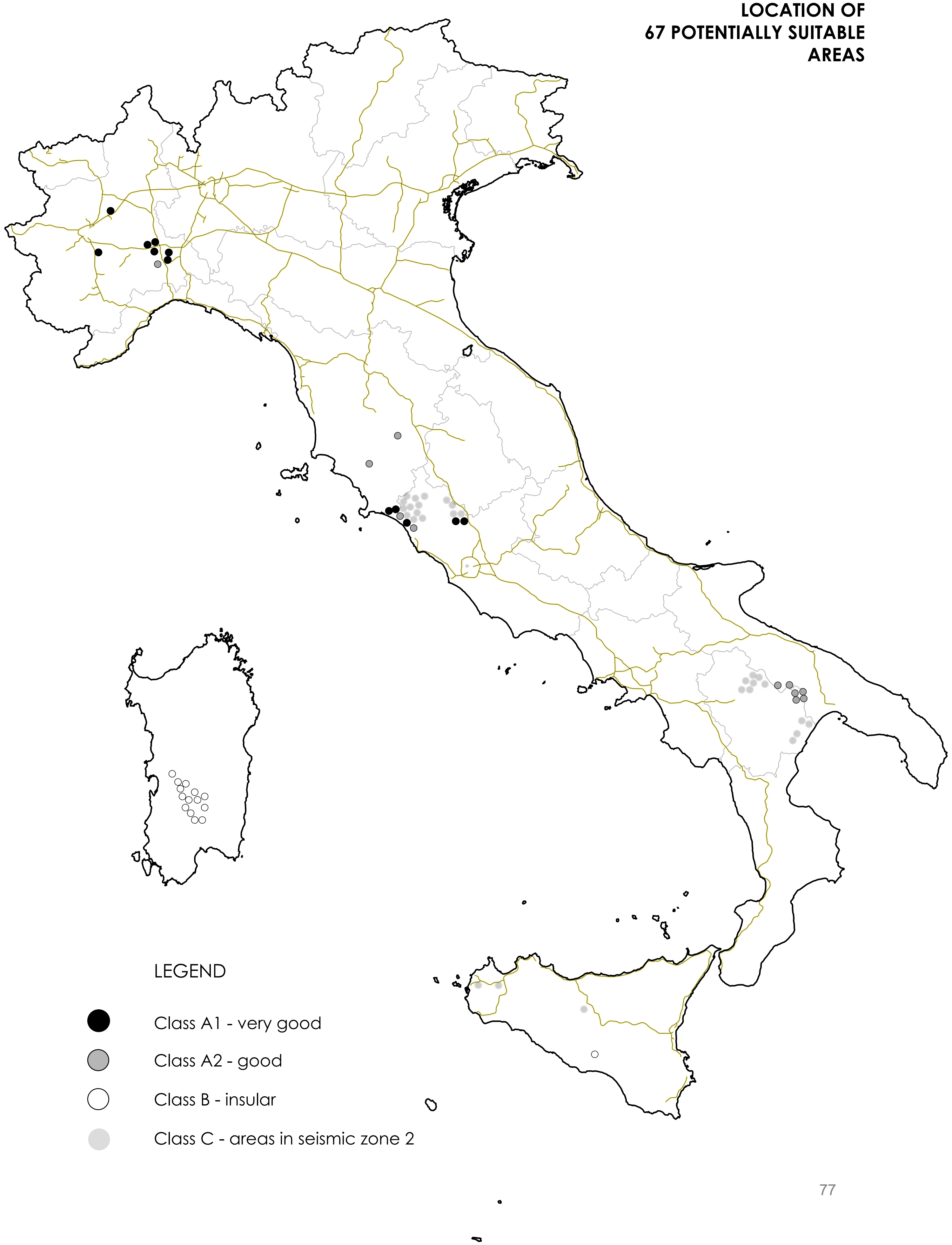
The proposed National Charter of Potentially Eligible Areas (CNAPI) constitutes the first step in a shared and participatory process. The process of applying the criteria mentioned above made it possible to identify 67 potentially suitable areas.[92] It will lead to identifying the unique site at a national level, where the National Repository and Technological Park can be built.

An order of suitability of these areas is proposed by grouping them into four classes with decreasing suitability order (A1, A2, B and C), considering socio-environmental, logistical and seismic classification aspects of an administrative nature.[93] This order of suitability, with the same safety conditions, characterizes every potentially suitable area from logistical and infrastructural efficiency aspects.

Twelve out of 67 potentially suitable areas refer to the suitability class A1. A predominant part of these sites is located in the region of Piedmont, while the rest one - in the region of Lazio.

[92] Sogin, *Proposta di Carta Nazionale delle Aree Potenzialmente Idonee*. Elaborato DN GS 00195 (2020).
[93] Sogin, *Proposta di ordine di idoneità delle aree CNAPI e relativa procedura a seguito del Nulla Osta del 30/12/2020*. Relazione Tecnica. Elaborato DN GS 00226 (2020), 36.

LOCATION OF 67 POTENTIALLY SUITABLE AREAS

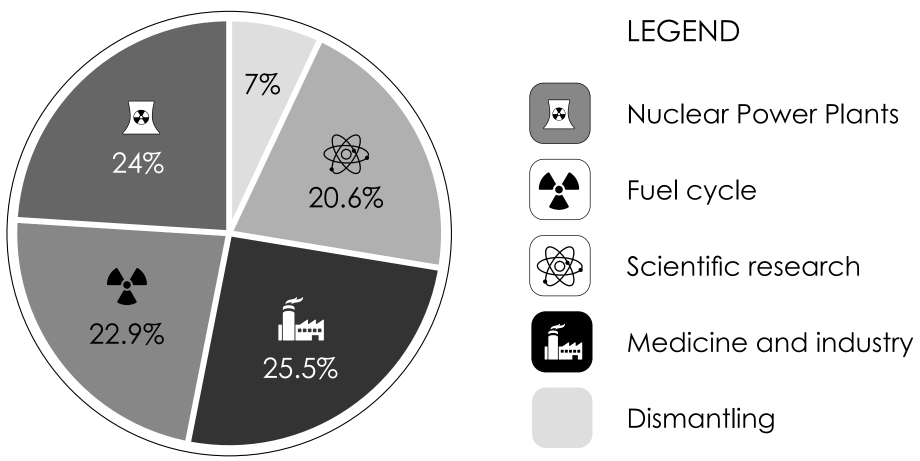


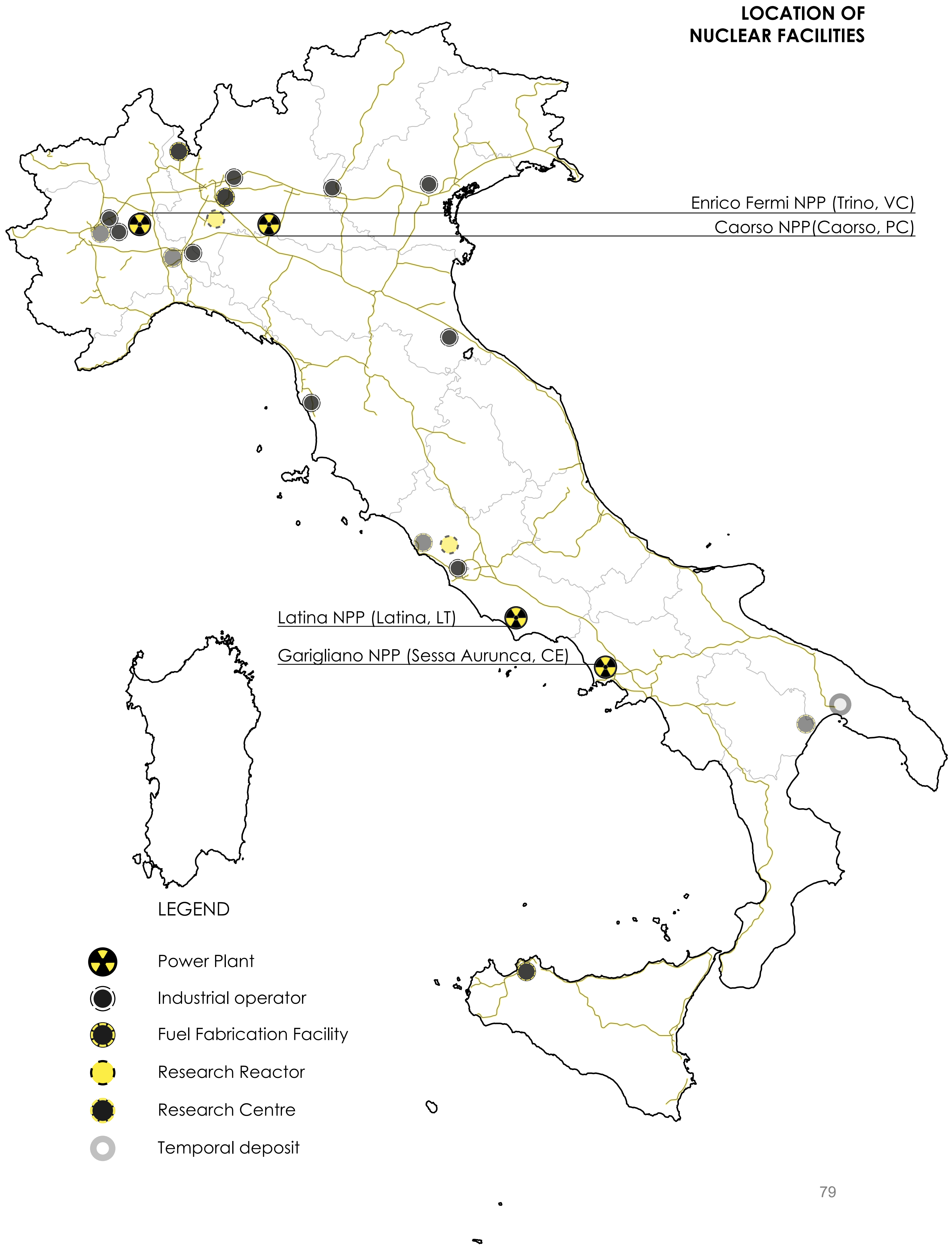
5.2 Italian Nuclear Cycle

In Italy, although there are no more nuclear plants in operation, except for some research reactors, there is a non-negligible quantity of radioactive waste, generated at the time, in the overwhelming majority, during the nuclear program that involved nuclear power plants, fuel cycle plants, research centres etc.

Waste generated from nuclear power plants and installations related to the fuel cycle is still stored in the sites where they were produced. To this waste is added one generated from medical, industrial and research activities.[94] It is, in particular, the health sector, in which radiopharmaceuticals are used for diagnostic and therapeutic purposes. It produces a limited but not negligible quantity of radioactive waste. Healthcare facilities deliver produced waste to authorized subjects for collection and storage.[95]

Distribution of radioactive waste
according to the various sources of origins





[94] Sogin, *Stima dei rifiuti radioattivi da conferire al Deposito Nazionale*. Relazione Tecnica. Elaborato DN SM 00007 (2020), 19.
[95] ISIN, *Inventario Nazionale dei Rifiuti Radioattivi - aggiornato al 31 dicembre 2018: Sintesi dei dati* (2019), 1-2.

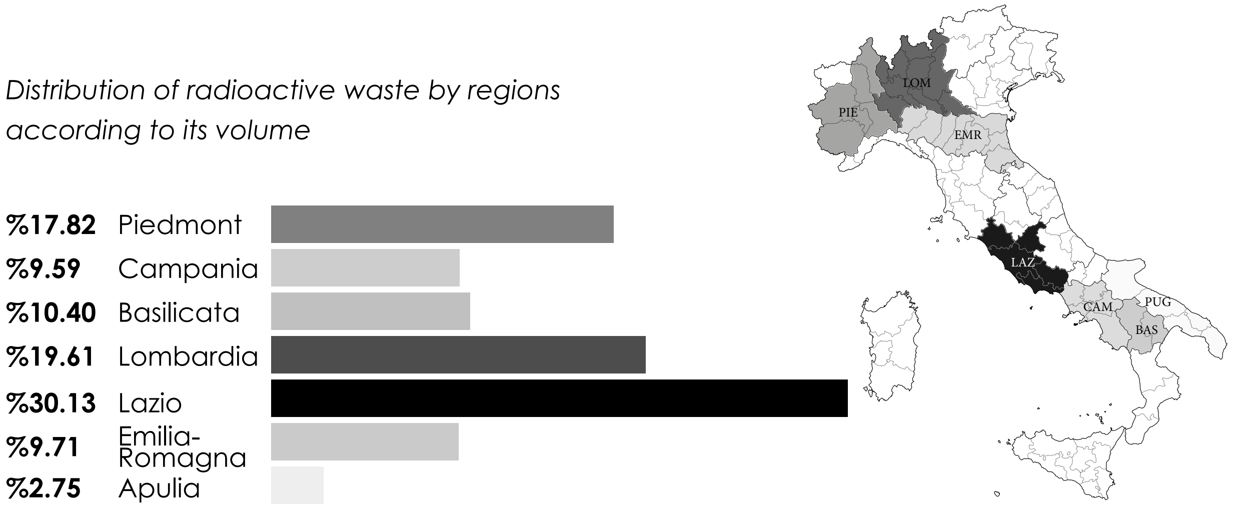
5.2.1 Distribution of radioactive waste present in Italy

The overall data is summarized in the final summary tables which include the distribution of radwaste, disused sources and spent fuel for each region, and the inventory of radioactive materials and waste deriving from the remediation of accidentally contaminated industrial installations.[96]

According to the graph illustrated below, the region that hosts the largest volume of radwaste is Lazio, with 9,311m^3, which is slightly less than a third of the total; followed by Lombardy, Piedmont, Emilia Romagna, Basilicata, Campania and, finally, Apulia.

The region with the greatest amount of activity is Piedmont - 2,165,554GBq, equal to 73.5% of the activity relating to all radwaste present in

Distribution of radioactive waste by regions according to its volume



Distribution of radioactive waste by regions according to its activity

[96] Ibid., 2-5.

Italy. It is also found in the regions of Campania, Basilicata, Lombardy, Lazio, Emilia Romagna and Apulia.

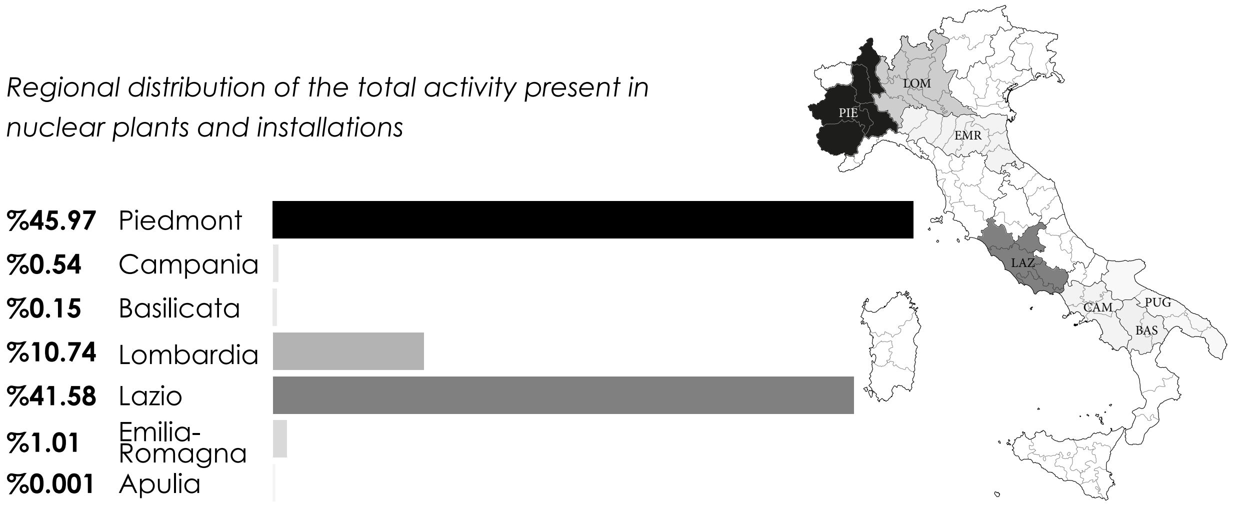
The region with the highest amount of irradiated fuel still present in Italy in terms of activity is Piedmont (83.78%). The remaining is distributed among the regions of Lombardia (11.87%), Basilicata (4.23%) and Apulia (0.12%).

The last chart, in addition to the activity of radwaste, disused sources and irradiated fuel, illustrates also the activity found in the structures and systems of nuclear plants and installations that have to be dismantled. As indicated, Piedmont is the region with the greatest activity.

To sum up, according to the data below, Piedmont is the region of a predominant part of nuclear activities.

Distribution of irradiated fuel by regions according to its activity

Regional distribution of the total activity present in nuclear plants and installations



5.3 The process of localization

Localization criteria

CNAPI redisposition

ISIN verification and validation

Transmission to MiSE and MATTM and no objection to publication

January 5, 2021
CNAPI publication, preliminary draft and related documents.

60 days
Public consultation and sending comments

within 60 days
National Seminar

30 days
Sending further comments

60 days
CNAI predisposition and transmission to MiSE

60 days
Approval and CNAI publication

90 days
Manifistation of interest

Technical investigations on candidate sites

Localization decree

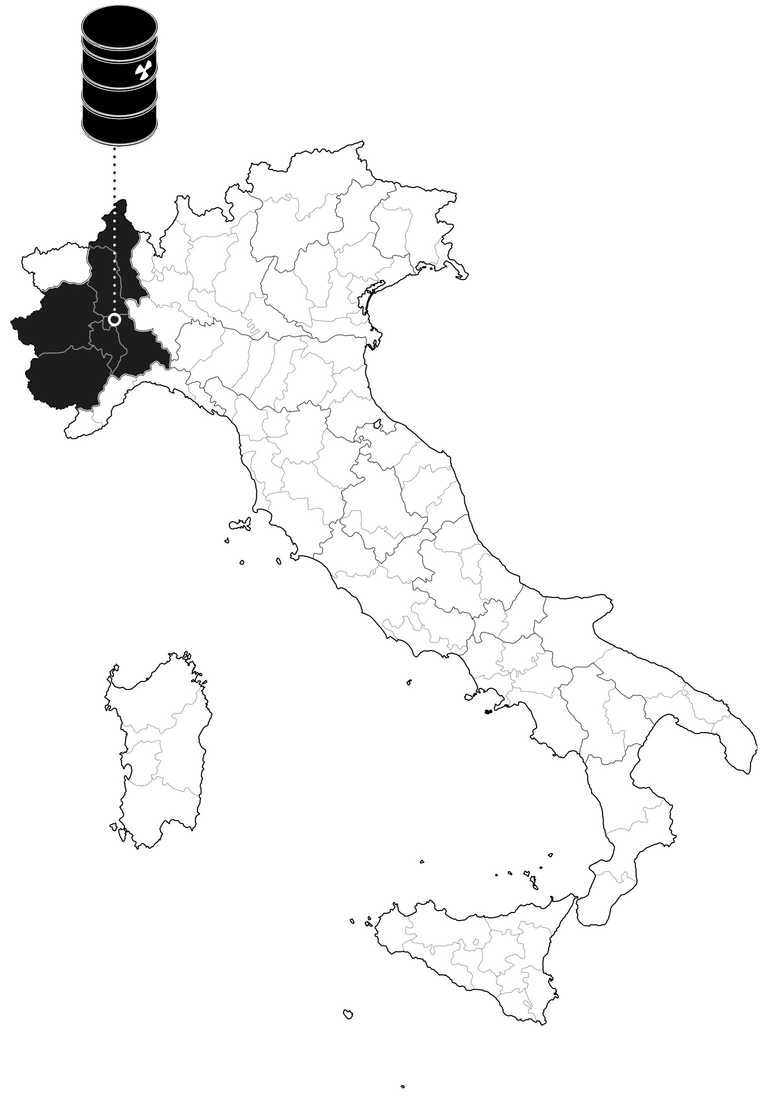
'Autorizzazione Unica' procedure and launch of the information campaign on the site

Project executive and DNPT realisation

Operation of the National Deposit

Note[1]:

- ● *Activities led by SOGIN*
- ○ *Activities not controlled by SOGIN*



5.4 ***THE REGION OF PIEDMONT***
SITE SELECTION

In this thesis work the region of Piedmont has been selected as the one to host the National Deposit and the Technological Park. The proposal was made according to the outcome of the "Site Selection Criteria" provided by SOGIN and the analysis of the Italian Nuclear Cycle, both of which were described in the previous subchapters of the paper.

THE REGION OF PIEDMONT:

NUCLEAR FACILITIES AND POTENTIALLY SUITABLE AREAS WITH THE RANK A1

In Piedmont 7 out of 8 of potentially suitable areas have acquired class A1, as a responce to at least 3 out of 4 of the following assessment factors (logistic, anthropic and environmental):

- Adequate distance from the railway lines
- Absence of residential buildings
- Limited presence of areas of great agricultural value
- Low presence of natural *valence*

LEGEND

Power Plant

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

Industrial operator

Leva-Nova Sorin Site Mgmt (Saluggia, VC)

Avogadro (Saluggia, VC)

Campoverde S.R.L. (MI)

Campoverde S.R.L. (Tortona, AL)

Fuel Fabrication Facility

EUREX (Saluggia, VC)

Bosco Marengo (AL)

Research Reactor

LENA - IniPV (PV)

Research Centre

CeSNEF PoliMI (MI)

ISPRA - 1 CCR (VA)

Potentialy suitable areas for the Italian National Radioactive Waste Repository

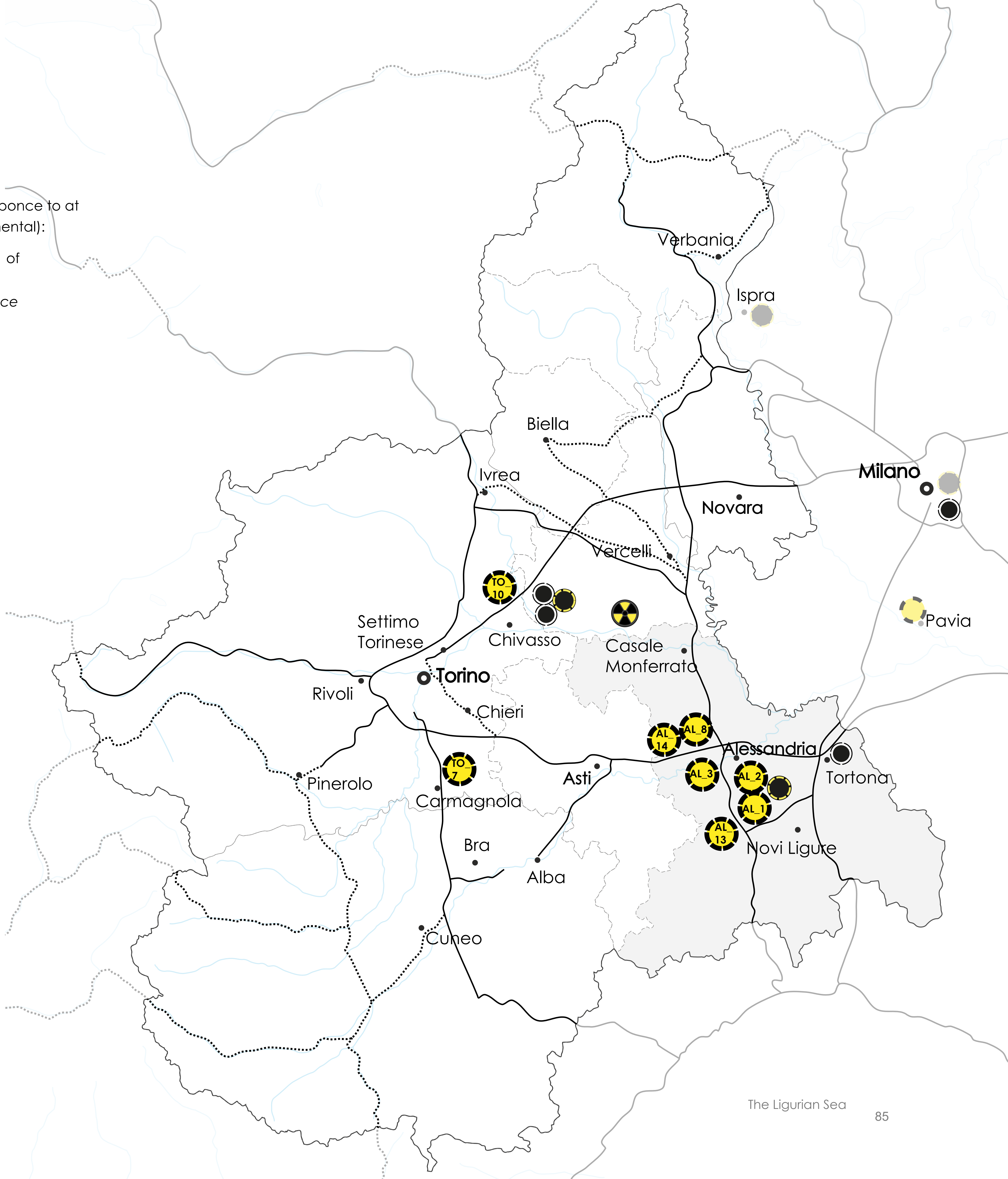
Highway

Principal roads

Hydrology (rivers, lakes)

Administrative border of Piedmont region

Administrative borders of provinces



THE REGION OF PIEDMONT:

THE SUPERIMPOSITION OF THE PRINCIPAL EXCLUSION CRITERIA AND THE SELECTED AREA

In this thesis work the area located in the province of Alessandira (AL_8) has been selected as the one to host the National Deposit and the Technological Park.

THE INDICATORS OF THE AL_8 AREA

- the maximum altitude in the area is of about *142 m a.s.l.*
- the area has a flat morphology with and average slope *<1%*
- the minimum altitude in the area is of about *100 m* above sea level. In addition, the minimum distance of the area from the coast is about *60 km*.
- the closest protected natural area *Bric Montariolo Nature Reserve* is about 9.6 km away.
- the closest residential zones (ISTAT) are as follows: *Quargnento - 1 km; Cà Angiolina - 1 km; Cornaglie - 1 km; Giardinetto - 1 km; Castelletto Monferrato - 2.6 km; Solero - 2.7 km* away.
- the main routes closest to the area are as follows: *A21 motorway - 1 km; A26 motorway - 1 km; Turin-Asti-Alessandria railway - 2.3 km* away.

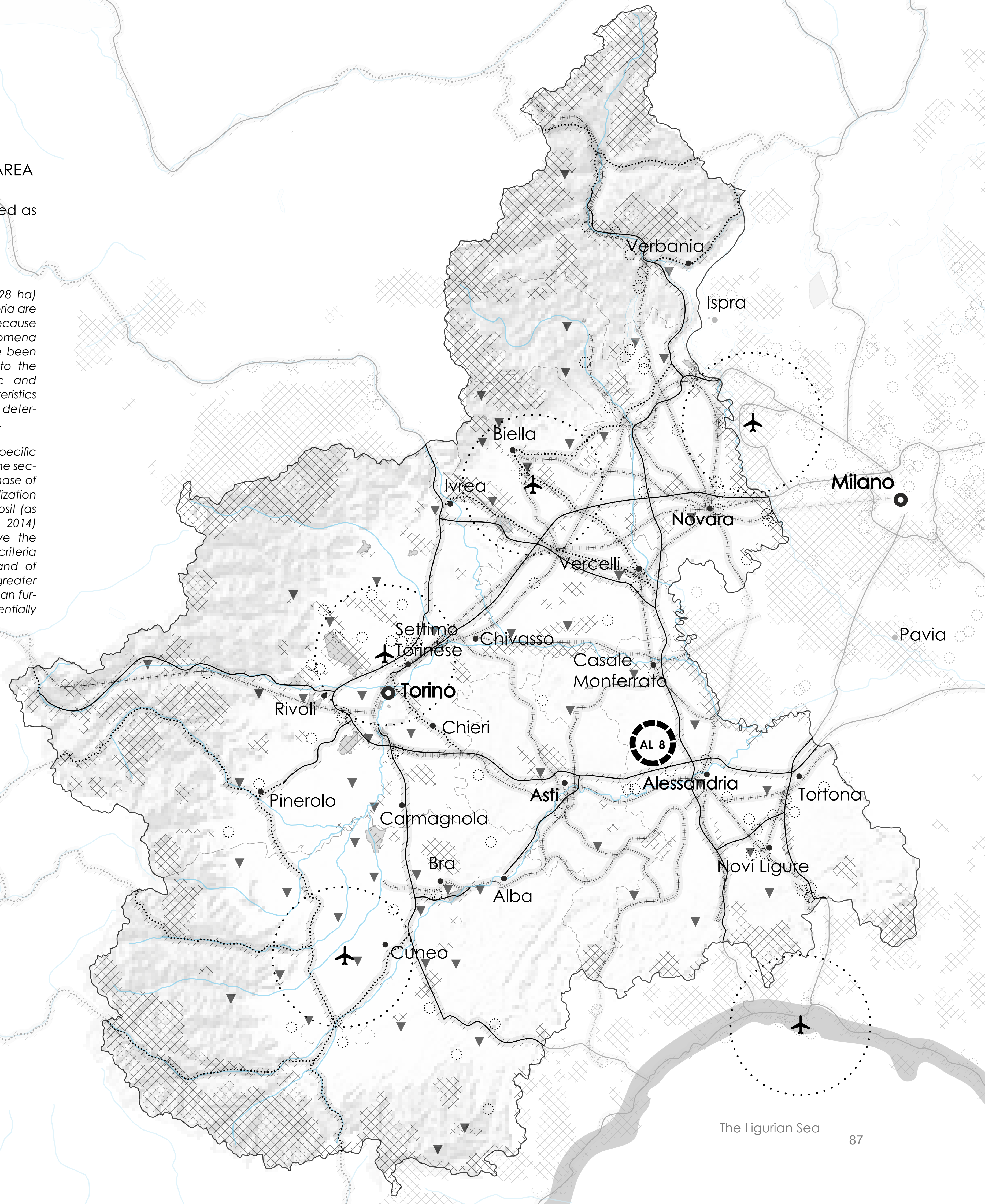
Note[2]:

In the AL-8 area (828 ha) all the exclusion criteria are positively verified because no conditions, phenomena and processes have been found with regard to the physical, naturalistic and anthropic characteristics of the area that determines their exclusion.

However, site-specific analysis, relative to the second and the third phase of the process of localization of the National Deposit (as identified in GT 29, 2014) and that will involve the verification of the criteria both of exclusion and of deepening to a greater degree of detail. It can further reduce the potentially suitable territory.

LEGEND

- Administrative border of Piedmont region
- Administrative borders of provinces
- Mountain areas
- Protected natural areas
- UNESCO sites
- Areas at a distance of 1 km from industries at risk of a major accident
- Areas at a distance of 1 km from highways
- Areas at a distance of 1 km from principal roads
- Areas at a distance of 1 km from train lines
- Areas at a distance of 15 km from the airports
- Area at a distance of 5 km from the coast
- Hydrology (rivers, lakes)
- Major historical centres
- Potentially suitable area AL_8



5.4.1 General characteristics of the potentially suitable area AL_8

According to the data provided by SOGIN[97], the AL-8 area is located in a large flat sector that extends between the foot of the southern slope of the Monferrato reliefs and the alluvial plain of the River Tanaro. The area is spread over an extensive surface with a weak slope of less than 1% towards the South and South-East.

As for the minor hydrographic network that affects the area, it is made up of prevalence from canals and irrigation ditches that connect to Rio della Maddalena and Rio Balocco and two minor waterways coming from N-NW that drain towards the Tanaro River.

The area is characterized by a landscape of agricultural type. The agricultural fabric is predominantly dominated by small fields. Inserted in the context of the Alexandrine Plain, the area is characterized by settlements constituted a system of households mainly linked to agricultural activities. Not to mention, in the municipalities within which the area is located (Quargnento, Alessandria and Castelletto Monferrato), agri-food chains are not a key aspect of the economy.

A built density is about 0.11 buildings/ ha, and, given the characteristics of the area, it is possible to hypothesize positioning of the design layout that does not directly interfere with the buildings. Furthermore, there are no aqueduct captations or mining activities. There are also no important underground resources.

Concerning infrastructure, the selected area is crossed in the central part by the SP75 "Della Fraschetta", with NE-SW direction. In the remaining territory, however, there are only minor local roads.

[97] Sogin, *Inquadramento geologico, naturalistico e antropico dell'area AL-8.* Relazione Tecnica. Elaborato DN GS 00145 (2020), 12, 29.


Corn crops


Area seen from the western boundary towards the north


Cherry trees

THE PROVINCE OF ALESSANDRIA:

URBAN CHARACTERISTICS OF THE SELECTED POTENTIALLY SUITABLE AREA AND ITS VICINITY

LEGEND

Functional zones

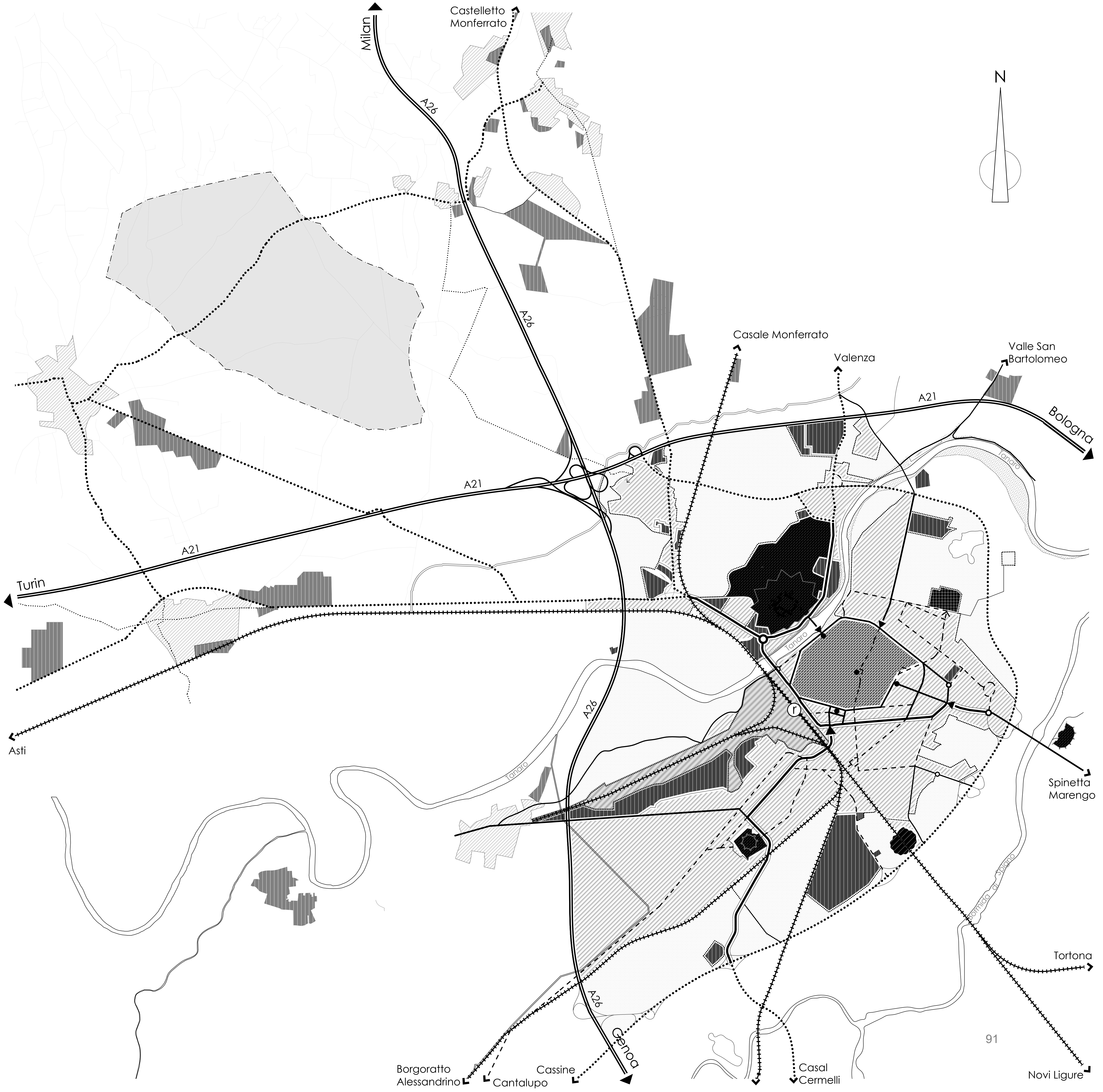
- Residential
- Industrial
- Public green
- Cemetery
- Historical core of the city
- Historical fortress
- Railway station
- Borders of the area suitable for radioactive waste repository (AL_8)

Accessibility

- Highway
- *Urban roads*
  - Principal
  - District
  - Neighbourhood
- *Suburban roads*
  - Principal
  - Secondary
  - Local interconnections
- Train line

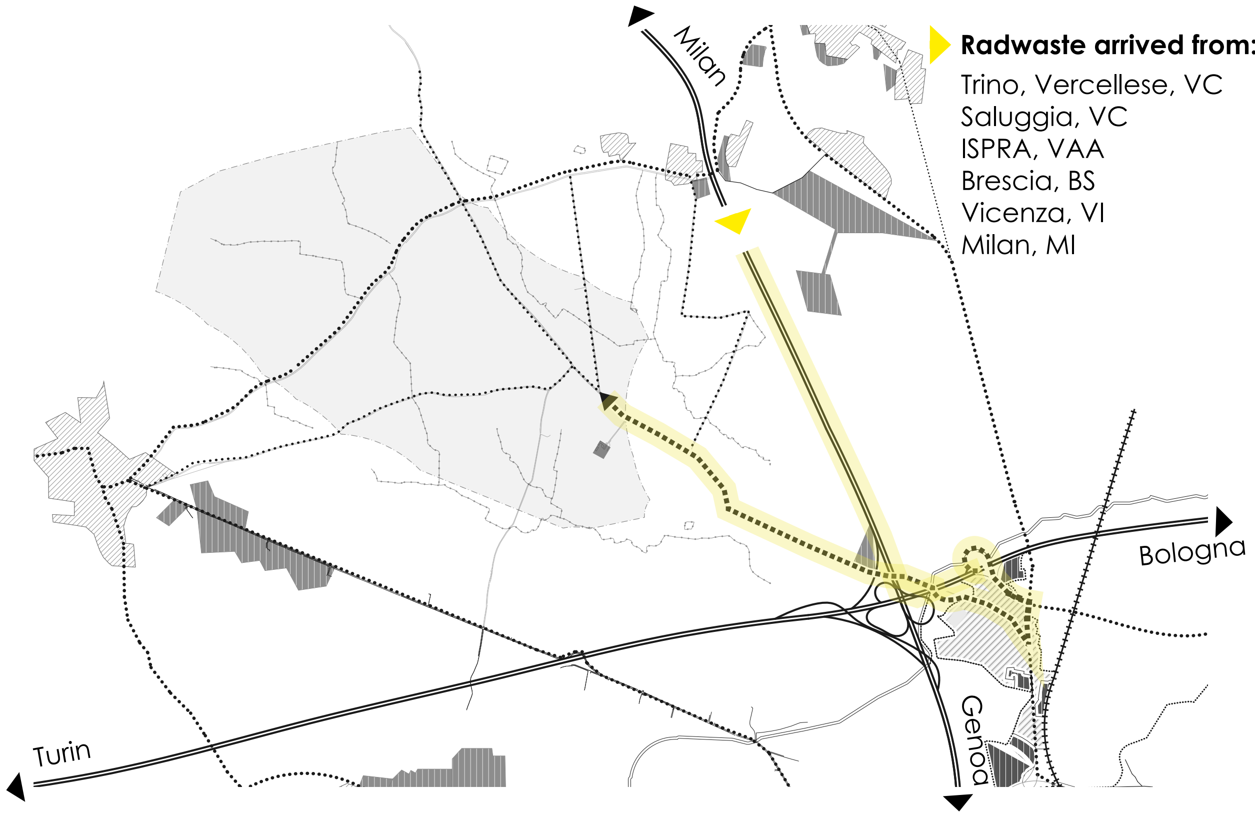
Other

- River
- Train station
- Main squares
- Borders

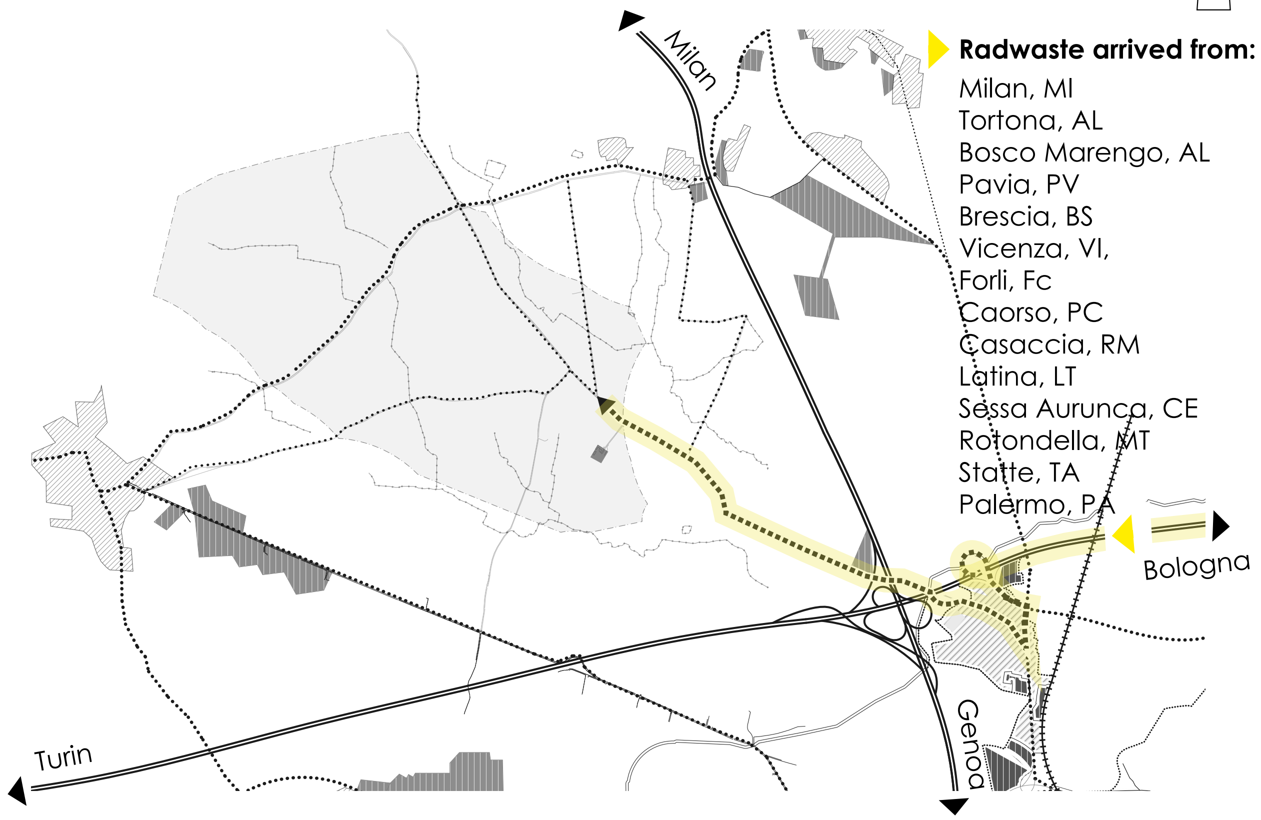


THE PROVINCE OF ALESSANDRIA:

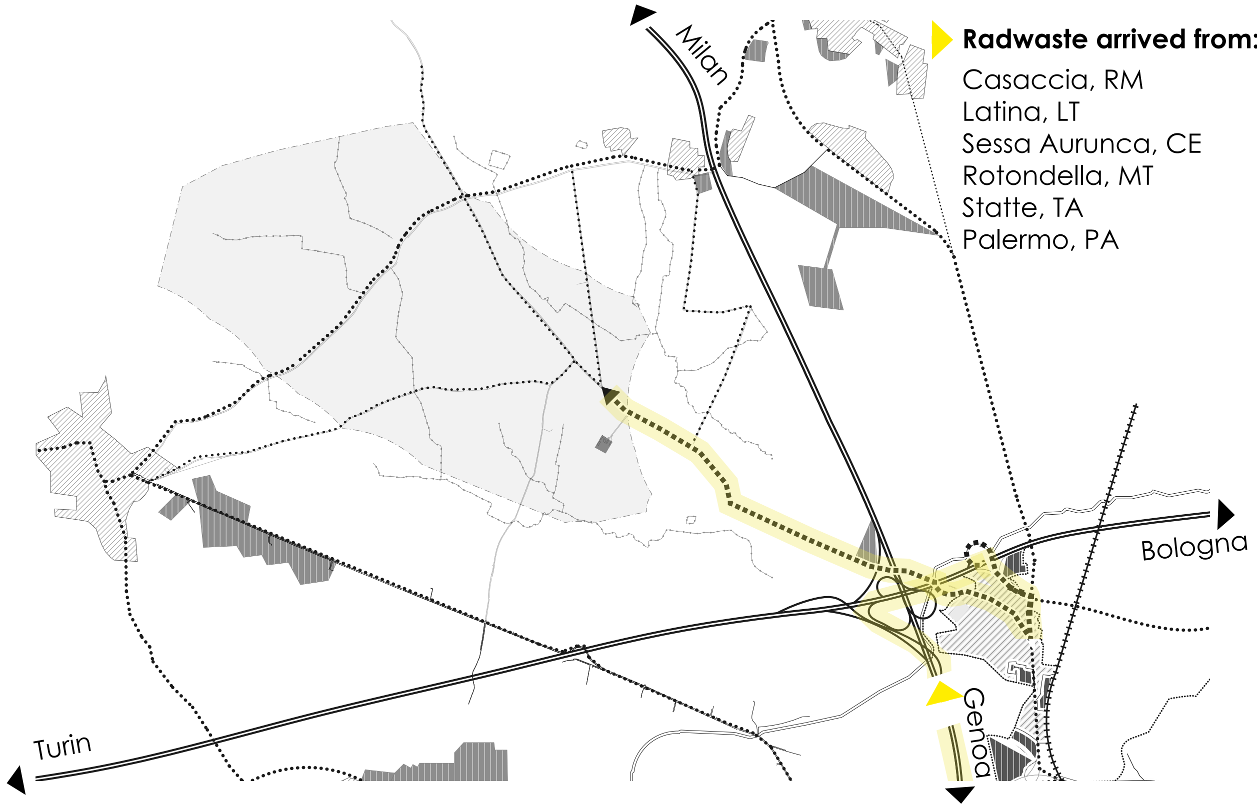
SAFE TRANSPORTATION OF RADIOACTIVE WASTE. ACCESS TO THE AREA FROM DIFFERENT DIRECTIONS



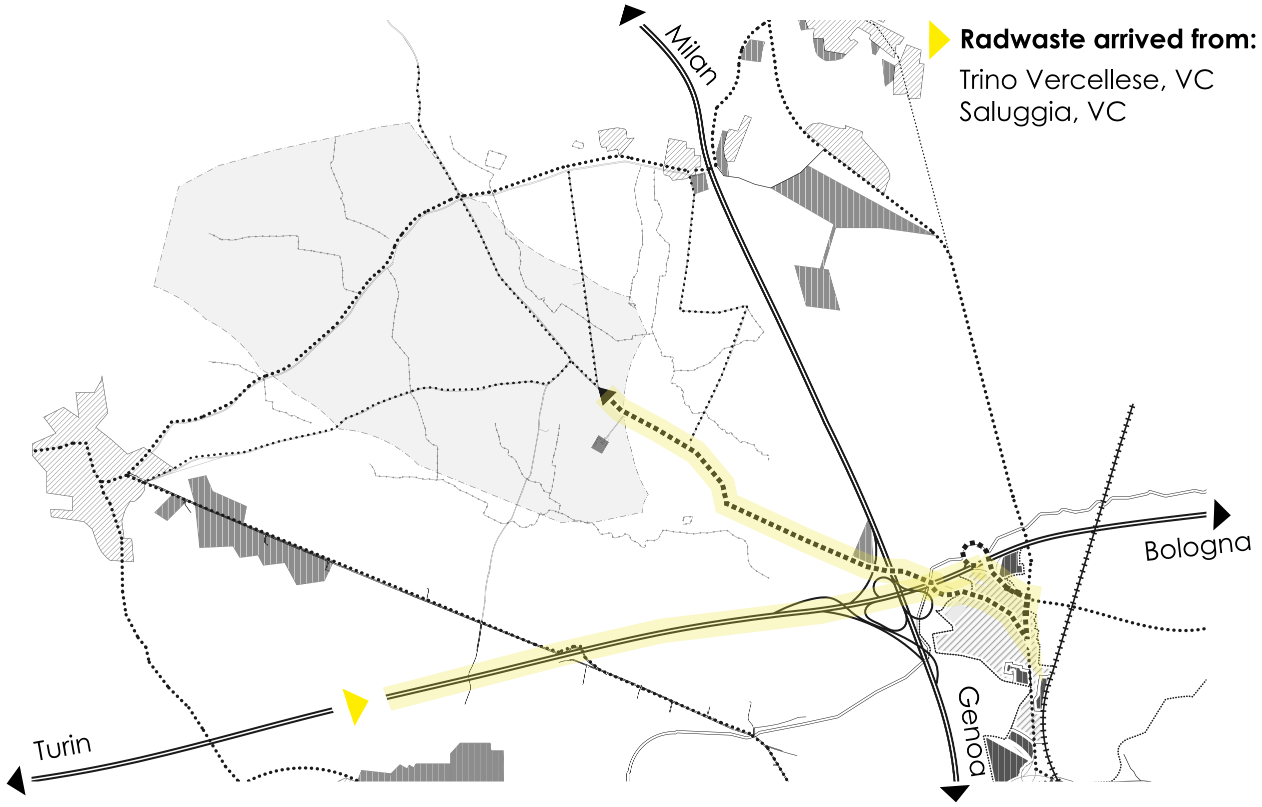
Radwaste arrived from:
Trino, Vercellese, VC
Saluggia, VC
ISPRA, VAA
Brescia, BS
Vicenza, VI
Milan, MI



Radwaste arrived from:
Milan, MI
Tortona, AL
Bosco Marengo, AL
Pavia, PV
Brescia, BS
Vicenza, VI,
Forlì, Fc
Caorso, PC
Casaccia, RM
Latina, LT
Sessa Aurunca, CE
Rotondella, MT
Statte, TA
Palermo, PA

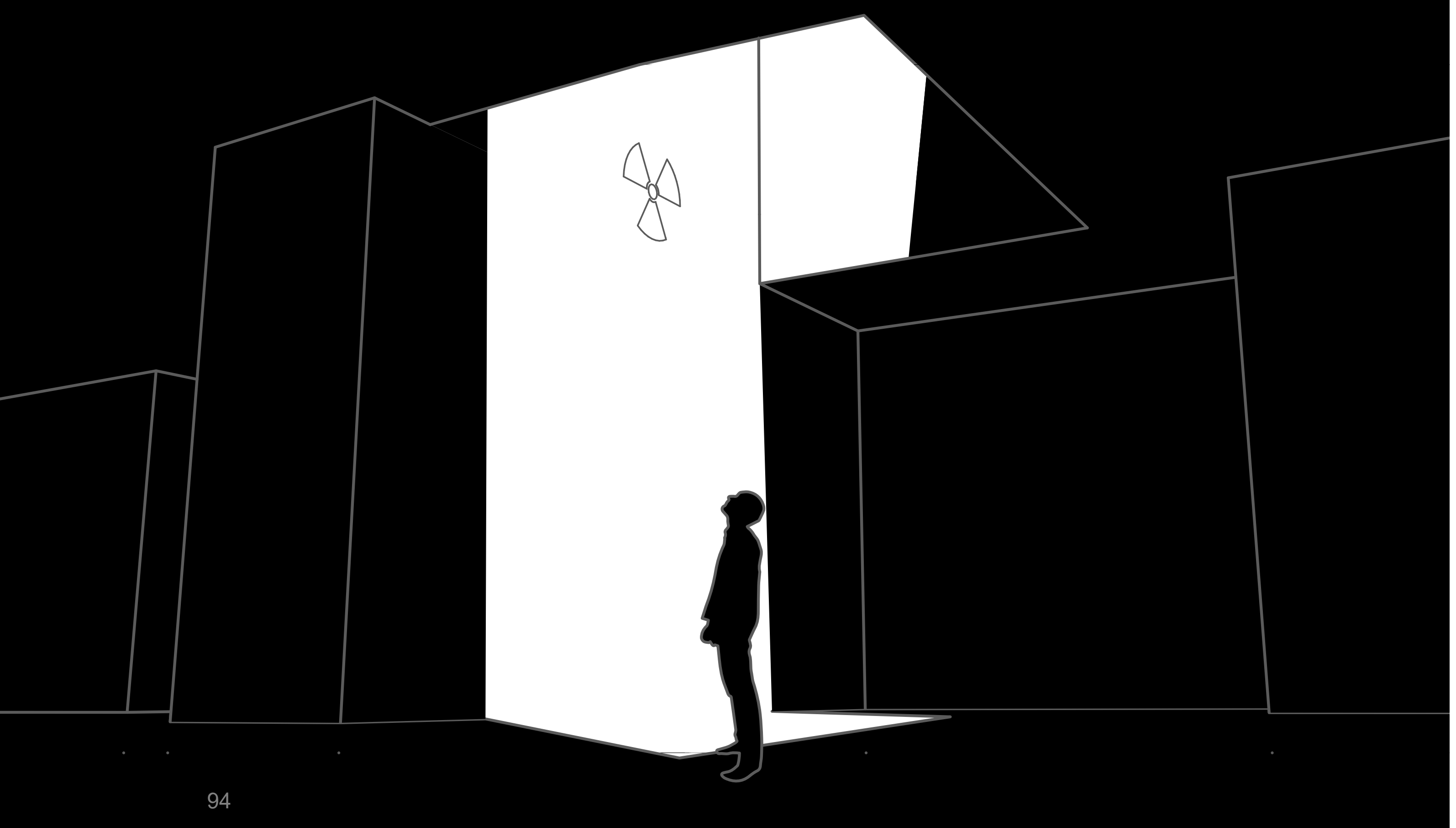


Radwaste arrived from:
Casaccia, RM
Latina, LT
Sessa Aurunca, CE
Rotondella, MT
Statte, TA
Palermo, PA



Radwaste arrived from:
Trino Vercellese, VC
Saluggia, VC

N



6 THE ARCHITECTURAL PROPOSAL

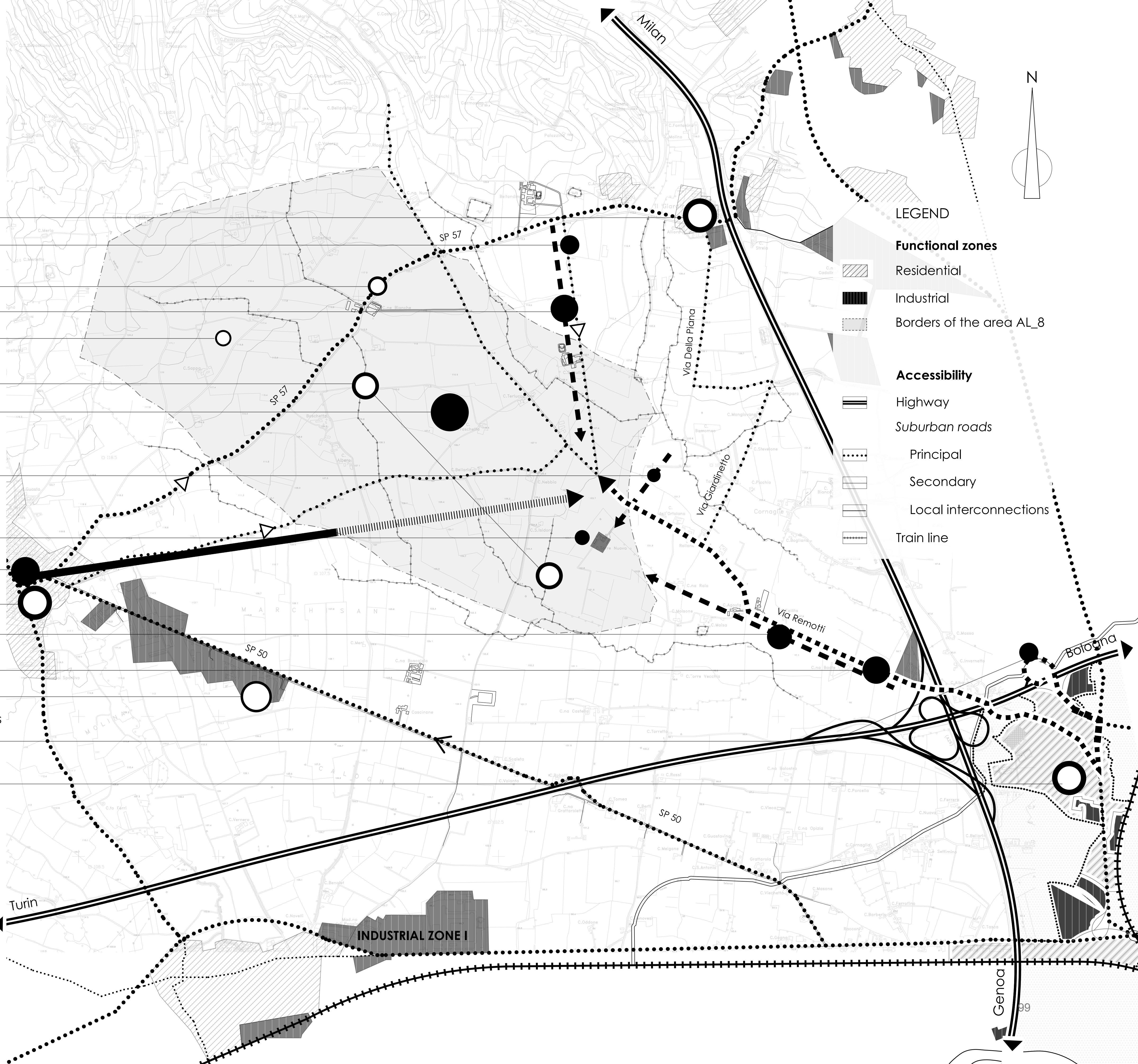
6.1

THE MASTER PLAN

SITE ANALYSIS:

EXISTING SITUATION and LOCAL FEATURES

- ○ **Residential area**
- ● **Possible secondary access**
- ○ **sp75-**existing connection between two residential areas
- ● **Axis towards the old farm**
- ○ **Territory with a slightly higher inclination**
- ○ **Canal -** possible border
- ● **Flat territory**
- ● **Axis towards the old farm**
- ● **Old farm - now b&b**
- ● **Visual connection with Quargnento**
- ○ **Residential area**
- ● **Axis towards the old farm**
- ● **Main access -** minimal interaction with residential areas
- ○ **Industrial site**
- ● **Motorway junction -** easy transport access with the minimal potential risk of accident
- ○ **Residential area**



● POSSIBILITIES

○ RESTRICTIONS

SITE ANALYSIS:

FIRST DESIGN PREMISES

Concept:

"Here is a scar in the landscape, telling that something important has happened."[98]

A near-surface radioactive waste repository is going to operate for at least 350 years, the time span which is far beyond an average human life-cycle. Accordingly, our main goal is to pass the memory and knowledge about this place to future generations.

If the main strategy of communication with the future generations is to leave an important message, one of the possibilities, according to Anna Storm[99], is to use nature (landscape) as a force that helps to make things visible, rather than hiding what has happened here. On the basis that 'post-nuclear' nature can mirror human-nature interactions, we may perceive the heritage we are going to leave - i.e. radwaste repository - in terms of a landscape. Using the idea of a landscape scar, here emerges the architectural proposal.

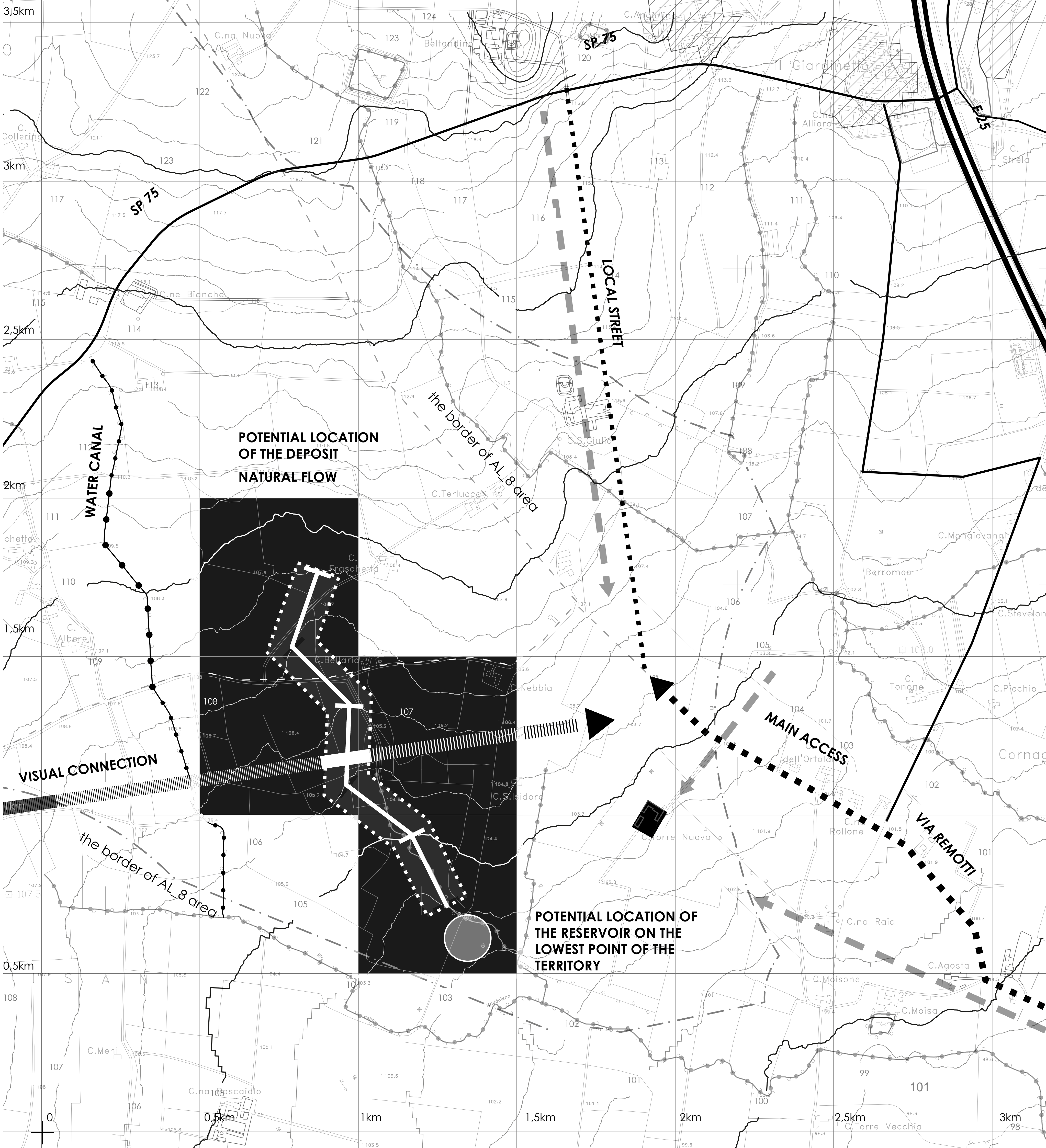
Strategy:

The main concept lays in developing an artificial landscape scar extracted from nature for 350 years and later merged within it. The use of natural characteristics of the site enables the concept of '*nature taking back*'. The integration of a natural landscape and artificial one was developed through topographical analysis of the area.

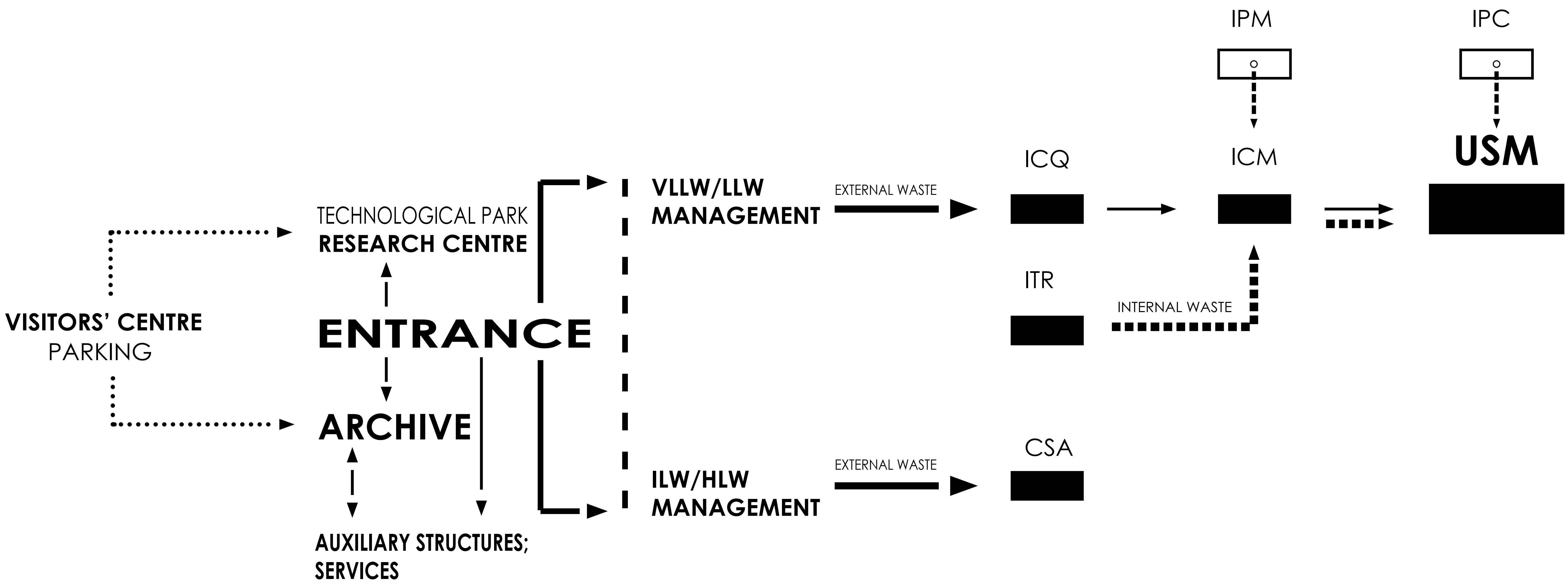
The application of the *steady gradient* has enabled the use of a natural slope of the territory, which in its turn directed the position of two major inseparable components of the master plan: the repository and the water reservoir. Since the repository is directly connected to the water reservoir from the beginning of its life-cycle, the latter was positioned as a continuation of the slope, at its lowest point.

Using the shape of the natural slope of the territory helps in the management of the repository's final cap. This provides an opportunity for the artificial landscape to merge with the natural one within many years.

[98] OECD/Nuclear Energy Agency, *Radioactive Waste Management and Constructing Memory for Future Generations. Proceedings of the International Conference and Debate, 15-17 September 2014 Verdun, France*. Radioactive Waste Management, NEA No. 7259 (Paris: OECD Publishing, 2015), 72.
[99] Ibid., 73.

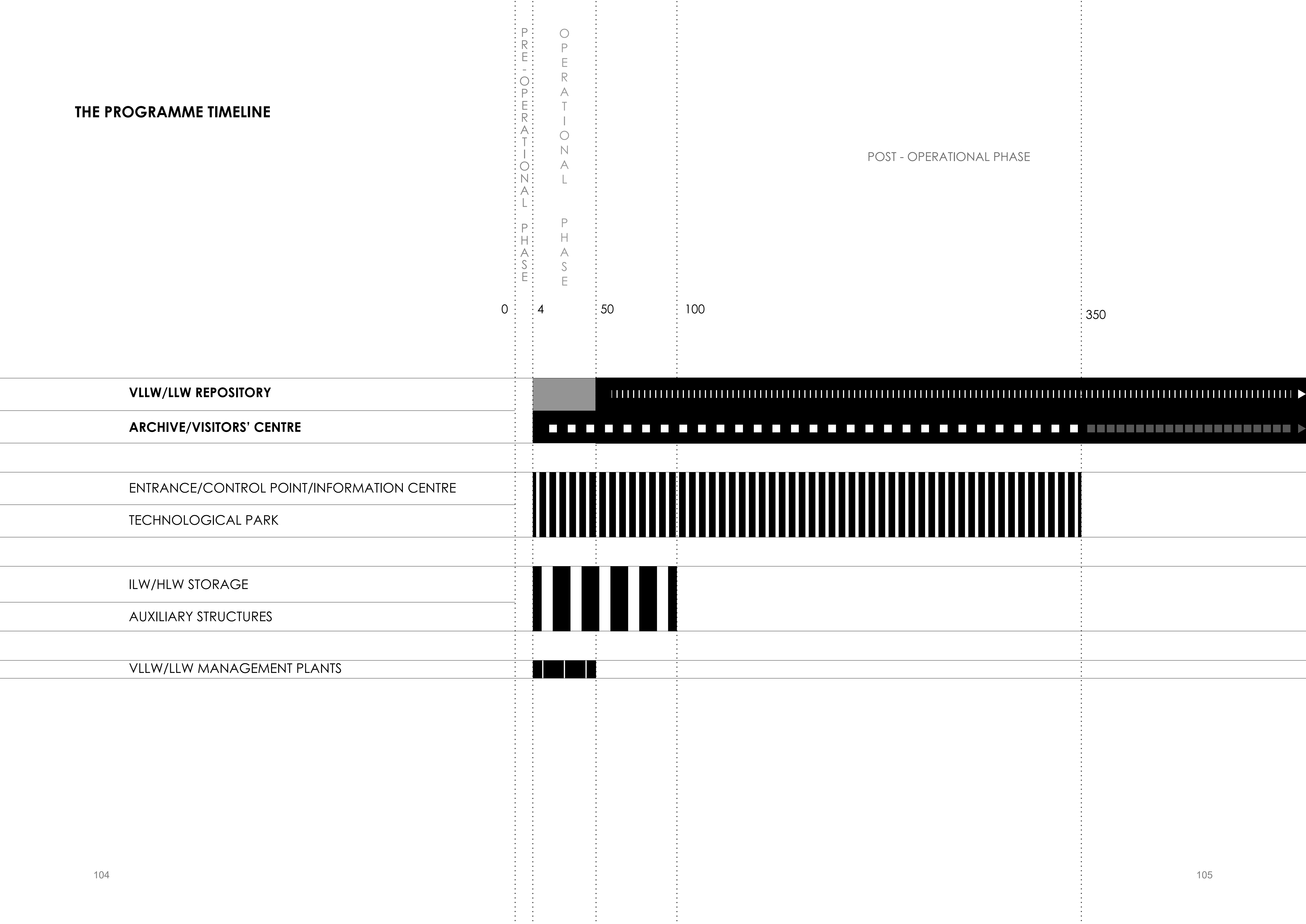


THE PROGRAMME STRUCTURE



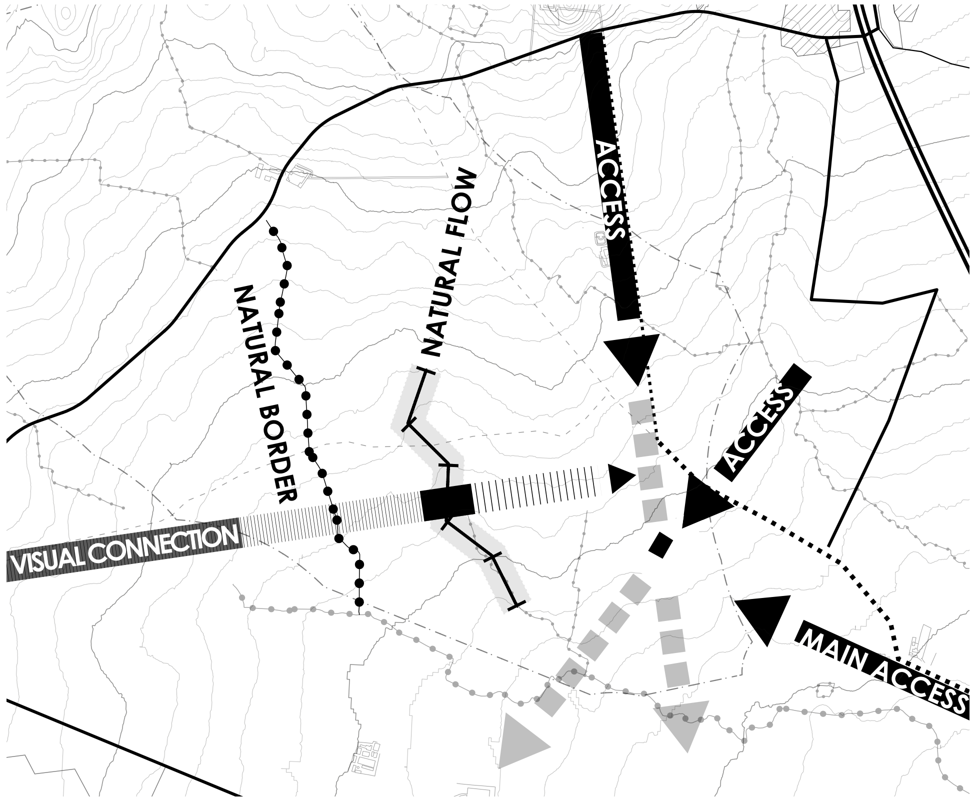
ICQ	QUALITY CONTROL PLANT
ITR	MODULES TREATMENT PLANT
ICM	MODULES PACKAGING PLANT
IPM	MODULES PRODUCTION PLANT
IPC	CELL PRODUCTION PLANT
USM	MODULES DISPOSAL UNIT
CSA	HIGH ACTIVITY WASTE COMPLEX

THE PROGRAMME TIMELINE



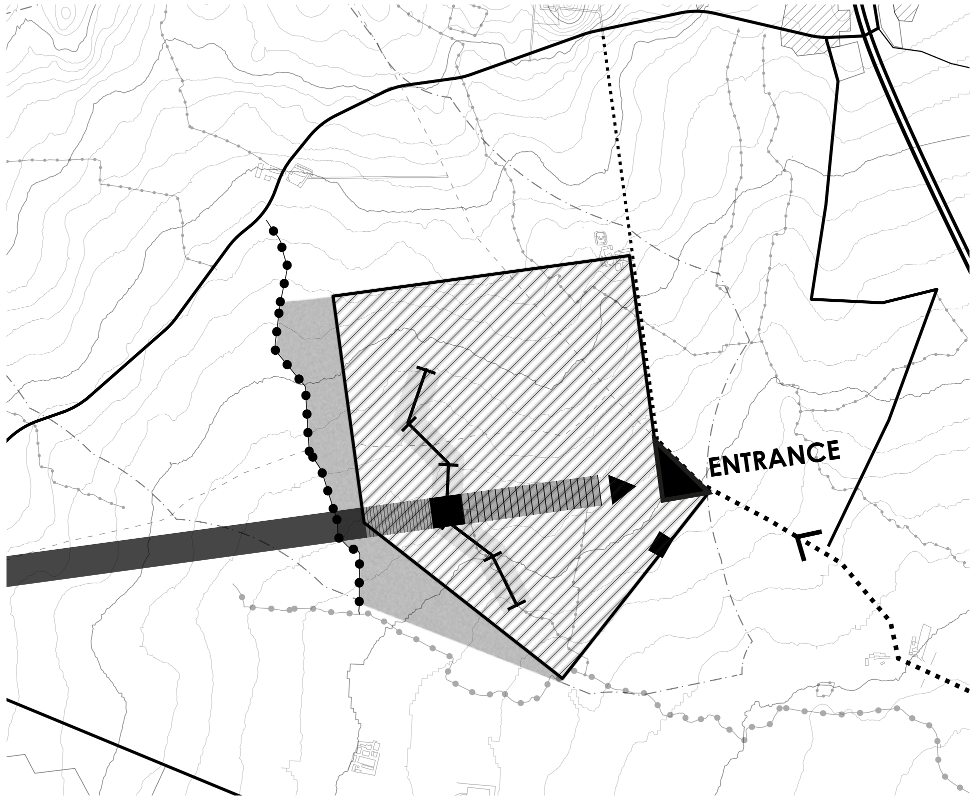
SETTLEMENT TACTICS

1



Applying local pressures to define the composition and the potential borders of the National Deposit and Technological Park.

2

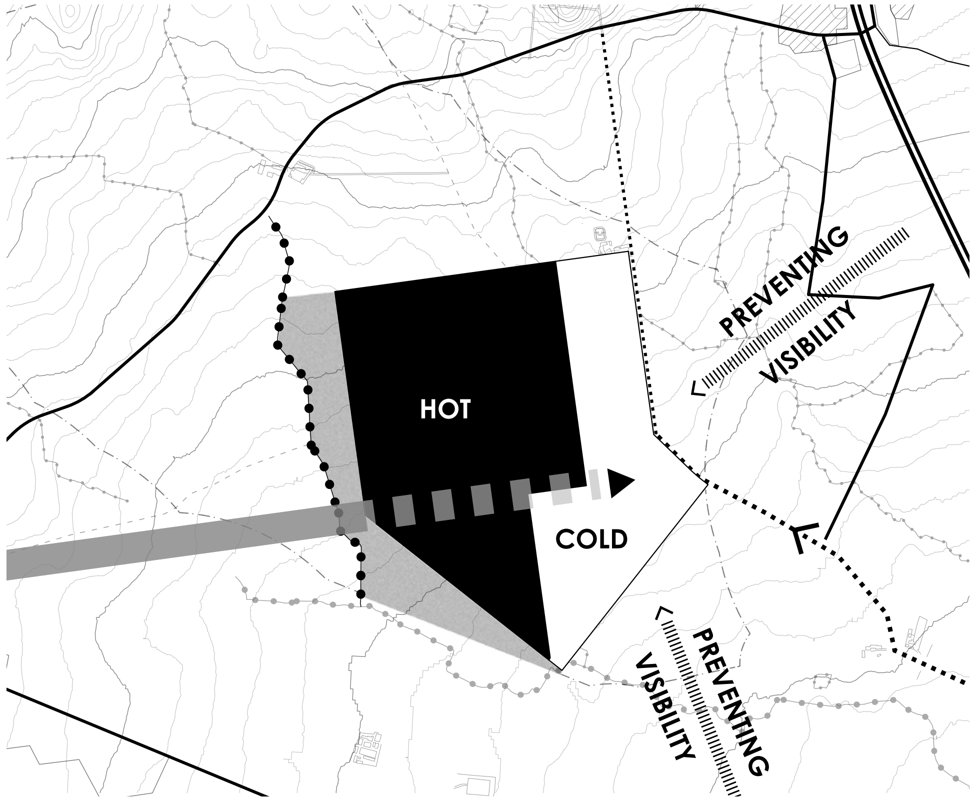


Identifying the borders of the site and its main entrance as by-products of the superimposition of natural restrictions, accessibility and design requirements.

3

Dividing the site into two domain zones: 'HOT' - which is a production area, and 'COLD' - an area without any direct physical activity with radioactive waste.

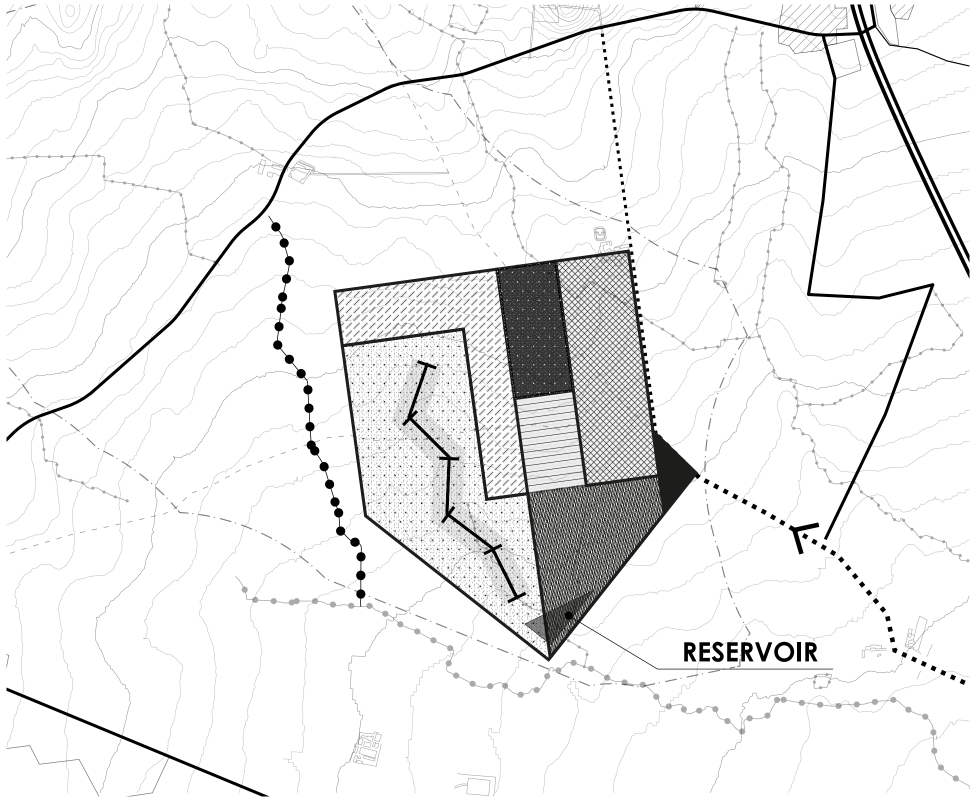
'COLD' zone serves also as a screen, which prevents the visual connection from the Highways. However, since the issue of transparency and democracy is not limited only to the abovementioned, it will be explored more deeply in the subsequent subchapters.



4

The functional zoning was identified as follows:

- The main entrance.
- Technological Park
- LLW/VLLW Repository
- Archive and Visitors Centre
- V L L W / L L W Management
- ILW/HLW Waste Management
- Auxilary Structures



THE MASTER PLAN:

YEAR 2061

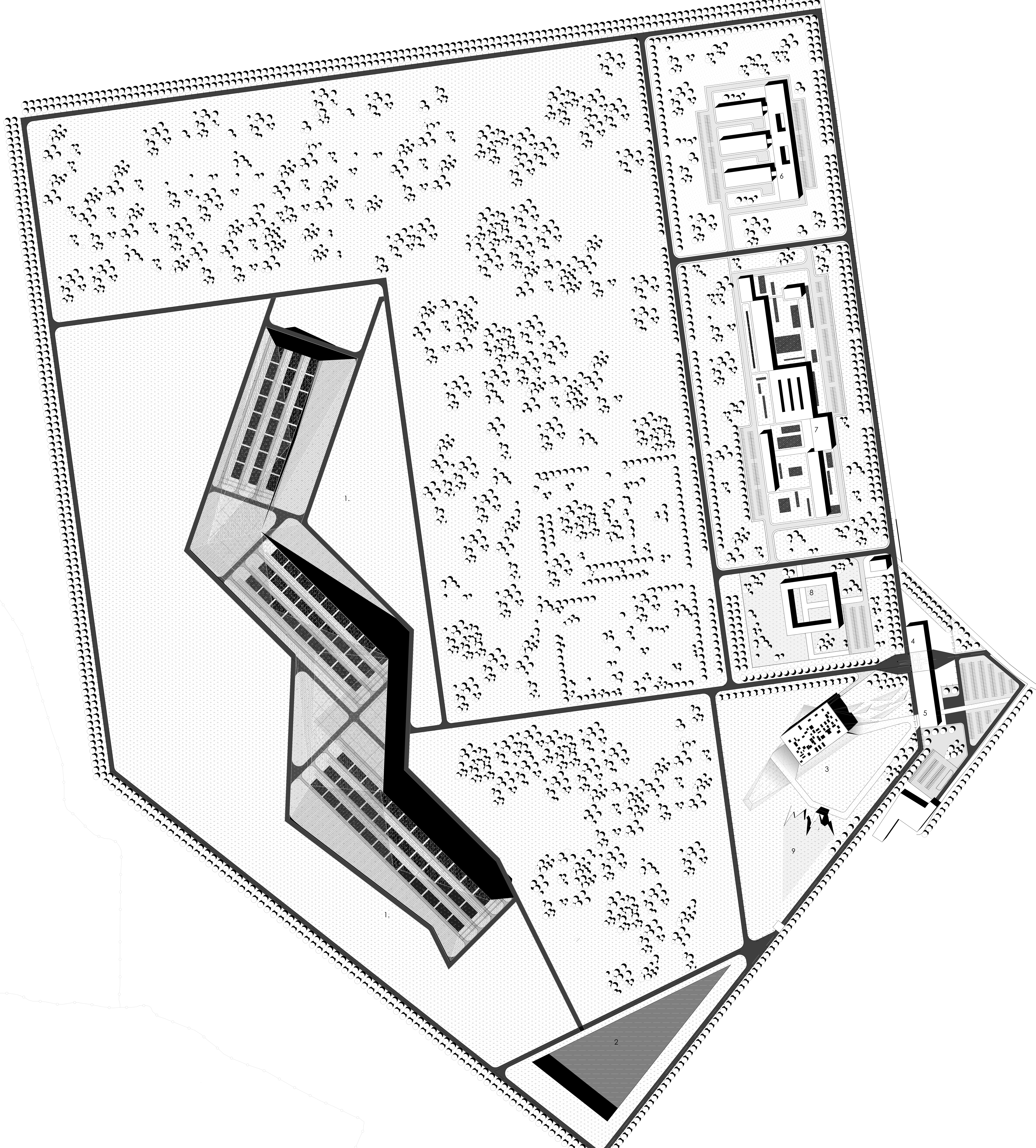
LEGEND

1. Waste Disposal Unit
2. Cell Production Plant
3. Modules Packaging Plant
4. Modules Production Pant
5. Waste Treatment Plant
6. ILW/HLW Storage
7. The Archive
8. Main Entrance
9. Public Entrance
10. Health Department
11. Fire Department
12. Office
13. LAB
14. Quality Control Plant
15. Service Constructions
16. Study and Experimentation Centre
17. Environmental Laboratory
18. Training School
19. Water Reservoir
20. Possible extension of the Waste Disposal Unit
21. A model of the Repository concrete cell, 1:1
22. Artificial hills
23. Old farm

0 50 100 150 200 m

THE MASTER PLAN:

YEAR 2161-2371



N

LEGEND

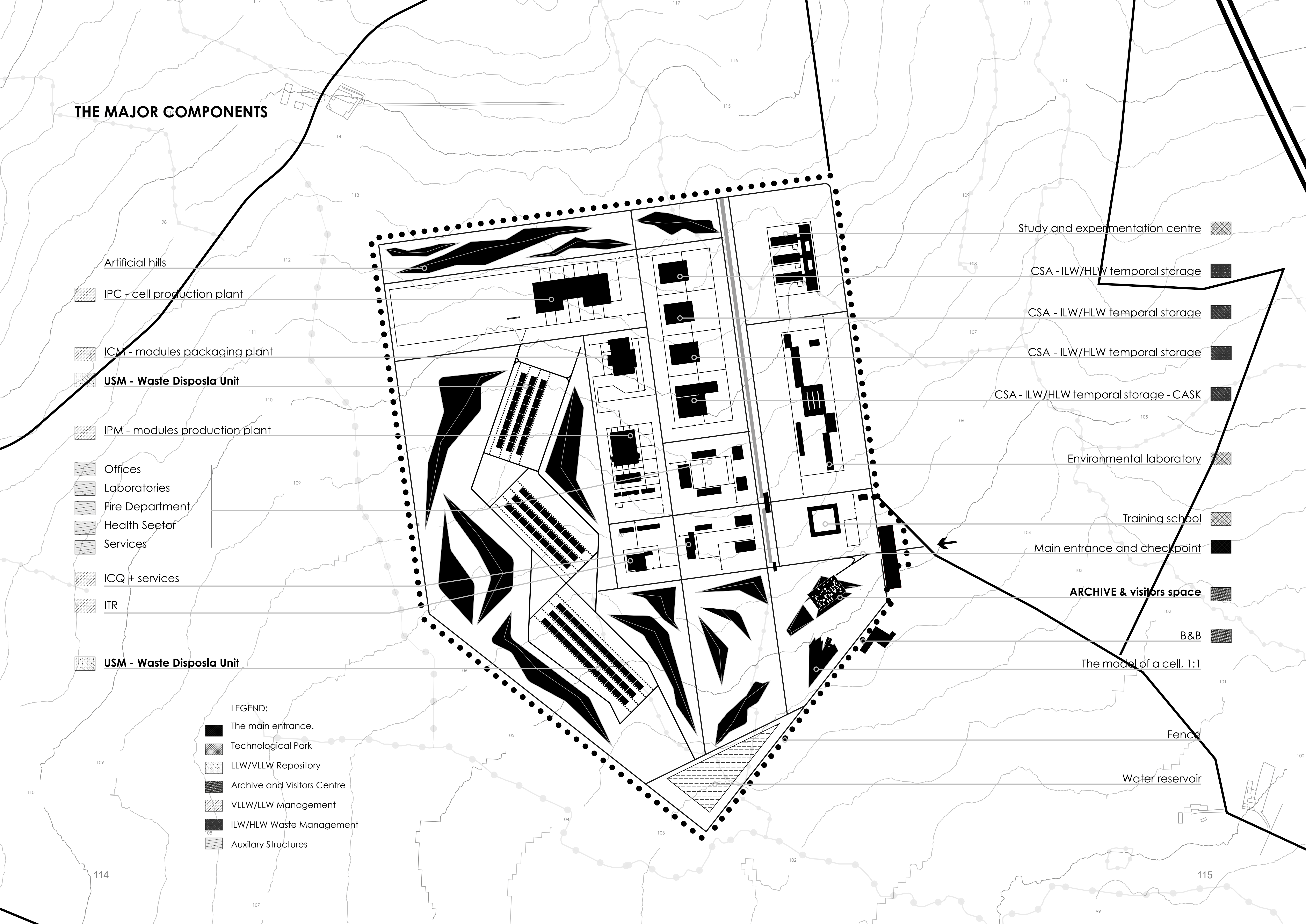
1. Waste Disposal Unit
2. Water Reservoir
3. The Archive
4. Main Entrance
5. Public Entrance
6. Study and Experimentation Centre
7. Environmental Laboratory
8. Training School
9. A model of the Repository concrete cell, 1:1

0 50 100 150 200 m

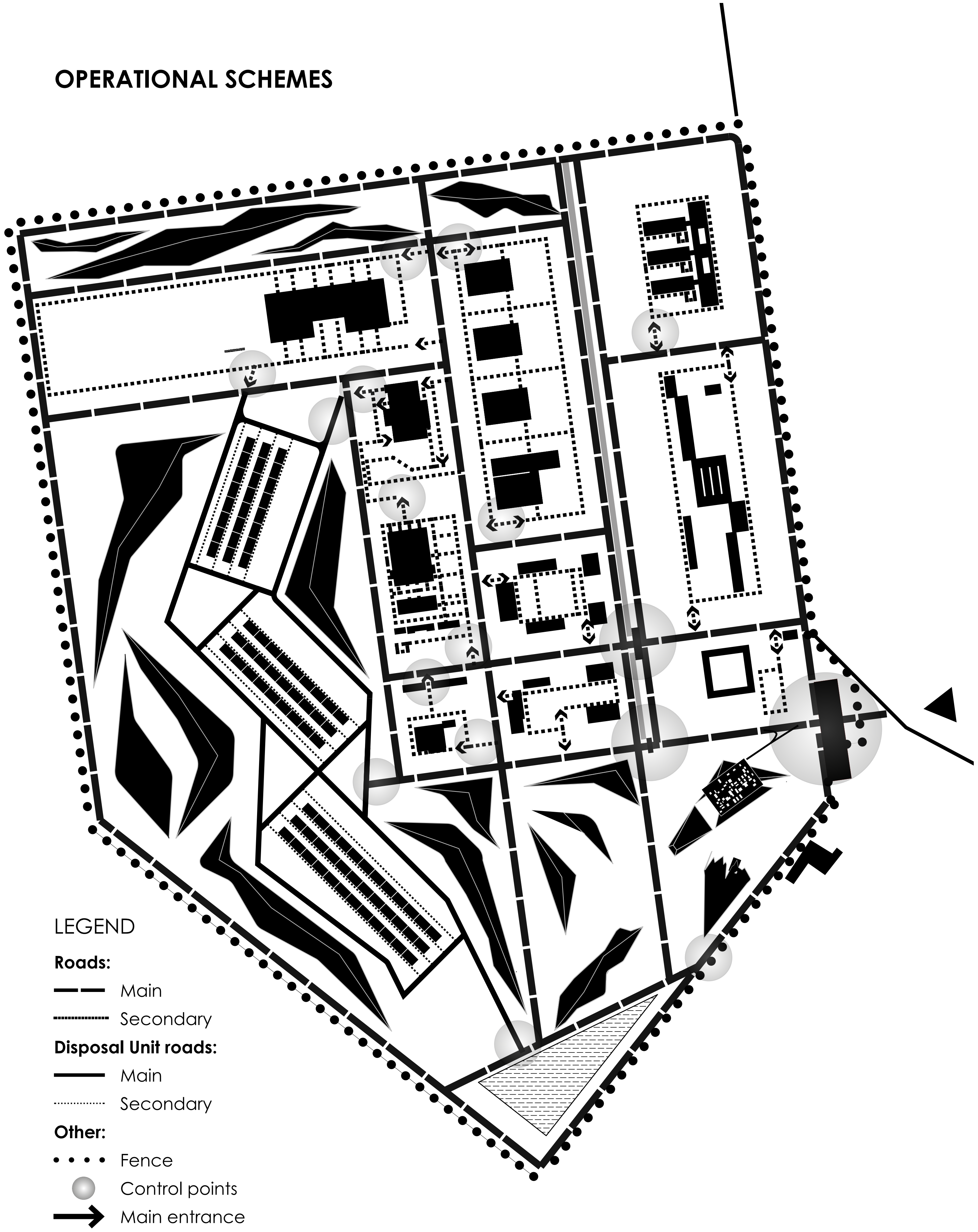
6.1.1

SPACE

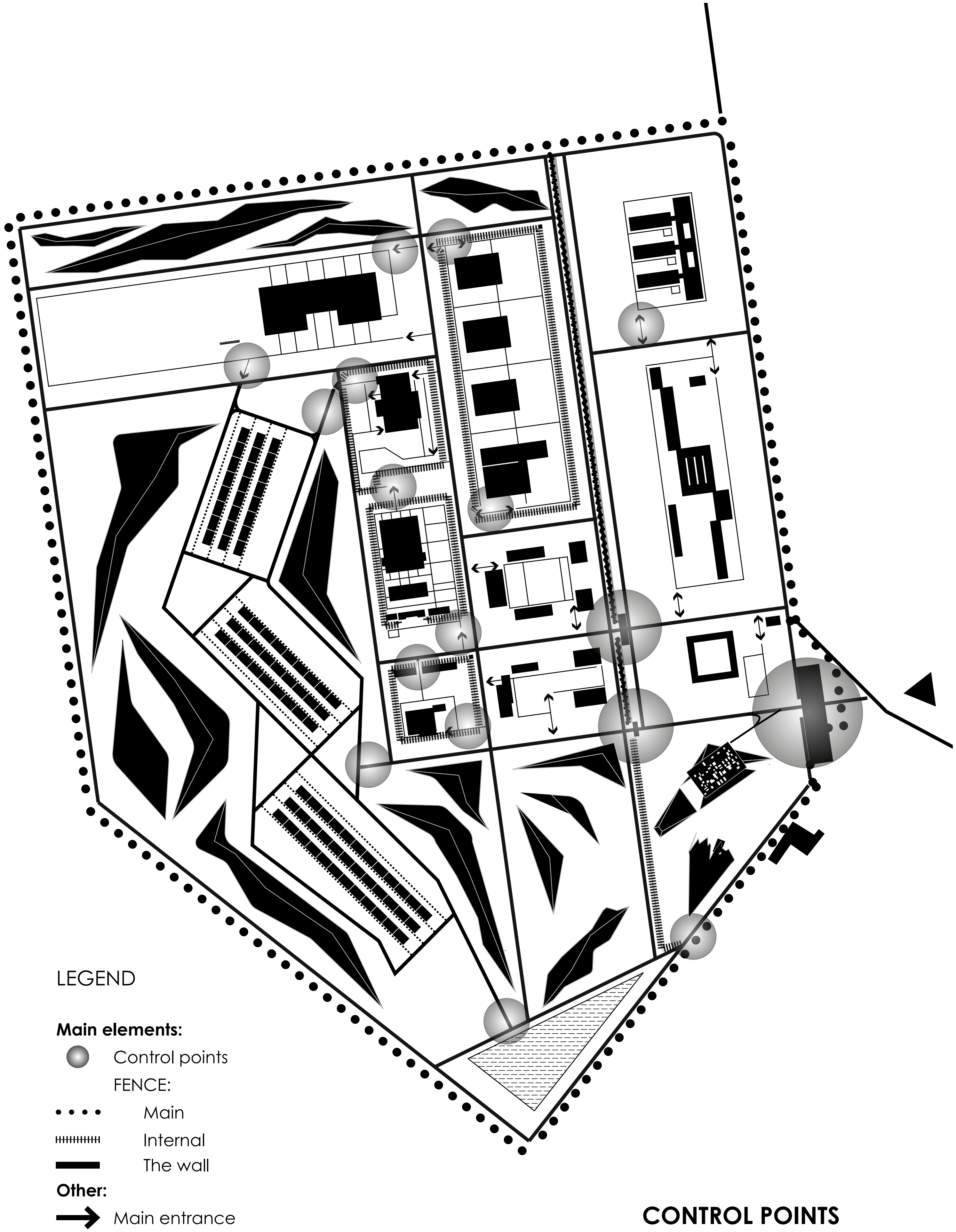
THE MAJOR COMPONENTS



OPERATIONAL SCHEMES

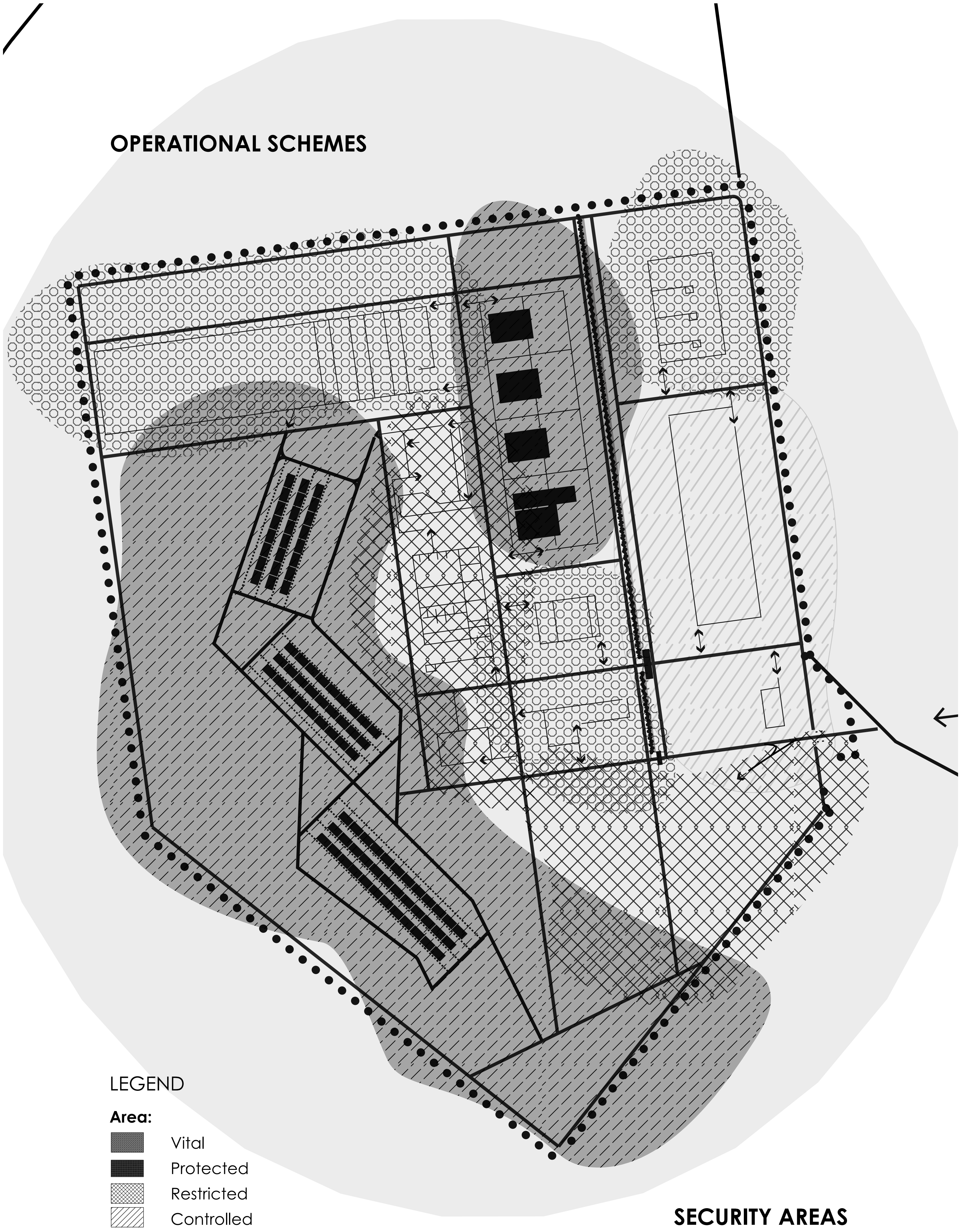


MOBILITY

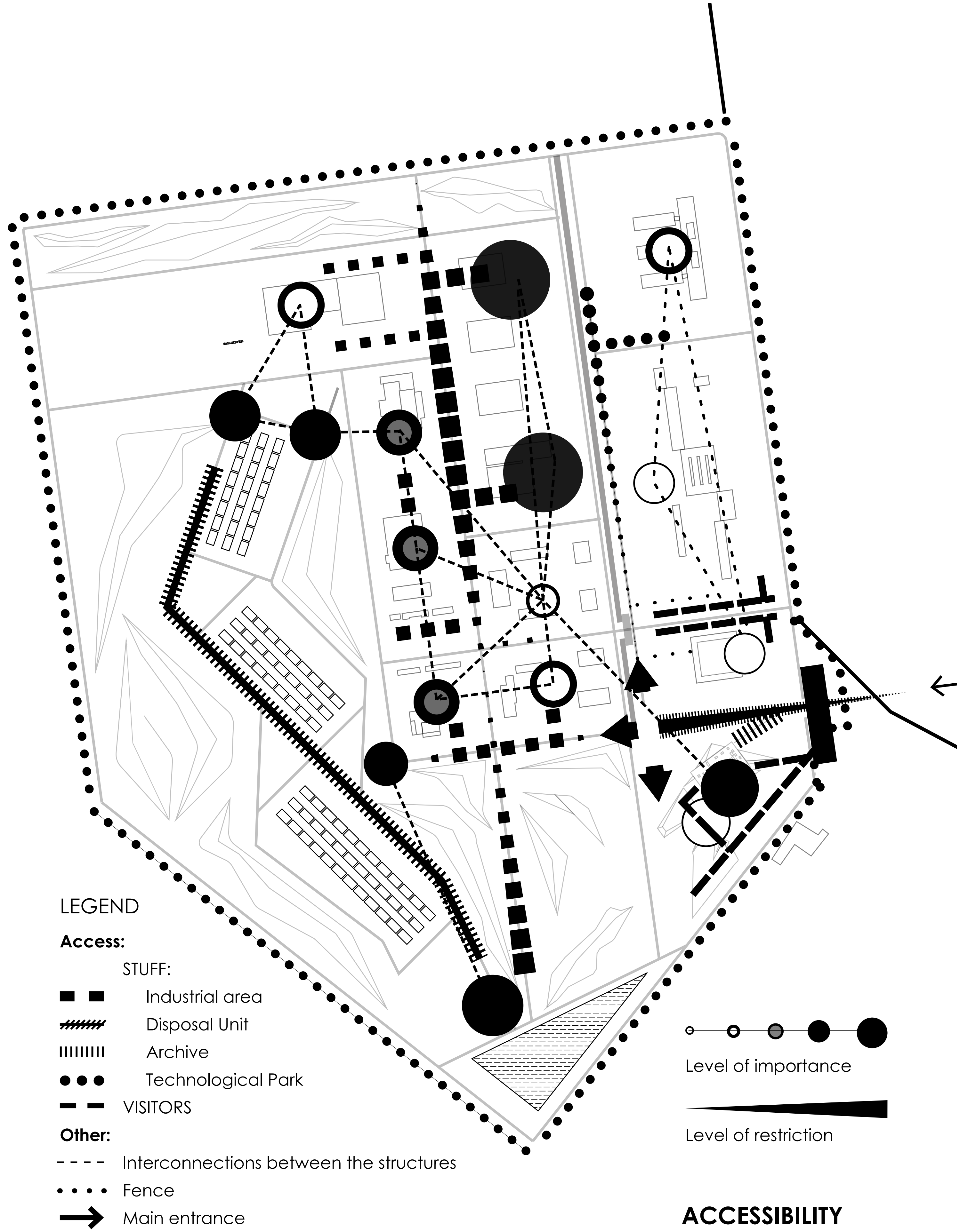


CONTROL POINTS

OPERATIONAL SCHEMES

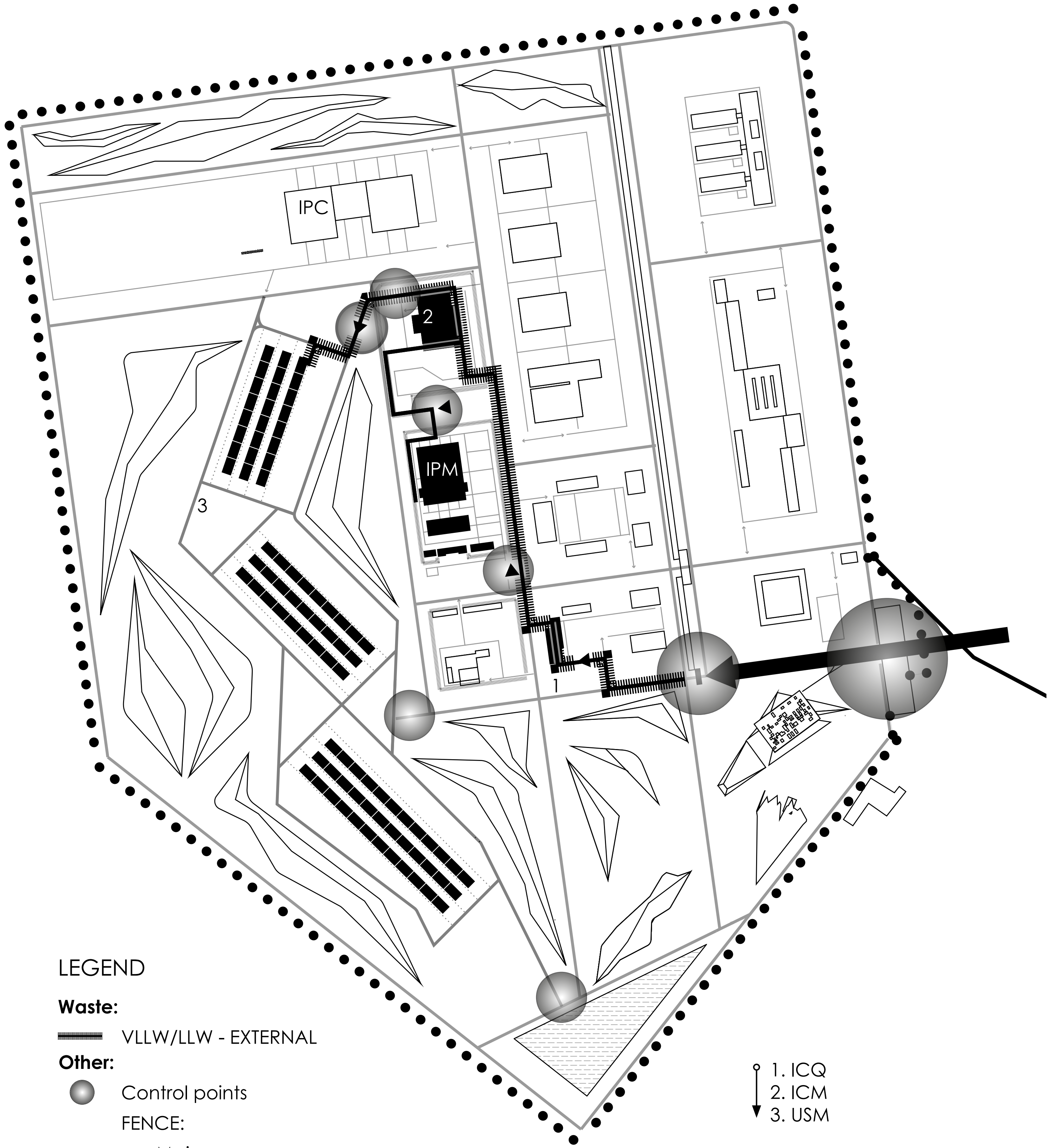


SECURITY AREAS



ACCESSIBILITY

WASTE DISTRIBUTION AND STEPS OF THE PROCEDURE



LEGEND

Waste:

VLLW/LLW - EXTERNAL

Other:

Control points

FENCE:

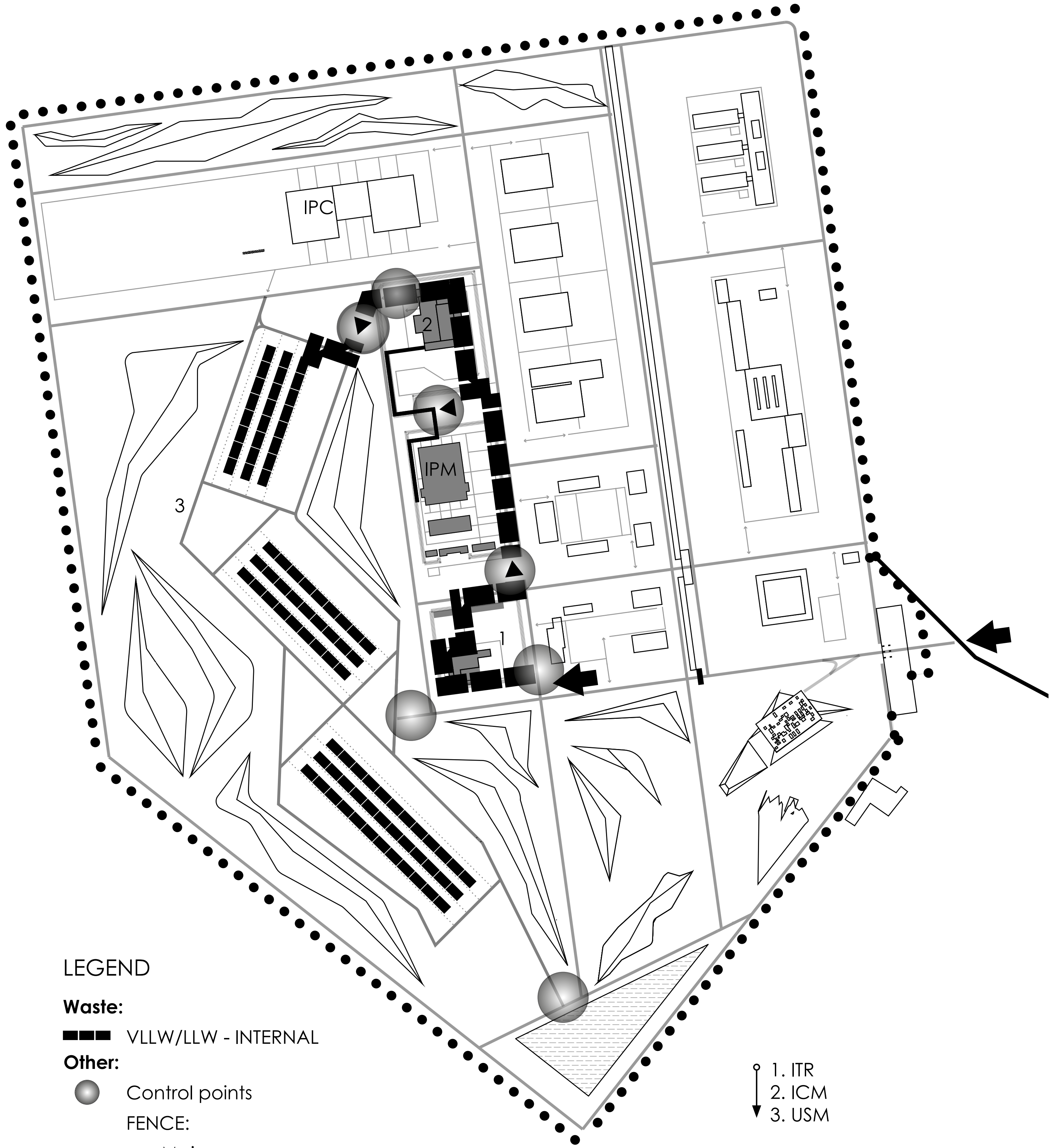
Main

Internal

Main axis

1. ICQ
2. ICM
3. USM

EXTERNAL VLLW/LLW



LEGEND

Waste:

VLLW/LLW - INTERNAL

Other:

Control points

FENCE:

Main

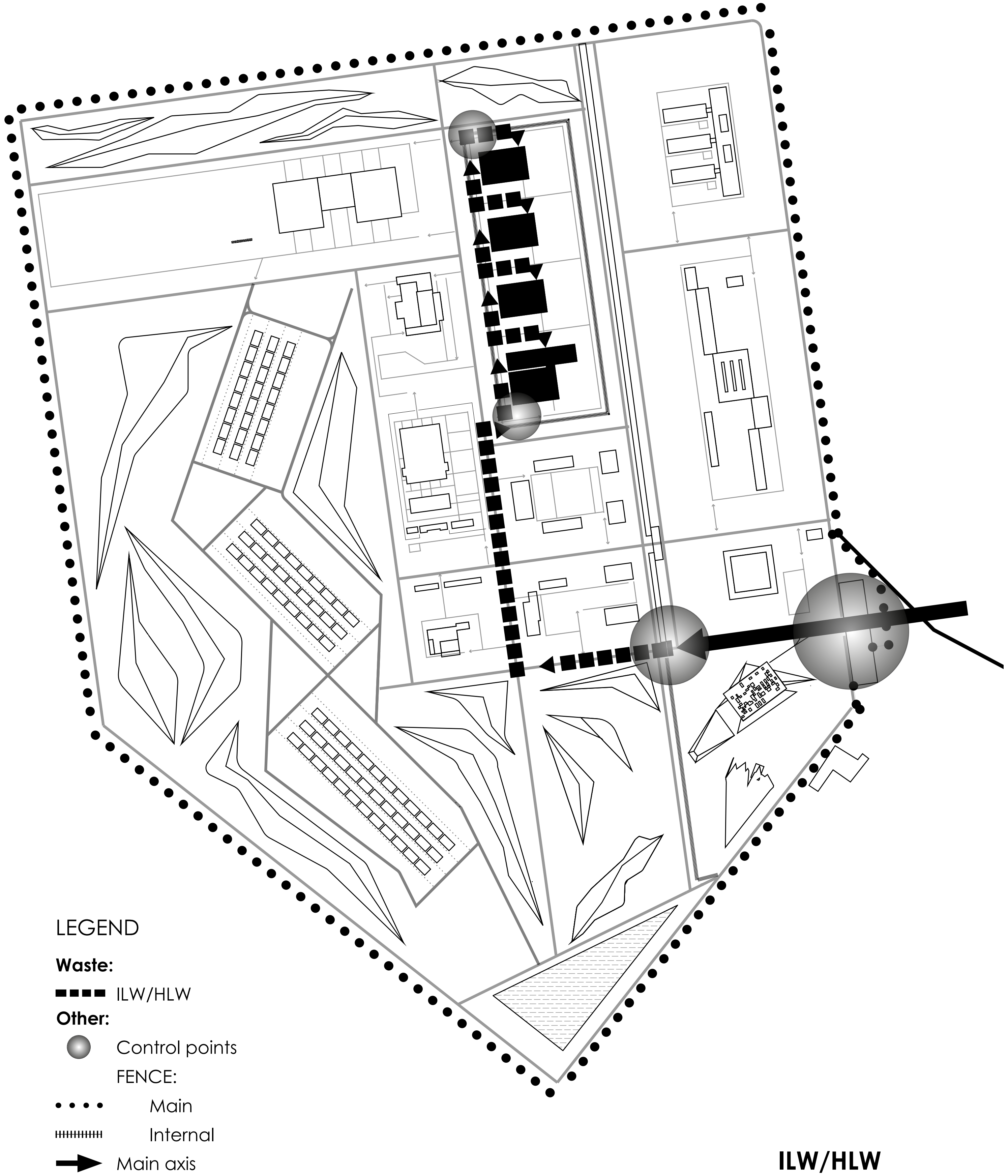
Internal

Main axis

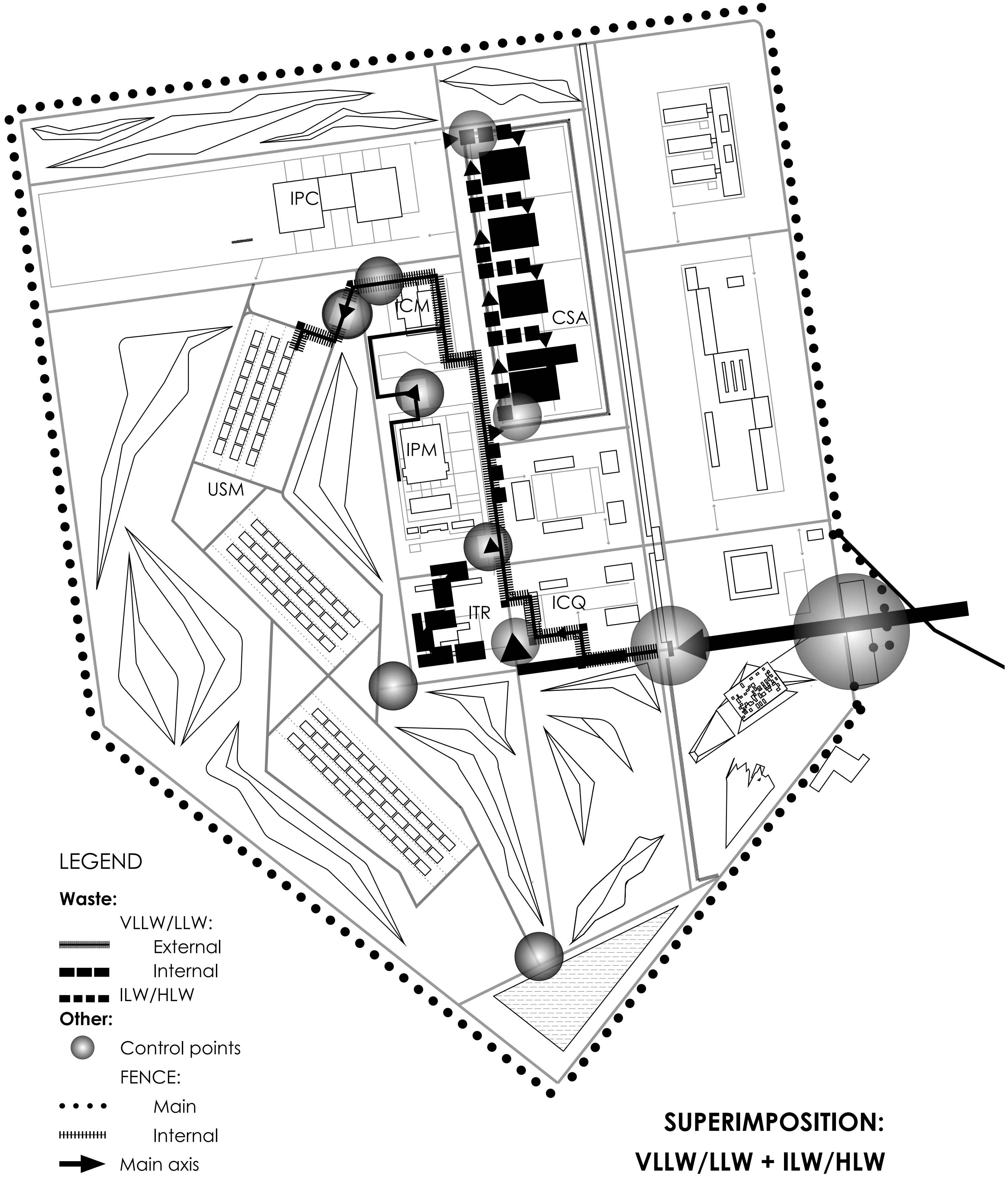
1. ITR
2. ICM
3. USM

INTERNAL VLLW/LLW

WASTE DISTRIBUTION AND STEPS OF THE PROCEDURE



ILW/HLW



SUPERIMPOSITION:
VLLW/LLW + ILW/HLW

6.1.2

TIME

THE PHASES OF MANAGEMENT:

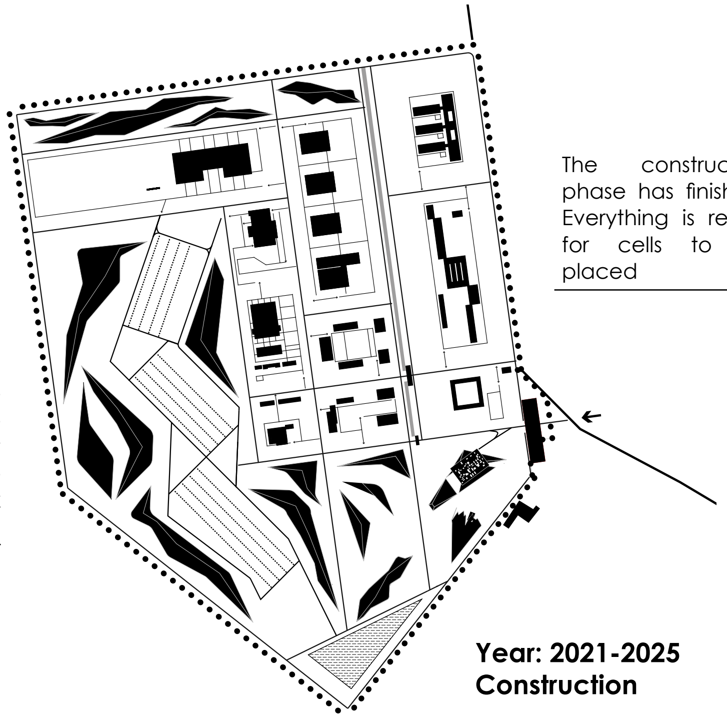
AN ON-GOING PROCESS

The end of the pre-operational phase. The first cells start to operate. At this stage, 50 cells have been inserted and closed.

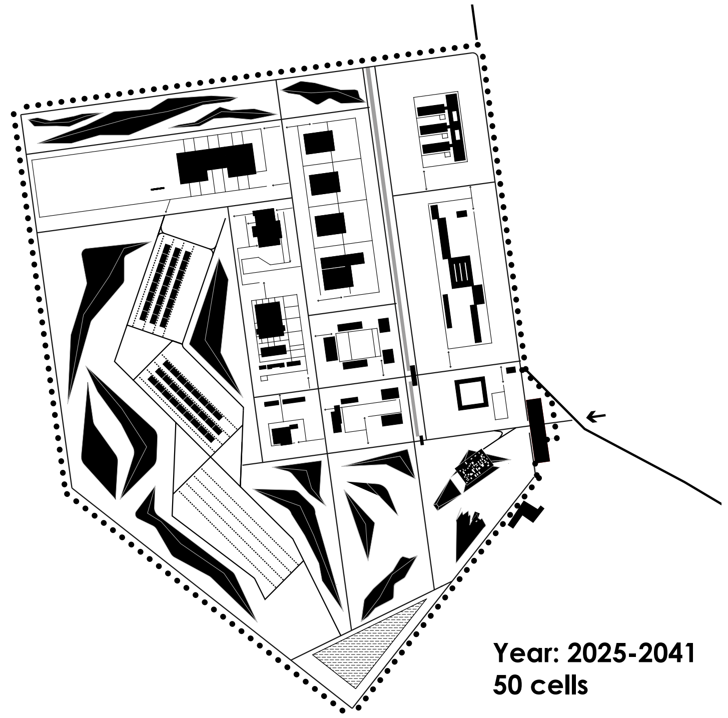
0 — **PRE-OPERATIONAL PHASE** — **4** years — **OPERATIONAL PHASE** — **20** years — **OPERATIONAL PHASE** — **40** years — **OPERATIONAL PHASE** — **50** years

The construction of the National Deposit and the Technological Park has initiated.

The construction phase has finished. Everything is ready for cells to be placed

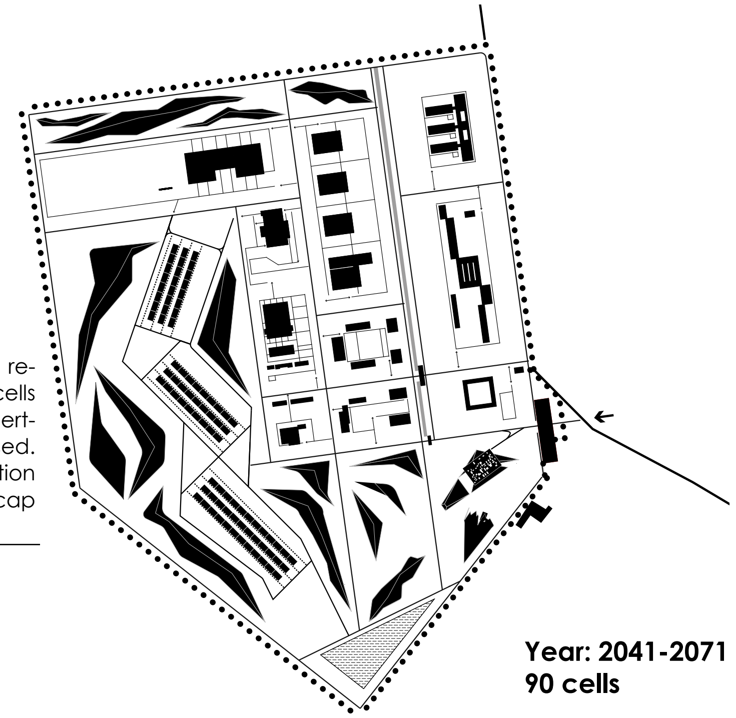


Year: 2021-2025
Construction



Year: 2025-2041
50 cells

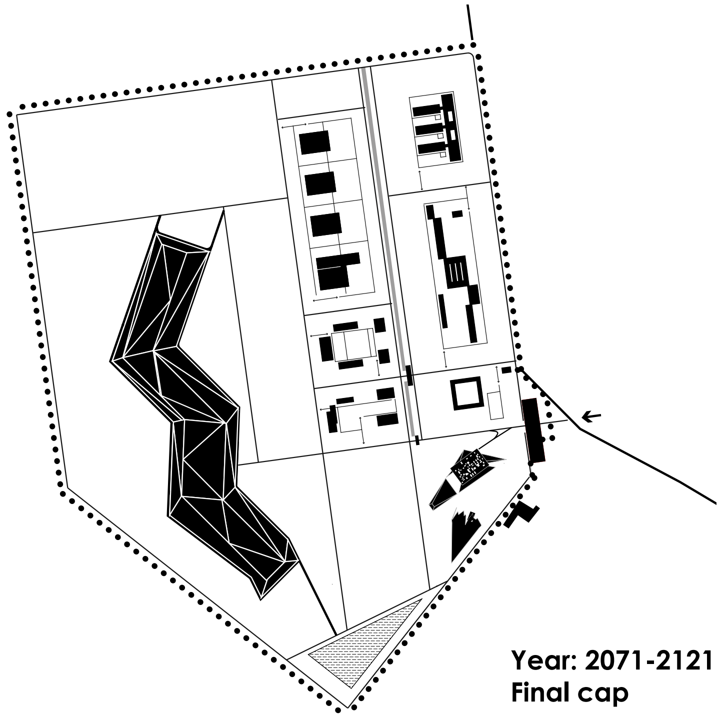
At this stage remaining 40 cells have been inserted and closed. The construction of the final cap has begun.



Year: 2041-2071
90 cells

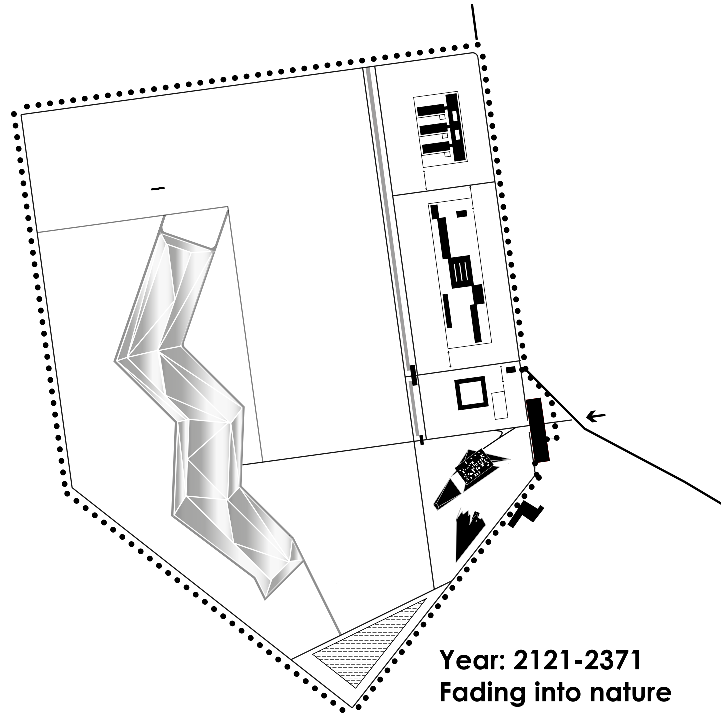
50 years — **POST-OPERATIONAL PHASE** — **100** years — **POST-OPERATIONAL PHASE** — **350** years — **POST-OPERATIONAL PHASE**

The end of the pre-operational phase. All the engineering containment and isolation features have been put in place, operational buildings and services have been decommissioned.



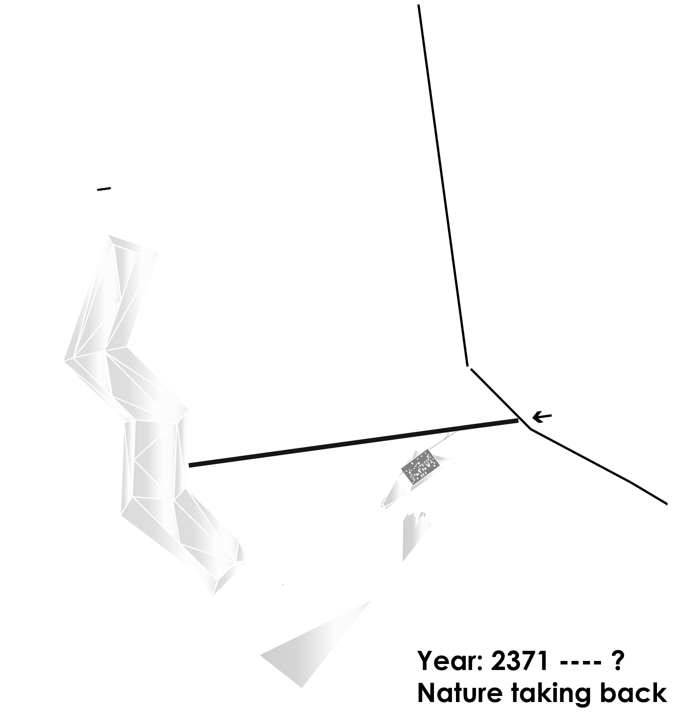
Year: 2071-2121
Final cap

The High Activity Storage buildings have been decommissioned. Only Technological Park and the Archive operate on site. However, control points are not discharged.



Year: 2121-2371
Fading into nature

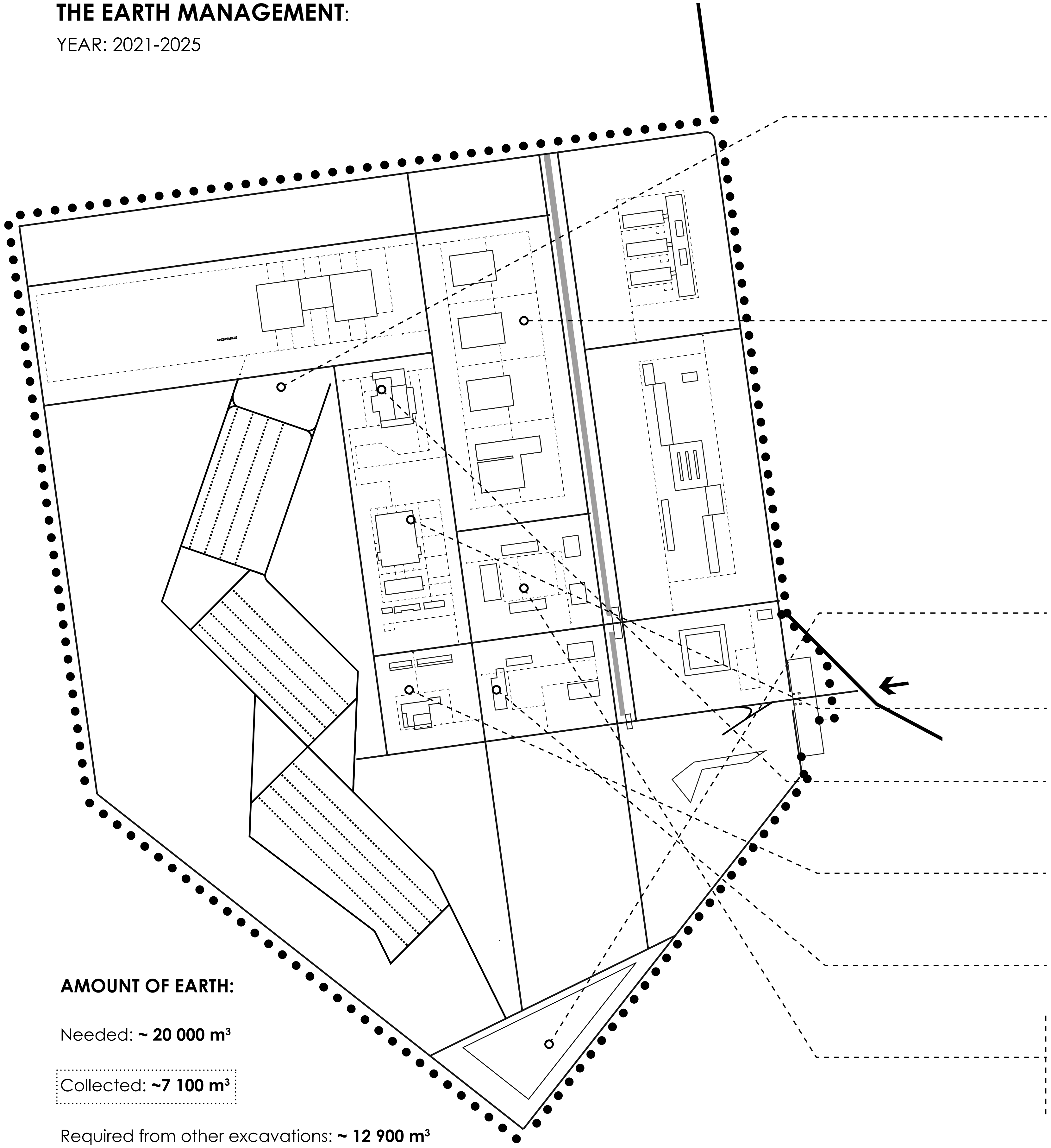
The site returns to its previous form and conditions. All the buildings, except the Archive have been demolished. The Toxic Heritage is melting into nature.



Year: 2371 ---- ?
Nature taking back

THE EARTH MANAGEMENT:

YEAR: 2021-2025



AMOUNT OF EARTH:

Needed: **~ 20 000 m³**

Collected: **~7 100 m³**

Required from other excavations: **~ 12 900 m³**

0 ⟶ 4 years

AMOUNT	STRUCTURE / SECTION
3 910 m³	**Modules Disposal Unit** cross section: -1,50 / -3,40 / -6,65 longitudinal section
1 160 m³	**HLW and ILW temporal storage buildings** -4,30 / -11,00 -4,30 -4,30 -4,30
~650 m³	**Water reservoir** -3,70
70 m³	**Modules production plant**
370 m³	**Modules packaging plant** -4,40
200 m³	**Waste treatment plant** -4,00
15 m³	**Quality control plant** -0,55
10 m³	**LAB** -0,55
10 m³	**Health sector** -0,55
~600 m³	**Other**

THE EARTH MANAGEMENT:

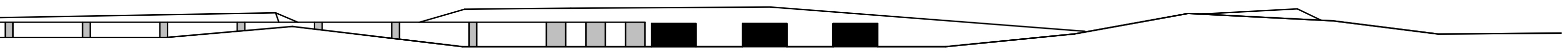
YEAR: 2025-2061

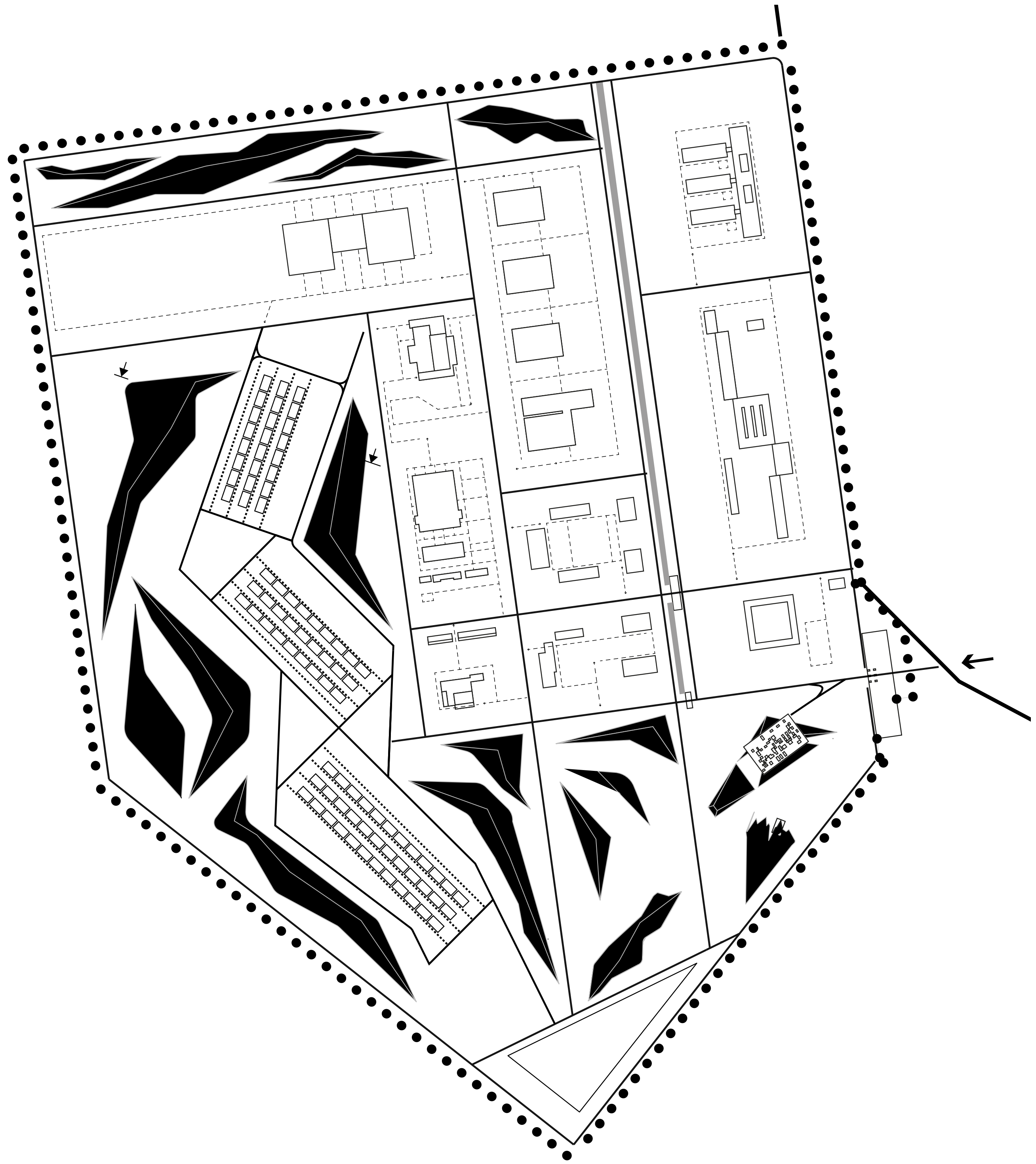
4 years - - - - - - - - → **40** years

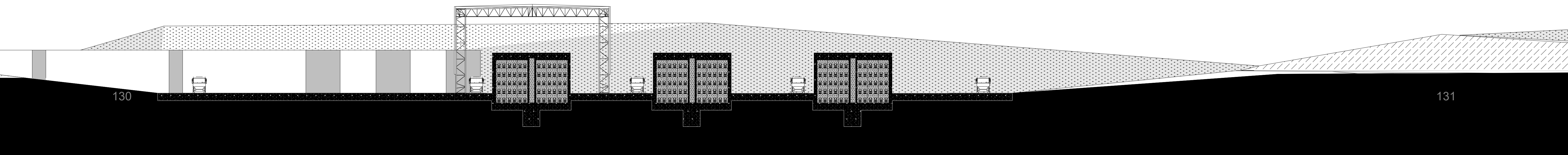
DISTRIBUTION OF THE COLLECTED EARTH:

THE ARTIFICIAL HILLS.

The artificial hills are distributed within the territory as the elements which prevent the visibility from the North, South and West.



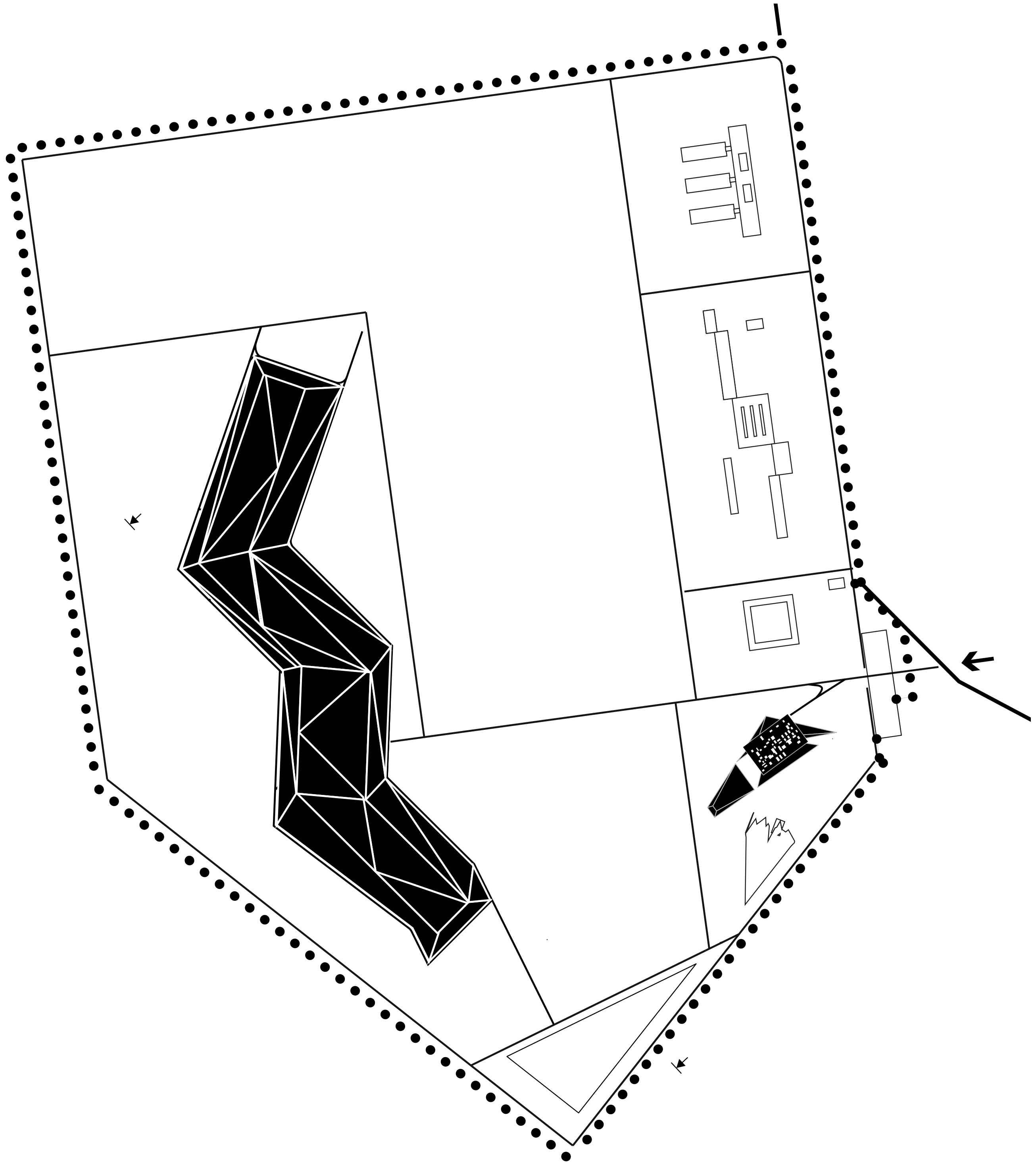


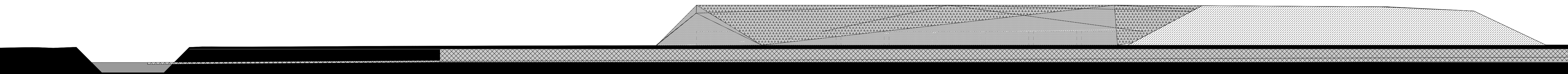


THE EARTH MANAGEMENT:

YEAR: 2071-2371

50 years **FINAL CAP.** → **350** years





HUMAN-NATURE INTERACTION

Hills formed from soil collected on site

Concrete ground

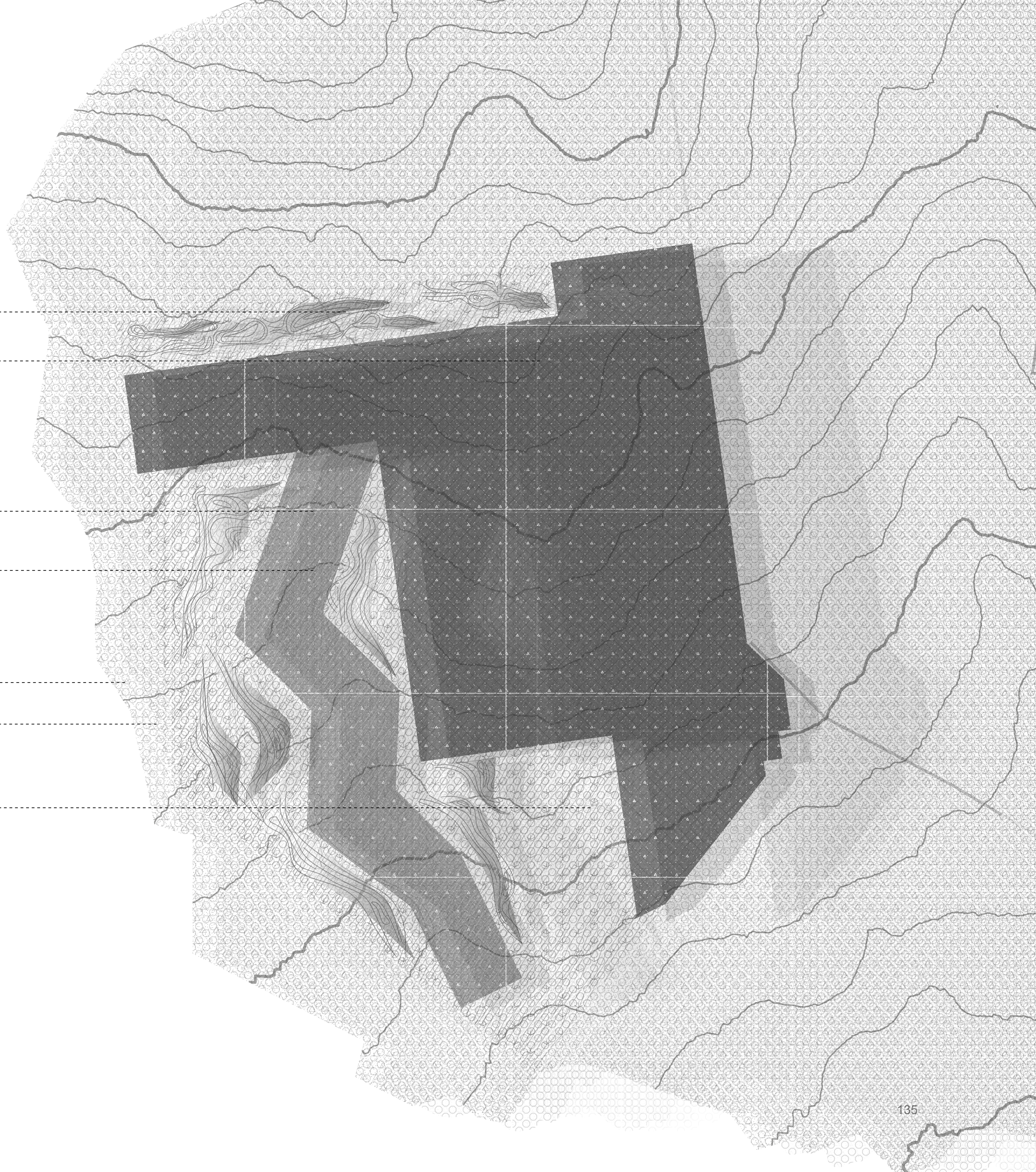
Waste disposal - concrete ground (0-50 years)

Waste disposal - hill (51-350 years)

Water canal

Land

Hills formed from soil collected on site



NATURE

SEMI-NATURE

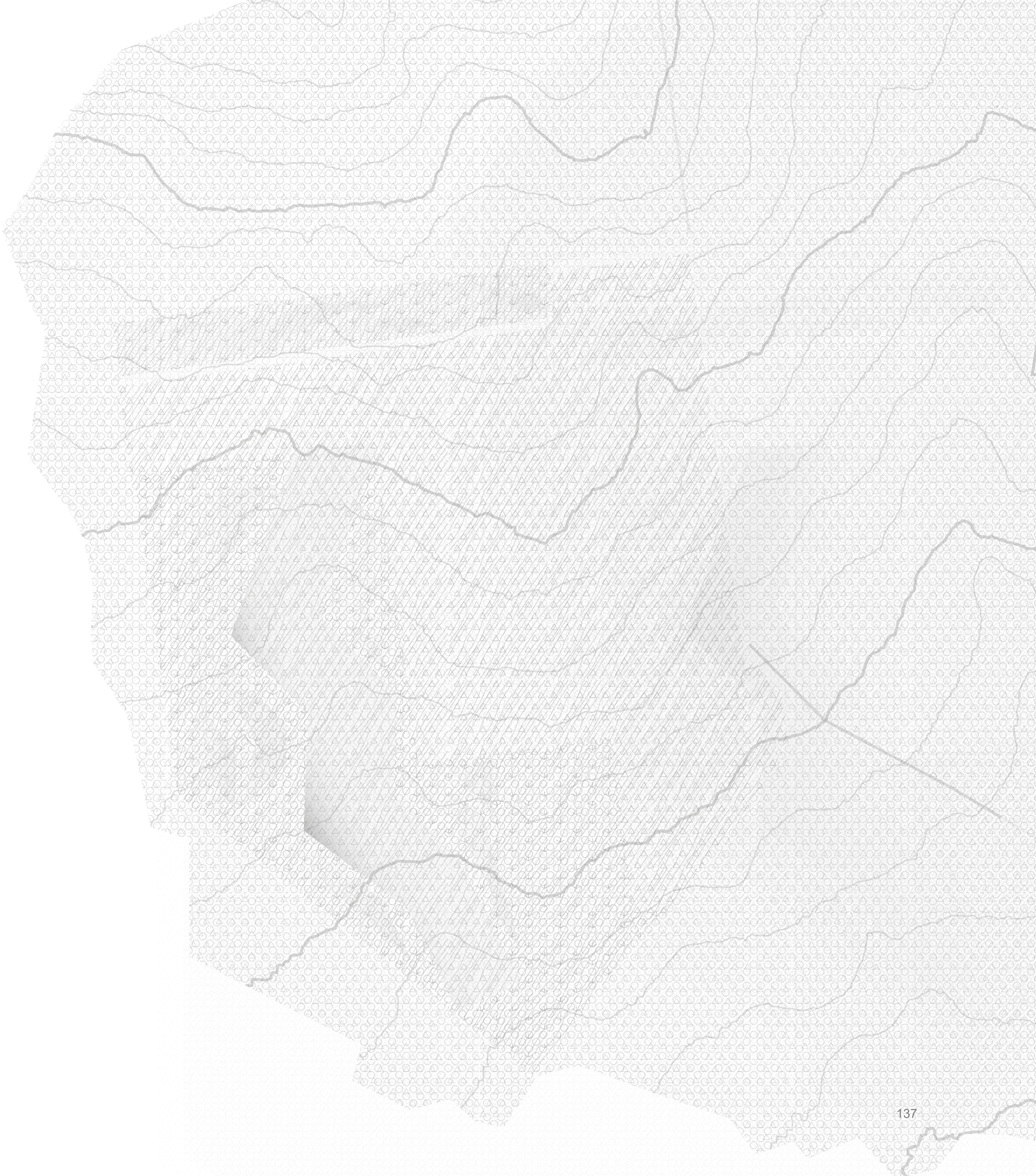
SEMI-ARTIFICIAL

ARTIFICIAL

HUMAN - NATURE INTERACTION:

AFTER 350 YEARS

Nature tacking back



"To make the story last, it has to be a thing of beauty and it needs vivid descriptions that appeal to emotions. Boring, complex, or difficult to understand metaphors, can turn an imaginative journey into a lifeless plot. Emotions are subconscious and they will leave a trace long after the words have been forgotten. Art and cultural heritage give such stories and provide compelling metaphors for radioactive waste."

— Codée and Verhoef, *"What's the story? Using art, stories and cultural heritage to preserve knowledge and memory,"* 56.

6.2

THE ARCHIVE

Concept:

How can a repository be perceived as a safe place? Why would people desire to visit it? How to overcome fear? One of the answers to these questions was in creating a space in which people will be able to find additional information than that on the repository.[100] For instance, the Archive with information centre/exhibition space and the Technological Park with the research centre and training school can help to make this a valuable and attractive place, worth visiting and informing oneself about. Besides, these functions enable other crucial aspects in the management of radioactive waste: they keep the place alive, which in turn means that the memory will be passed and the knowledge to future generations will be delivered (see subchapter 3.3.1).

Context:

On the grounds of the abovementioned, this master thesis provided an architectural proposal for an Archive - a heritage institution within the repository site. The Archive is defined as a "collection of records that have been selected for permanent preservation due to their continuing administrative, informational, (legal and historical) value as evidence of the work of the creating organisation or programme."[101] Since the durability of the Archive is the same as of the Deposit (350 years), the major problem lays in controlling and protecting not only the written base but also the building itself. The hazards that the institution could face are of different types: political and geopolitical (such as armed conflicts), natural (such as floods), economic and social (such as censorship and book burning) and everyday hazards (such as small-scale fires).[102]

Referring to the international standards[103], the records are created in all the phases of radioactive waste management. They can be organised into three copies:

- detailed record
- summary record
- public utility easements

[100] OECD/Nuclear Energy Agency, *Radioactive Waste Management and Constructing Memory for Future Generations. Proceedings of the International Conference and Debate, 15-17 September 2014 Verdun, France*. Radioactive Waste Management, NEA No. 7259 (Paris: OECD Publishing, 2015), 28.
[101] Ibid., 23.
[102] Ibid., 22.
[103] Ibid., 23.

For long-term consideration, all records should be duplicated on 'permanent paper'. It enables long-term durability, easy and secure access to the documents, and detours the impossibility to demonstrate that digital archives will be legible for at least 300 years. The Archive houses not only written records but also an enormous number of images and illustrations. Moreover, it may offer around 30-40 full-time jobs and several temporary posts.

The Archive is an ongoing process, therefore, as long as people are involved, the knowledge that it contains, remains alive. Furthermore, the Archive may be a place where not only the *'knowledge'* has been preserved, but also - the place of remembrance, the place that holds *'memory'*. In this case, the Archive will serve as a point of attraction for citizens living nearby, tourists and general visitors of the Toxic Heritage. It will be a tool of communication between the private sector and people; between present and future generations.

Strategy:

Being strongly connected to the master plan, the project is an outcome of an experience design: the experience of people of the present and of the future; employees and visitors. The proposal consists of three fundamental parts: *the thick horizontal slab (the Archive)* that rises marginally off the ground; *the excavated space (the visitors' centre)* under the slab, which, in turn, slightly transforms into the *artificial hill (panoramic point)* in the open air. Both the excavated space and the hill are designed for public experience, while an independent thick slab - only for private users. As a whole, a *'floating tombstone'* - spreads above the entrenched memorial, a *'cave'* with linguistic, diagrammatic, scientific and illustrative communications engraved into walls.

The landscape plays a fundamental role within the general composition: it holds the connections between the inside (knowledge) and the outside (memory); leads people by showing them where to go and what to see; separates public and private parts; establishes multiple relations between the entrance, the cave and the hill, thus defining the public path (or ritual/processional path); and finally, generates and structures the open space.

The floating slab above the cave creates an effect of a strong visual compression over the artificial landscape: it gives the impression of a looming weight. The darkness of the 'cave' is interrupted by the light penetrated from a series of holes pierced into the elevated form. The building seems like a detachment: monumental and huge.

Note[1]:

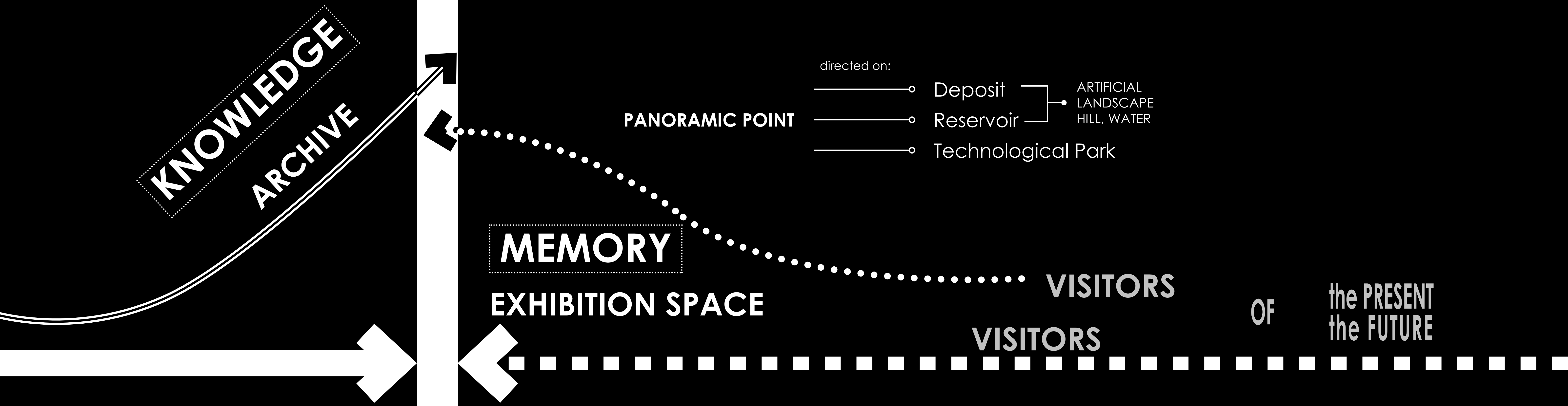
The impossibility of predicting which languages will survive in the future or how will they evolve, it is commonly accepted to use at least six UN languages: Arabic, Chinese, English, French, Russian and Spanish.

Note[2]:

Even longer than the stories and written texts are the pictures that give information to others and pass it on the next generations. As pictures do not require any knowledge of words and language, the drawings can have a meaning far into the future.

FIRST DESIGN PREMISES:

PASSING THE KNOWLEDGE AND KEEPING THE MEMORY

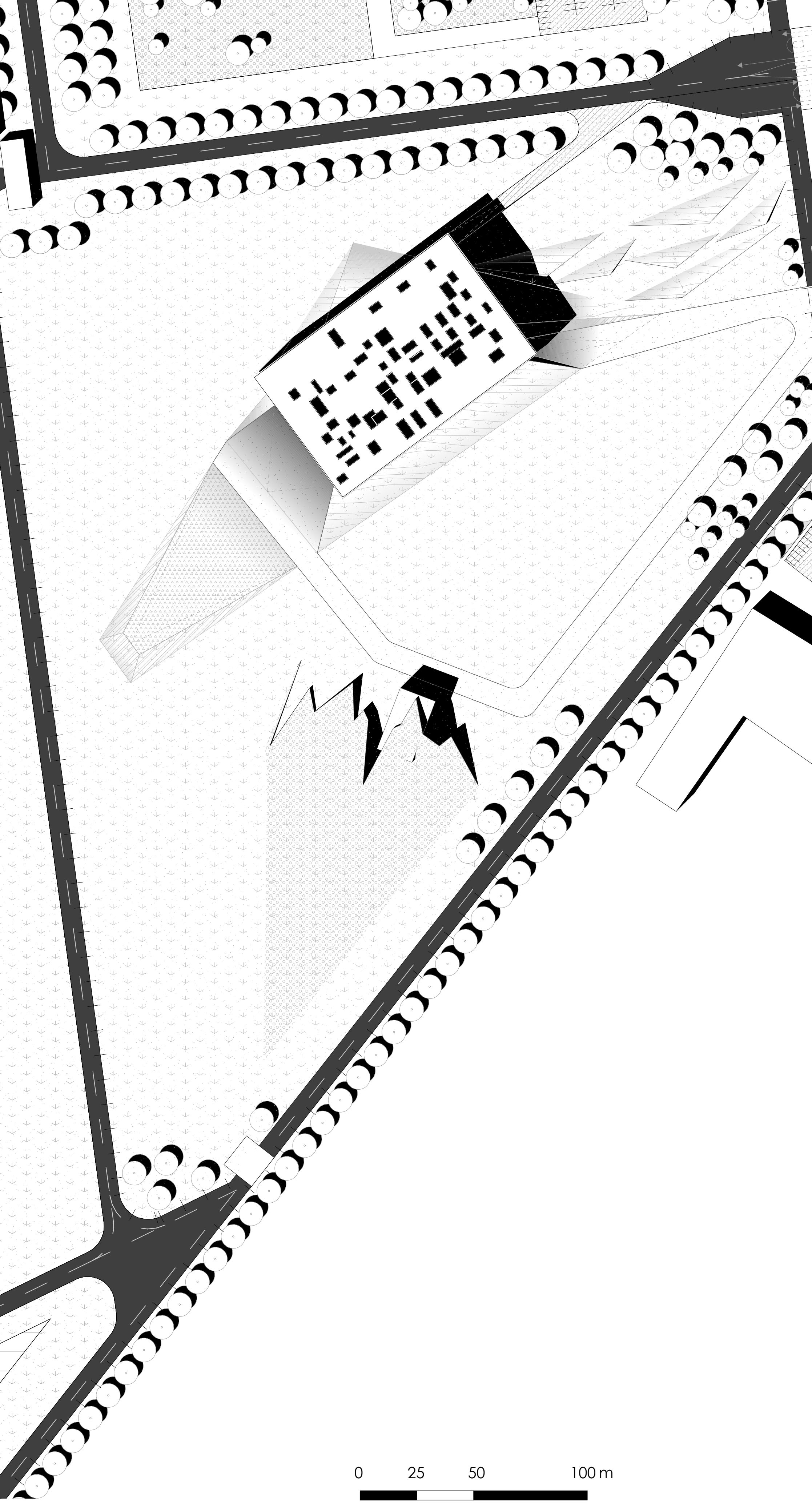


INSIDE

Archive - the repository of information; deposit; internal atmosphere; **knowledge.**

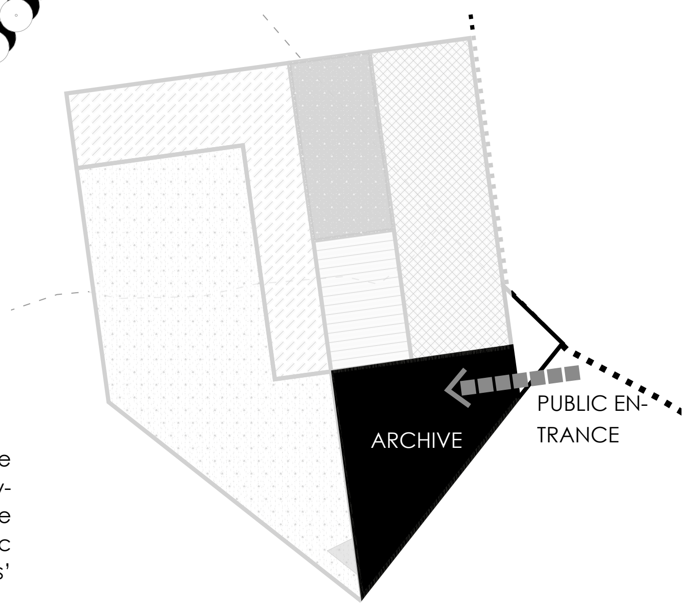
OUTSIDE

Visitors; information centre; exhibition space; demonstrative point; **memory.**



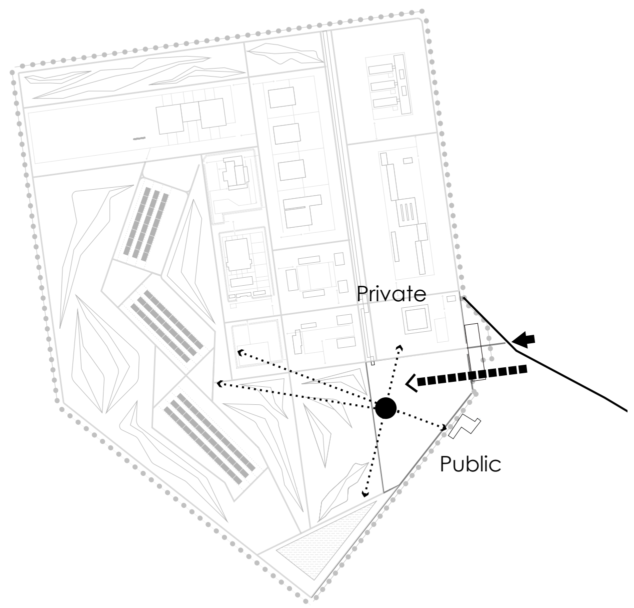
CONCEPTUAL DIAGRAMS

1



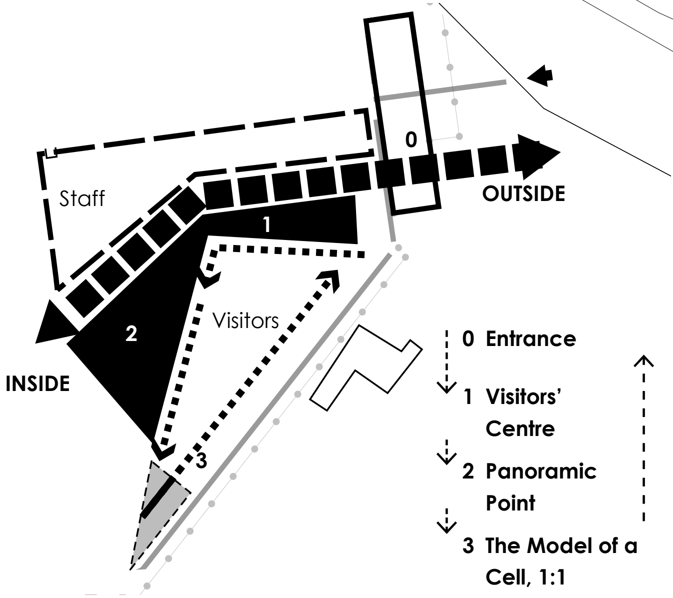
Connection with the Master Plan. Identifying the location of the Archive and public Entrance for Visitors' Centre.

2



Identifying the possible point with visual connections towards the Deposit (considering also the development in 50 years), the water reservoir and the Technological Park. The location of the panoramic point plays a significant role since it is one of the destinations of visitors.

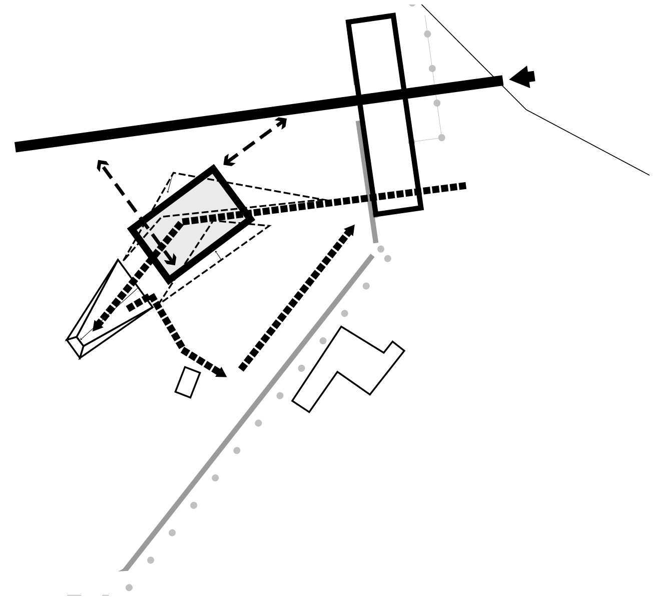
3



The connection of the Entrance and visual point; knowledge and memory. Identification of the visitors' Processional Path.

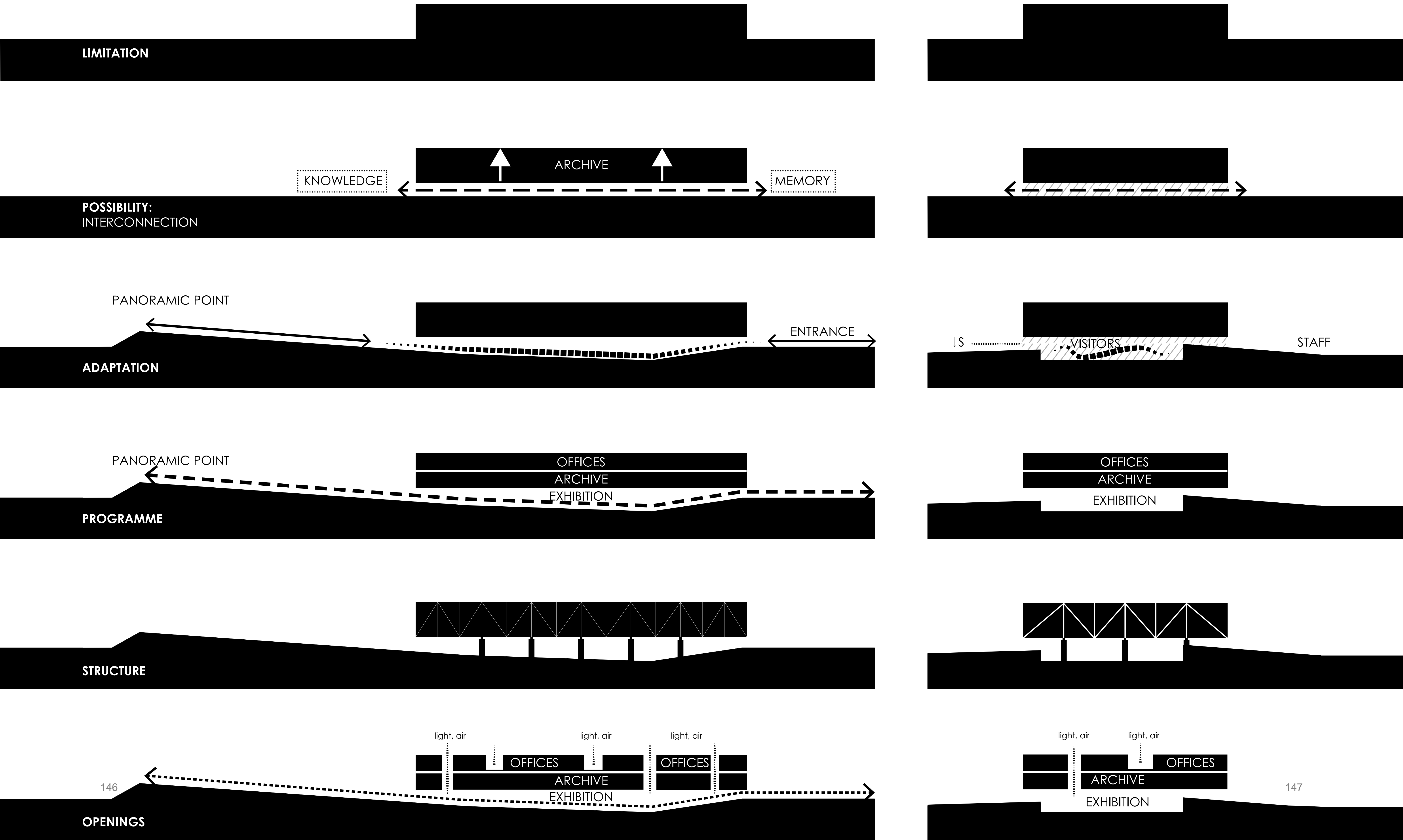
Division the space into public/private.

4

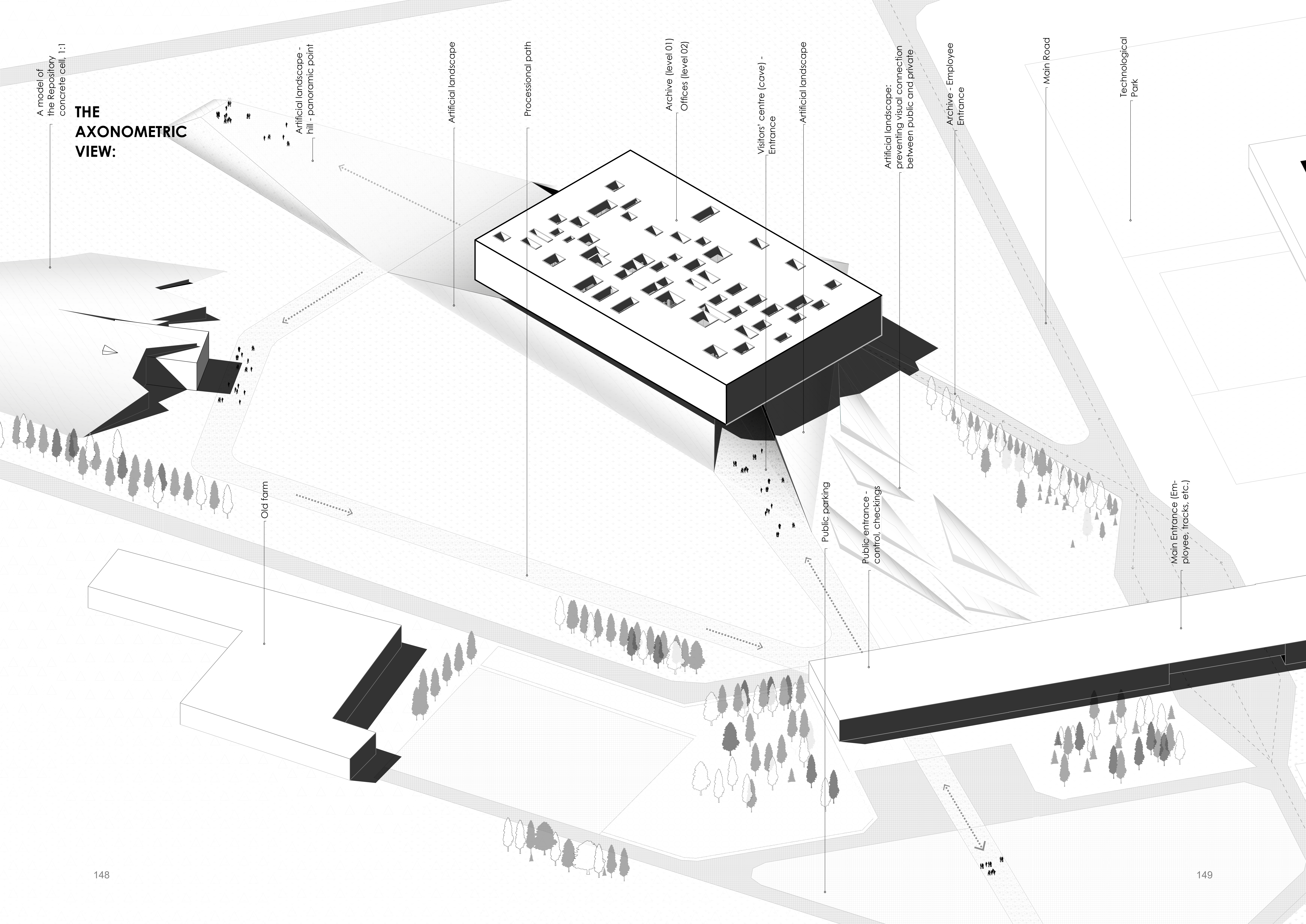


Identification of the Archive position. Adaptation of the landscape by referring to **a.** the Processional Path; **b.** the division into public and private.

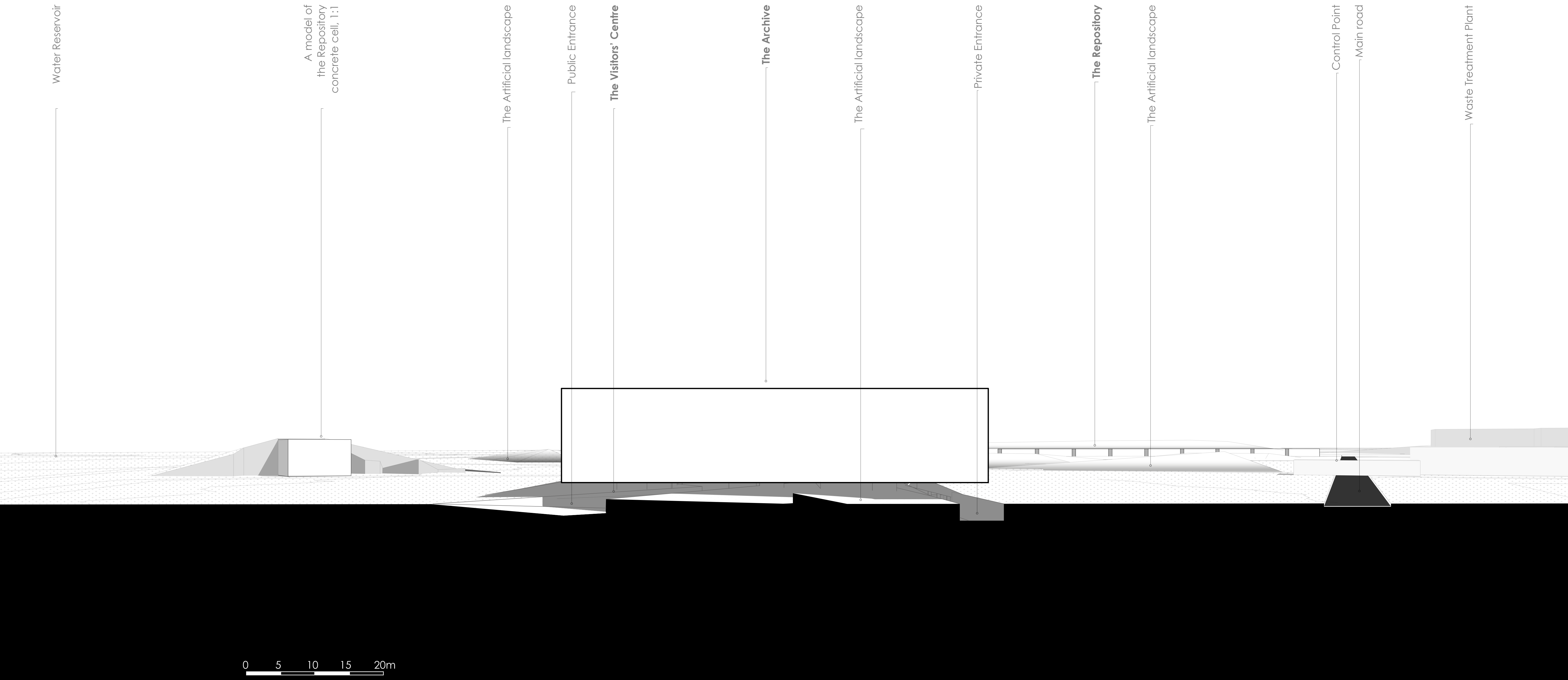
CONCEPT DEVELOPMENT



THE AXONOMETRIC VIEW:



THE ELEVATION:
North East



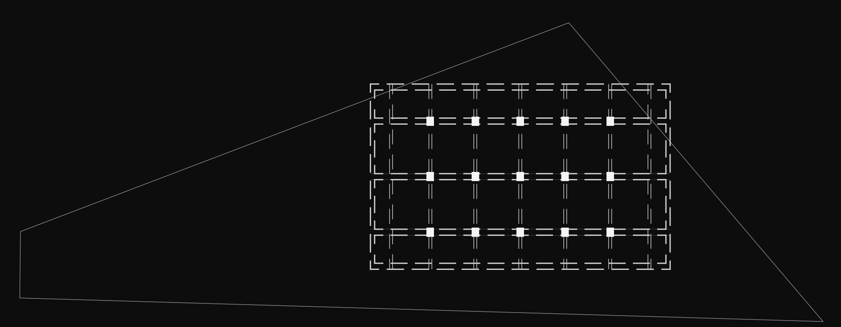
THE PLAN:

LEVEL - 01

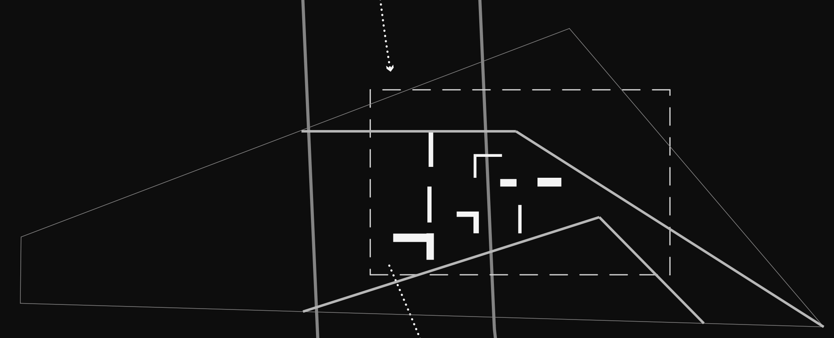
LEGEND

1. Visitors' centre
2. Communication walls
3. Employee entrance
4. Archive entrance

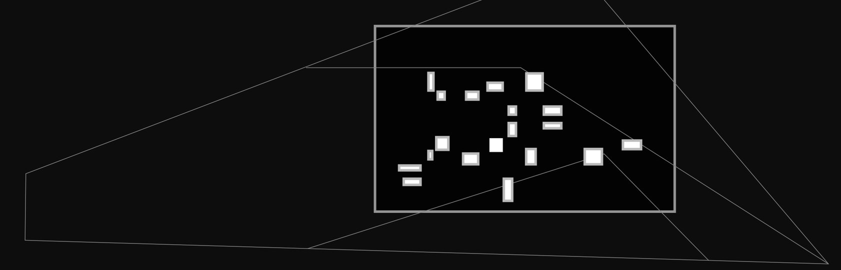
STRUCTURE



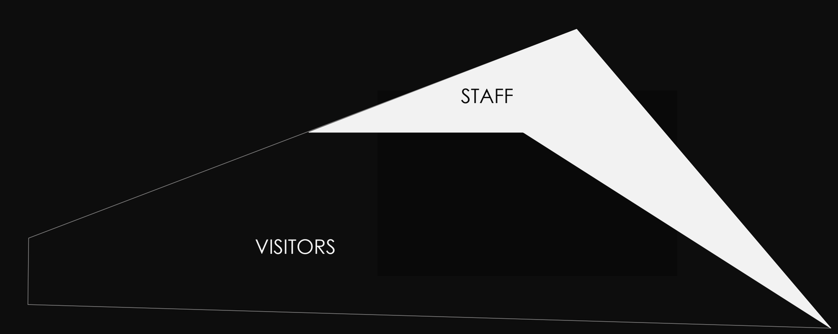
COMMUNICATION WALLS



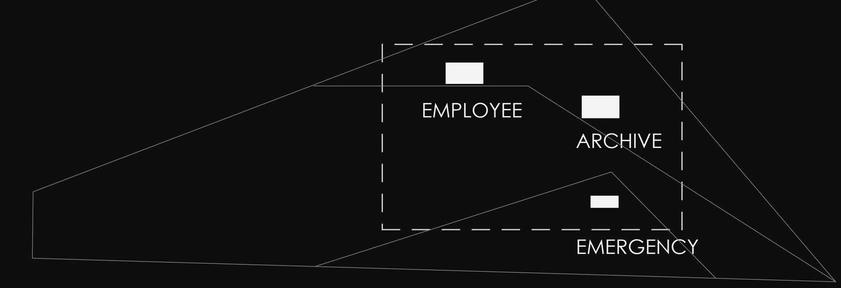
LIGHT/AIR



PUBLIC/PRIVATE



PRIVATE ENTRANCES

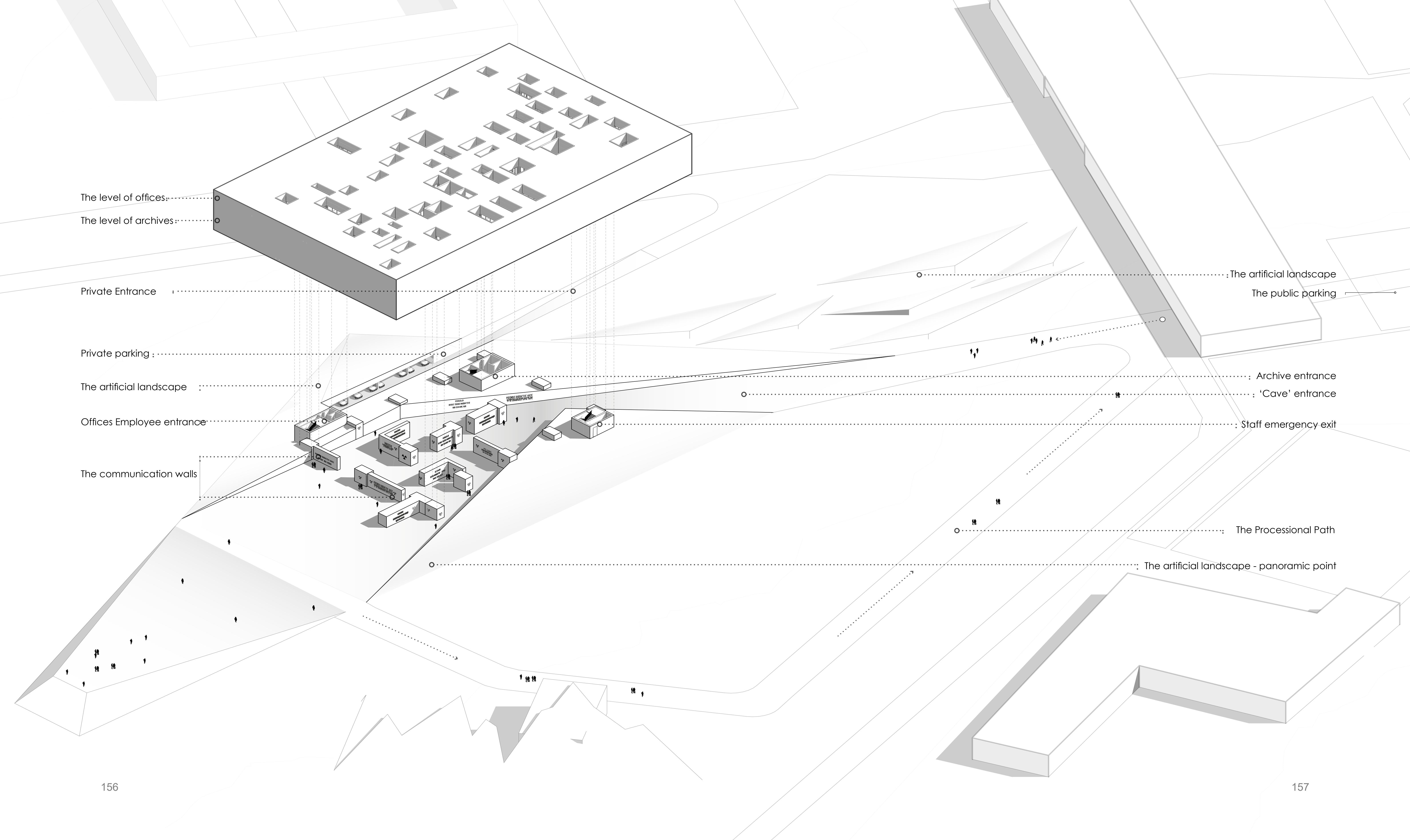


THE PLAN:

LEVEL 00

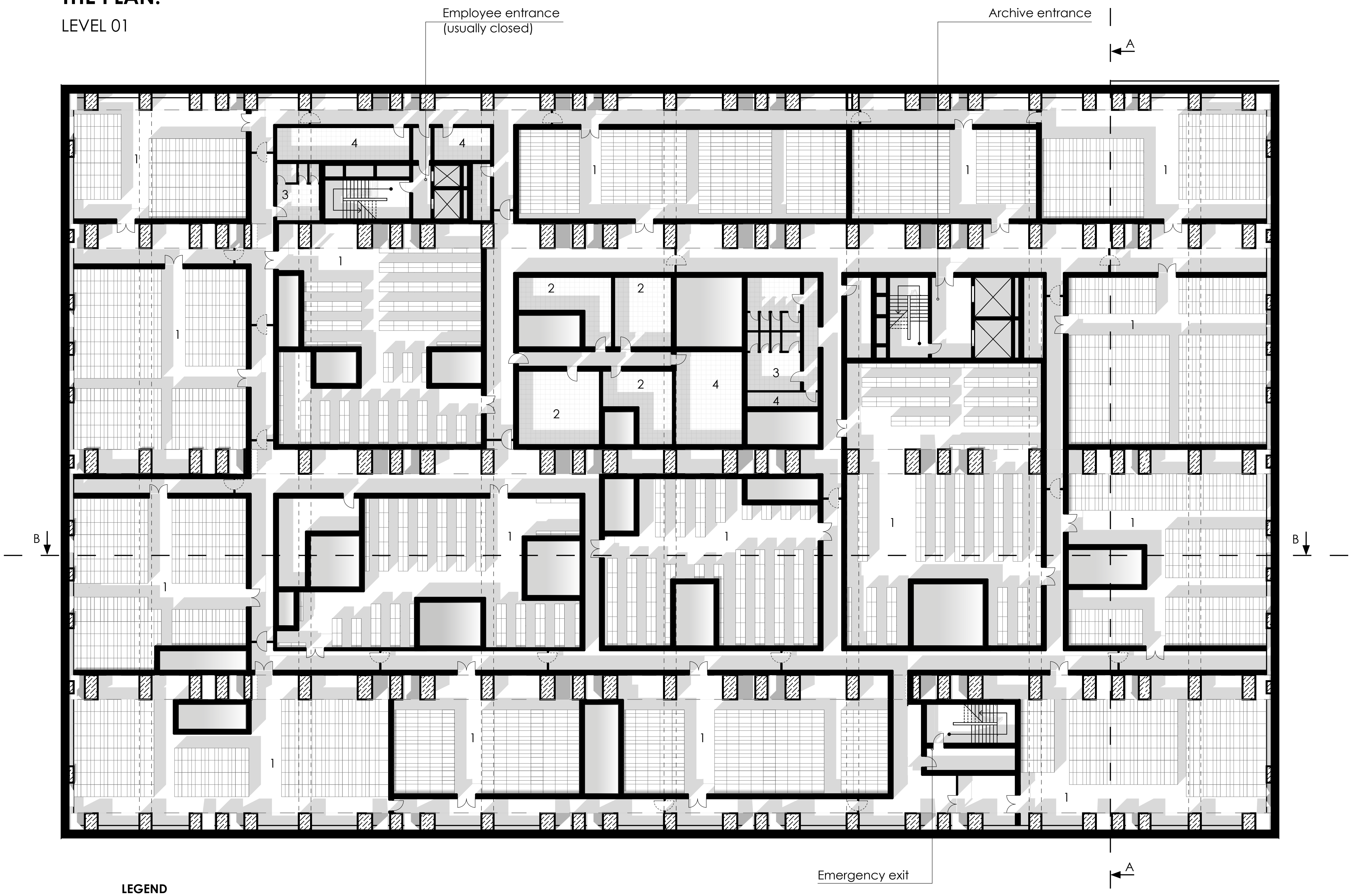
THE AXONOMETRIC VIEW:

LEVEL -01; LEVEL 00.



THE PLAN:

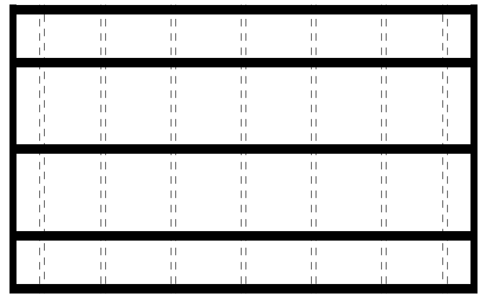
LEVEL 01



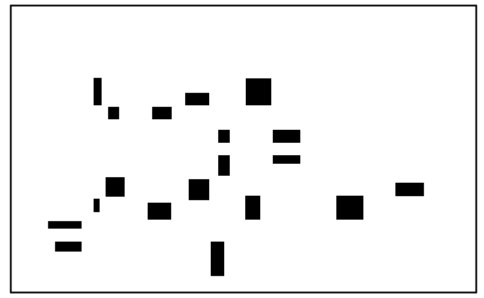
LEGEND

1. Archive
2. Storage
3. Services
4. Technical room

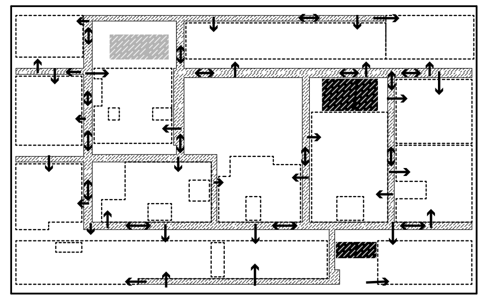
0 5 10 15 20 m



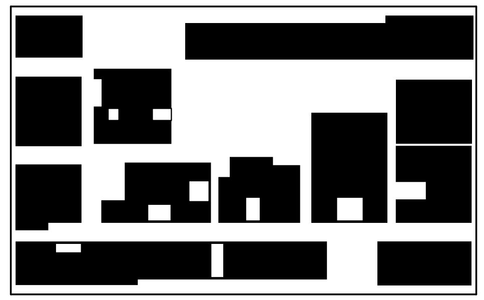
STRUCTURE



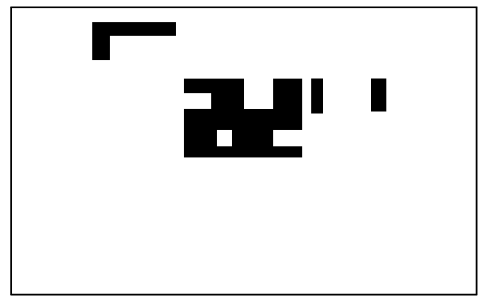
OPENINGS



CIRCULATION, ENTRANCES



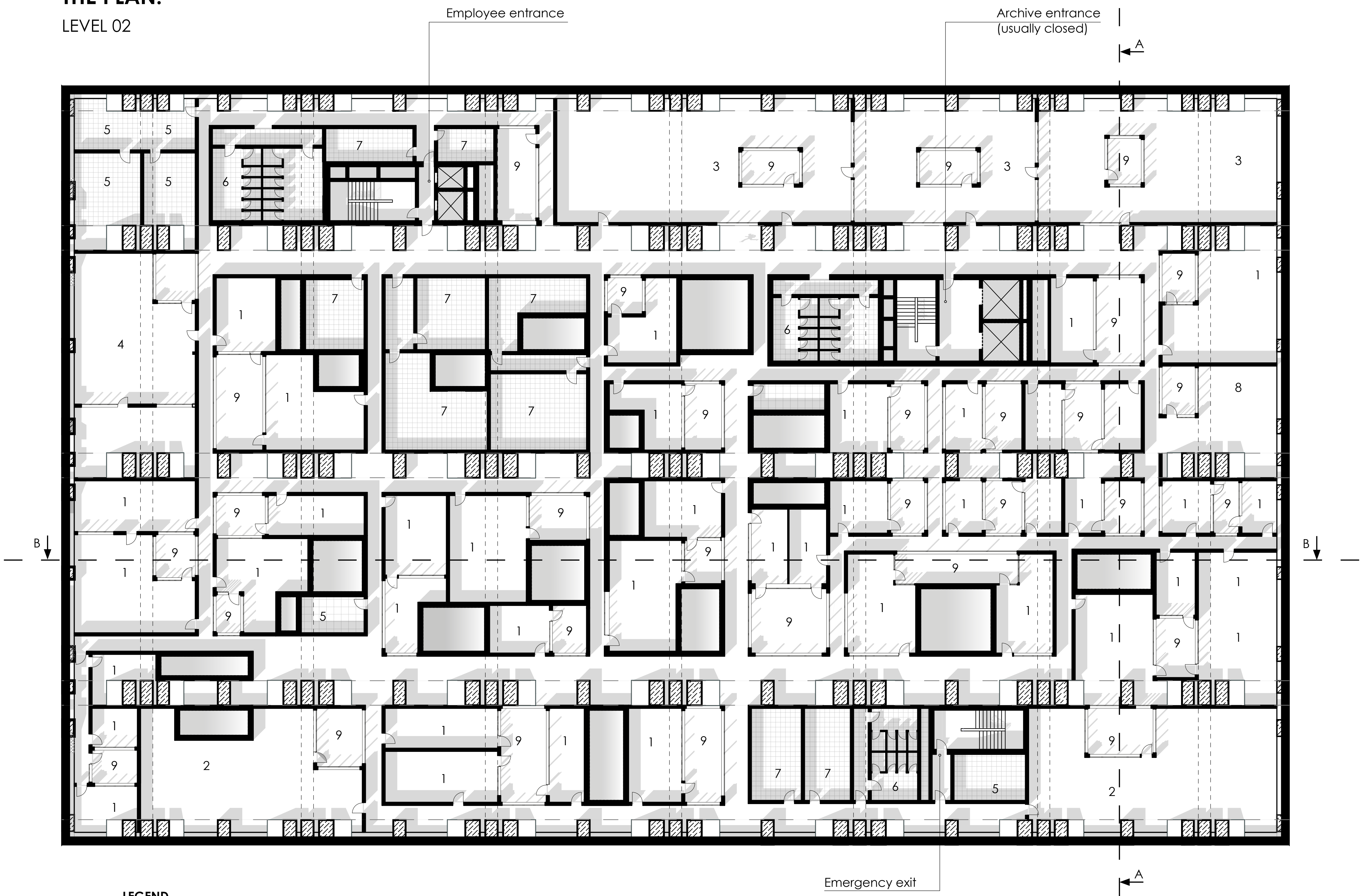
ARCHIVES



TECHNICAL ROOMS, STORAGE AND SERVICES

THE PLAN:

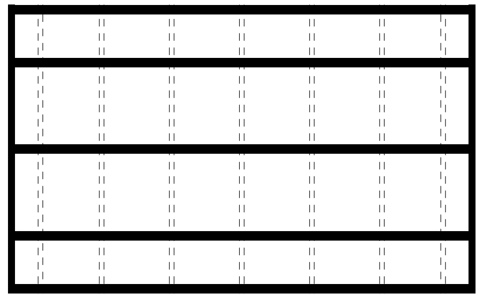
LEVEL 02



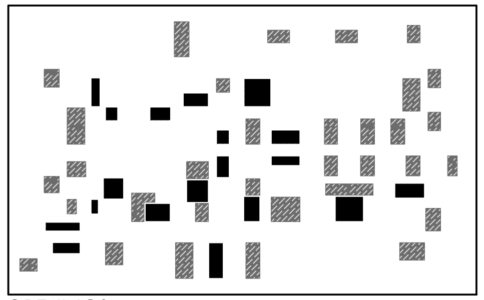
LEGEND

1. Office
2. Laboratory
3. Workshop
4. Meeting room
5. Storage
6. Services
7. Technical room
8. Open space
9. Courtyard

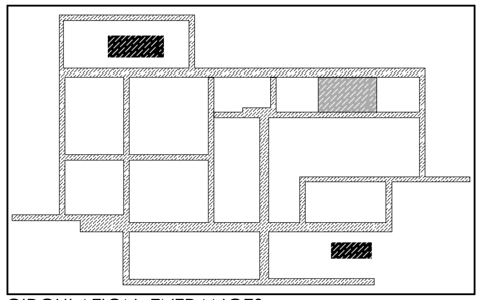
0 5 10 15 20 m



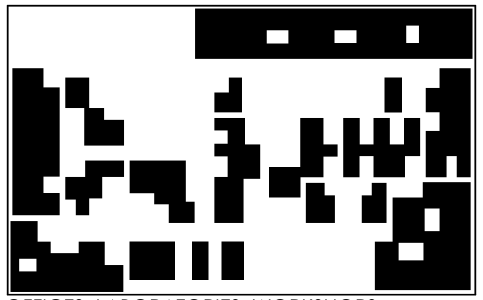
STRUCTURE



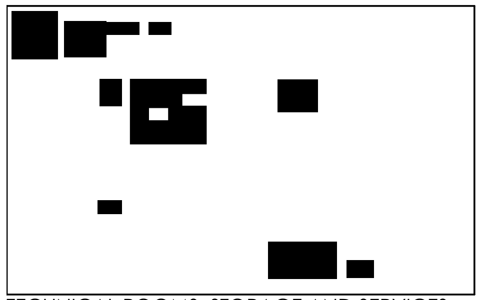
OPENINGS



CIRCULATION, ENTRANCES



OFFICES, LABORATORIES, WORKSHOPS



TECHNICAL ROOMS, STORAGE AND SERVICES

THE SECTION:

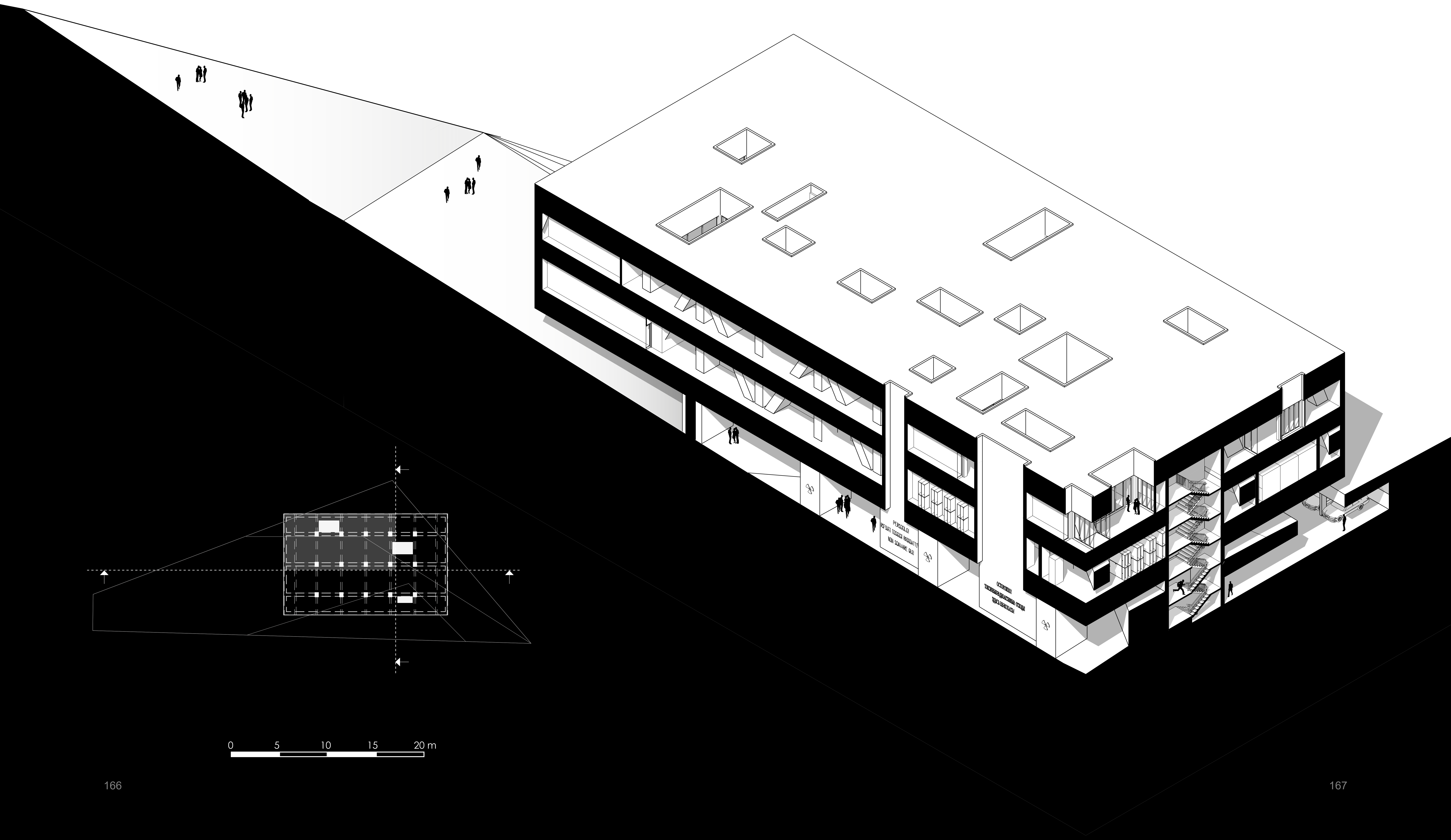
AA

THE SECTION:

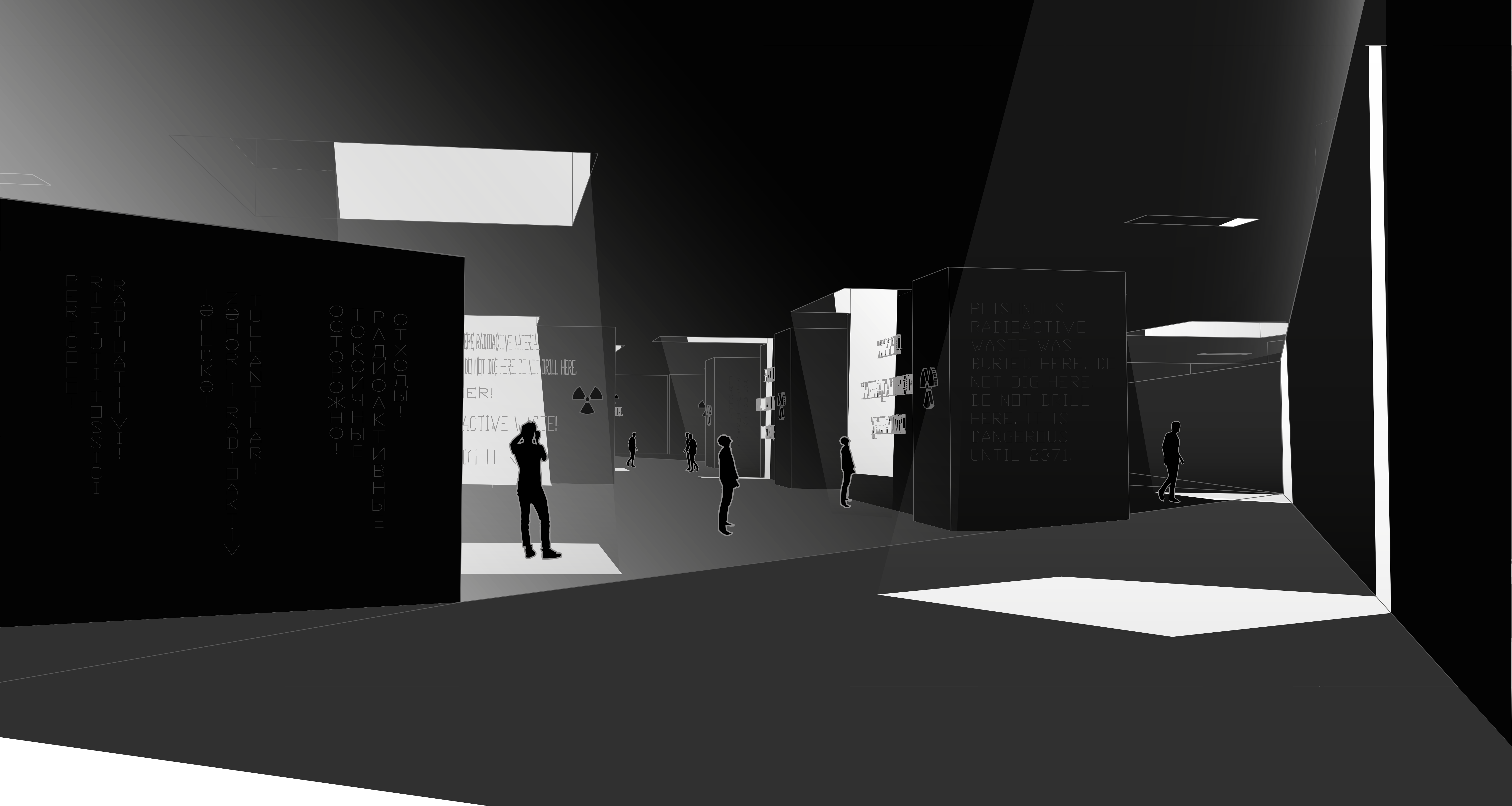
BB

THE SECTION:

AXONOMETRC VIEW

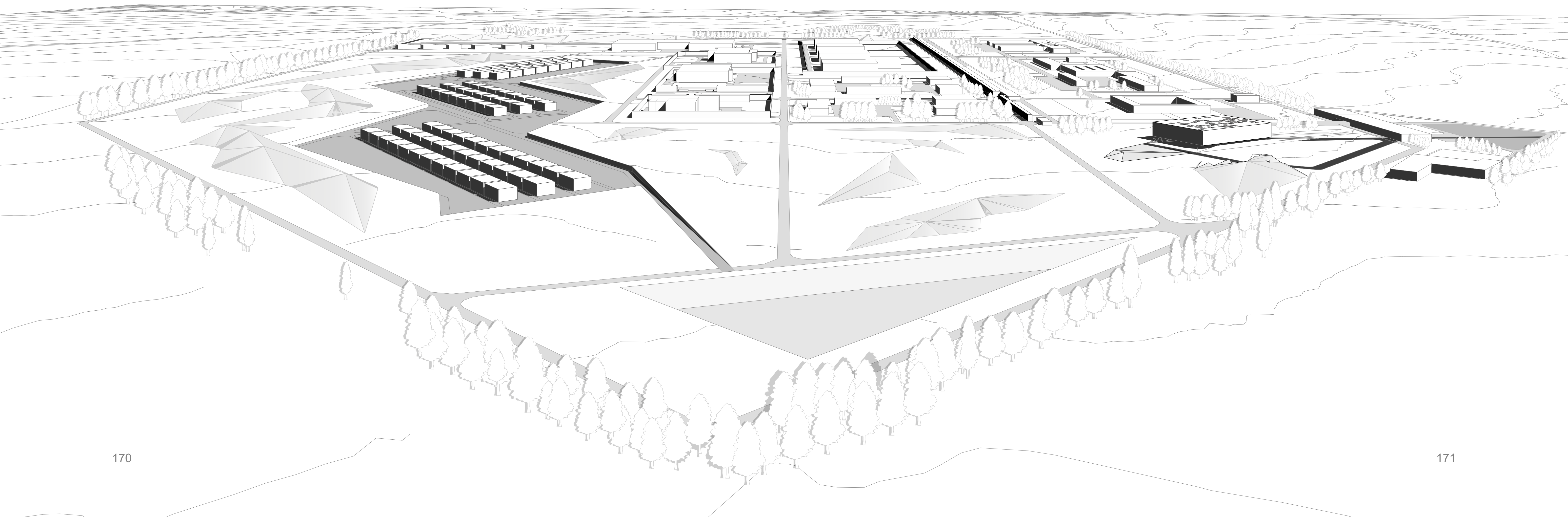


THE VIEW:
THE VISITORS' CENTRE



THE VIEW:

THE NATIONAL REPOSITORY AND THE ARCHIVE



CONCLUSION

> "One could say that a monument *to* something is an anchor of presence dropped into time by a people unsure that they will be remembered or perhaps *how* they will be remembered if they are at all. Monuments are left to posterity to things worth remembering, to things of value, that we value, things for which we wish to be remembered. In this sense, such undertakings are not exactly about the future. Rather, they are about the anxiety of the present—an ontological anxiety — precisely with respect to the very uncertainty of the future *(le dur désire de durer)*. The desire is to make permanent that which threatens to disappear irretrievably. The very idea of a monument to something that we wish would never have come to presence to begin with—and something that persists (literally) in the present, and actively performs its danger on the safety of the future, even as it impinges on our own—is a very unsettling thing." [104]

This thesis was intended to develop the architectural proposal for the Italian National Repository of Radioactive Waste and Technological Park. The study shed light on the social, cultural and psychological aspects in the management of radioactive waste, which were proven to be as important as technical ones. The research revealed huge aspects which stand behind radwaste management: its particularly long life span and the uncertainty of the future.

The integral part of the industrial process should be the transmission of knowledge and memory. Apparently, if the message must reach future generations, we should start involving a current one. The matter of radioactive waste should attract a particularly large amount of attention in society, from media, politicians to grassroots activists. This could be done in any possible way: for instance, cultural heritage, storytelling and art seem to be relevant in this task. By learning from the examples of the survived monuments, the archaeological applications have drawn the lessons of what attracts more attention and what has acquired a cultural significance. A new generation, a new culture must come to decrypt this place in the landscape, in a way we decrypt the Pyramids of Giza (2700-2500 BC), the Acropolis (447-424 BC) or the Stonehenge (2700-2600 BC).

The architectural proposal involved the master plan, which was elaborated as an integral part of the existing landscape and through adaptation of it to the standards and proposals, provided by SOGIN. The master plan was established as an ongoing process within different phases of management. Such issues as safe transportation of radwaste, transparency and democracy, security and accessibility, the industrial process and social involvement, human-nature interactions were taken into account.

[104] Peter C. Van Wyck, *Signs of Danger: Waste, Trauma, and Nuclear Threat* (Minneapolis and London: University of Minnesota Press, 2004), 80-1.

Besides, the thesis has considered a national institution - the Archive - as a tool of communication with future generations. The Archive is revised as a space where heritage and art, knowledge and memory, publicity and privacy, control and transparency while being separated, merge into one. At the same time, these relations are directly connected to the management of radwaste. Mixed and related, they cannot be set apart. The building is supposed to be cultural heritage, a statement by itself. Through such institutions, people will be able to visualise radioactive waste, thus "creating an international community of guardians, weaving a link from one generation to the next."[105] Such proposals would work towards studying all the non-technical resources that could preserve the functions of this site in its landscape.

Not to mention, the processional path for visitors represents a fundamental aspect in the architectural intervention, since a direct connection between the management of radioactive waste and long-term preservation of heritage enables in creating the atmosphere of reliance and belief. As expressed by Kevin A. Lynch[106], ceremonies like this - "[a] deliberate engagement with the waste […]" - will not take away bad emotions, but instead could offer means of expression, with the help of which fear and confusion might be overcome. That is to say, that the less traumatic association might give a more balanced view.

The memory of each historical period of human civilization is expressed in the emergence of monuments. The monument, which has been revised in this thesis, symbolises a period, in which nuclear energy can be dangerous and uncertain. Containing the information on our nuclearized era, the monument here is an inversion by itself: it draws our attention not precisely to the past and not exactly to the future. The traces that both the Repository and the Archive will leave are likely to survive for centuries, and within that time they will acquire cultural importance. Humans will project in them their fears and desires over long-term timespans. The Toxic Heritage will extend the memory in relation to the place. An idiom, which will tell: *this is a place that we should remember to forget.*

[105] OECD/Nuclear Energy Agency, *Radioactive Waste Management and Constructing Memory for Future Generations. Proceedings of the International Conference and Debate, 15-17 September 2014 Verdun, France*. Radioactive Waste Management, NEA No. 7259 (Paris: OECD Publishing, 2015), 16.
[106] Kevin A. Lynch, *Wasting Away: An Exploration of Waste: What It Is, How It Happens, Why We Fear It, How To Do It Well* (San Francisco, CA: Sierra Club Books, 1990), 192.

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