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The decision path to site a near-surface repository

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Artist impression of the Dessel repository by ~ 2080 A.D.

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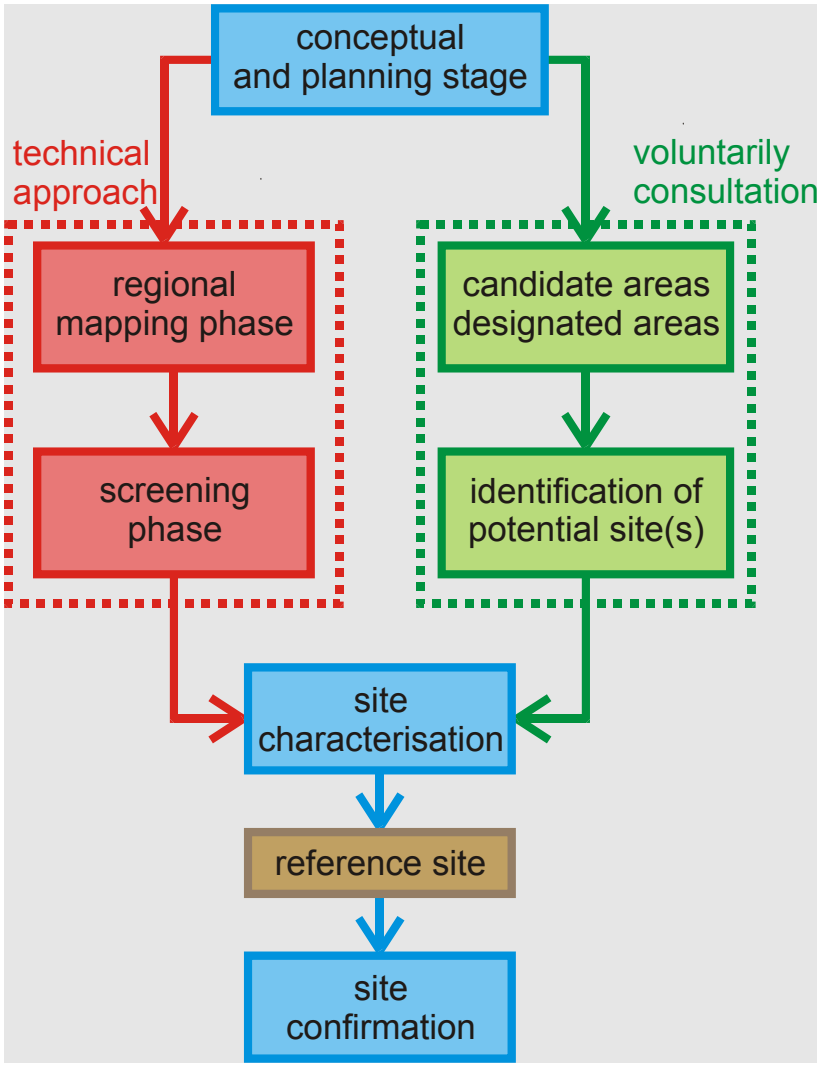
Outline

- *The site selection and confirmation process*
- *Regulator's guidance*
- *IAEA guidance*
- *Process of site selection and confirmation in Belgium*
- *Indicators of site suitability*
- *Assessment of site suitability versus regulator's guidance*

The site selection & confirmation process:
two stepwise approaches with different emphasis



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IAEA guidance on site selection

IAEA guide to siting of near surface facilities [International Atomic Energy Agency, *Siting of near surface disposal facilities – Safety Guide*, IAEA Safety Series No. 111-G-3.1, IAEA, Vienna, December 1994]:

- " *The purpose of siting is to locate a site which, along with a proper design, waste form, type and quantity of waste packages, other engineered barriers and institutional controls, will provide radiological protection in compliance with requirements established by the regulatory body…*"
- *"A suitable disposal site may be chosen either by narrowing the field of candidates from a number of sites or by objectively evaluating a single designated potential site.* ***For either method it is not essential to locate the best possible site, but to provide a waste disposal system which can be convincingly shown to comply with the safety, technical and environmental requirements****. …* "

IAEA guidance on near surface disposal (1)

IAEA Safety Guide on near surface disposal of radioactive waste [International Atomic Energy Agency, *Near surface disposal of radioactive waste – Draft Safety Guide*, IAEA Safety Standards DS356, 22 August 2008]

- " Experience has shown that the effective and safe isolation of waste depends on the performance of the overall disposal system, which consists of three major components**: the site, the disposal facility and the waste form**".

- "The suitability of a site will depend largely on **its capacity, in conjunction with the facility design and waste form, to support the confinement of radioactive wastes** for required periods of time, and thereby to limit release rates of radionuclides and potential adverse impacts of the disposal system on humans and the environment. Moreover, **shortcomings in some site characteristics may at least partially be compensated for by the robustness of engineered barriers**, which should take into consideration the isolation and confinement ability of the entire disposal system."

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IAEA guidance on near surface disposal (2)

- "In considering siting requirements for near surface disposal facilities, it is important to bear in mind that near surface disposal is primarily suited to wastes containing mainly short-lived radionuclides … and only low concentrations of long-lived radionuclides. The hazard of the waste therefore declines with time, and the period for which such facilities are expected to provide containment and isolation is therefore limited. Considerations such as site stability need to be assessed for the period of time during which the activity of waste is decaying to safe levels. "
- "In practice, governance considerations can determine that the **technical evaluation process for considering possible sites is conducted within the framework of a wider process of public and stakeholder engagement**. Depending on the national context, this might include, for example, the expectation that **siting should be based on the voluntary participation of potential host communities**. This would mean that candidate sites are restricted to areas where local populations have indicated a willingness to participate, rather than being based on purely technical factors. … "
- "… it is acknowledged that social and political considerations, alongside wider environmental factors, may well mean that **the identification of a preferred site will not necessarily be based on identifying the best location on the basis of long term disposal considerations alone**. …"

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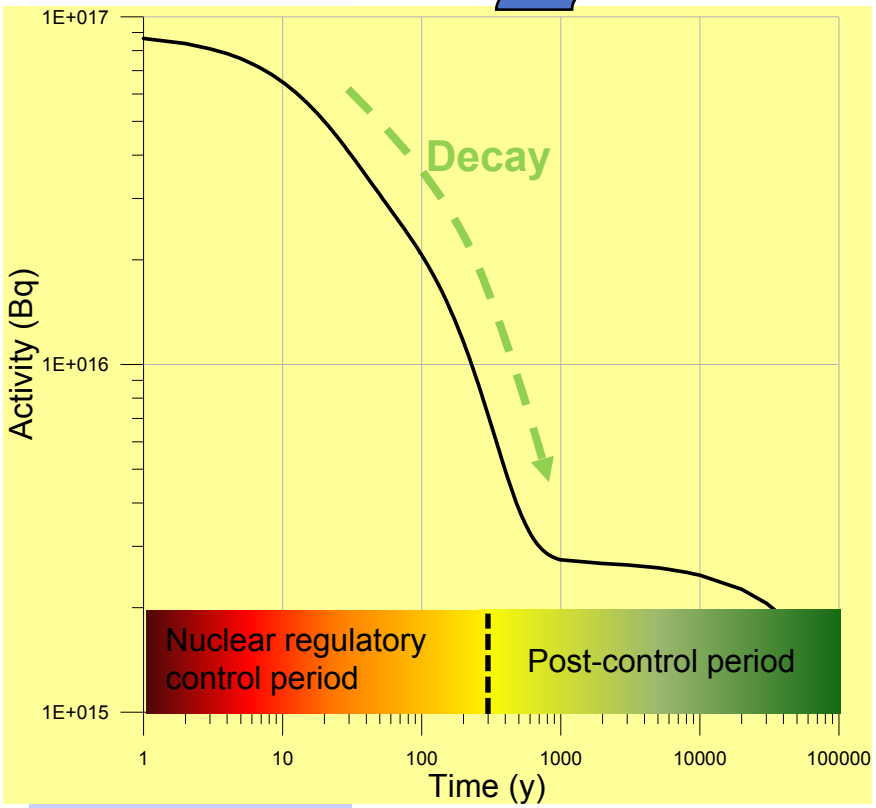
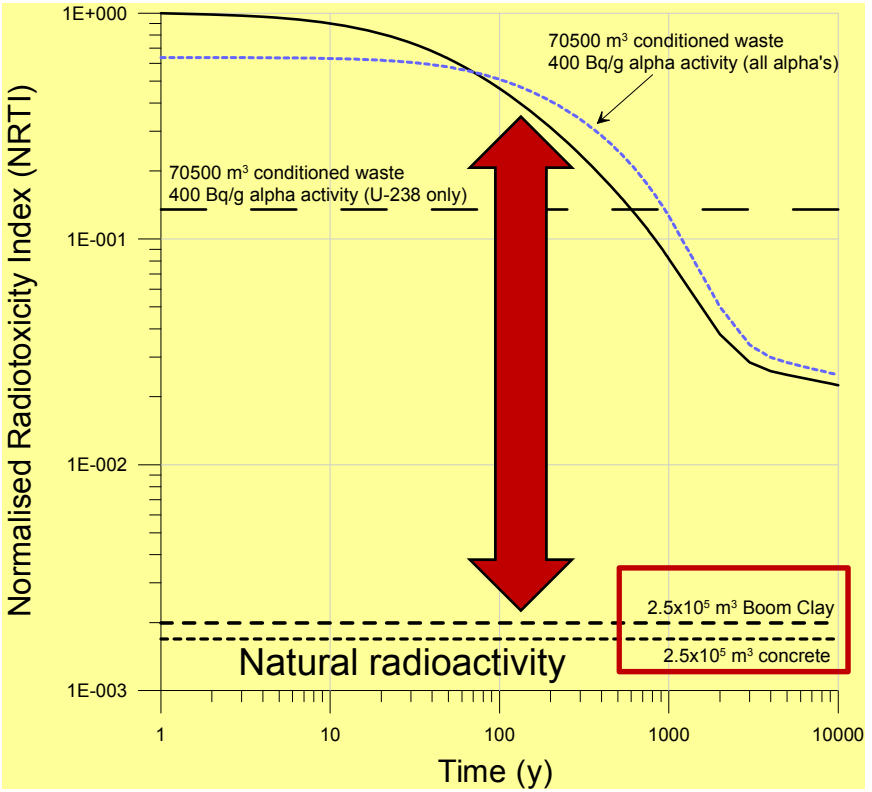
Typical LILW-SL radionuclides - subject to revision -

≤ 10^2 y	10^2 – 10^3 y	10^3 – 10^4 y	10^4 – 10^5 y	> 10^5 y
^{60}Co (5.3)	^{241}Pu (143)	^{14}C (5700)	^{59}Ni (7.6×10^4)	^{36}Cl (3.01×10^5)
^{63}Ni (100)	^{241}Am (433)	^{226}Ra (1600)	^{94}Nb (2.0×10^4)	^{99}Tc (2.14×10^5)
^{90}Sr (29)		^{240}Pu (6560)	^{239}Pu (2.41×10^4)	^{129}I (1.61×10^7)
^{137}Cs (30)			^{240}Pu (6.56×10^3)	^{234}U (2.46×10^5)
^{238}Pu (88)				^{235}U (7.04×10^8)
				^{238}U (4.47×10^9)

Activity and radiotoxicity evolution in disposal facility

Dose factor ingestion (Sv/Bq)





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LILW-SL alpha-emitter inventory
Natural radioactivity

- Average alpha-emitter concentration in LILW-SL: ~25 000 Bq / kg
- By comparison:
  - Natural uranium-activity

Soil	:	10 - 1500 Bq/kg
Coal	:	10 - 1300 Bq/kg
Fosphate fertiliser	:	1700 - 9200 Bq/kg

  - Natural radium-activity

Drinking water	:	0,015 Bq/l
Badoit/Chaudfontaine	:	0,1 à 0,5 Bq/l
Gipsum	:	10 - 1000 Bq/kg
Fosphate fertiliser	:	50 - 5000 Bq/kg
Concrete	:	20 - 300 Bq/kg

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Regulator's guidance (1)

- The site and its surroundings must contribute to the long-term "Isolate and Confine" strategy and the implementation of the safety principles that underpin this strategy:
- The site and its surroundings must limit and delay the release of radionuclides into the biosphere. The combination of geochemical and hydrogeological conditions and characteristics must, therefore, be favourable to this purpose.
- The site and its surroundings may not affect the isolation and confinement properties of the repository:
- The geology and tectonics must be stable and the site must present a low level of seismicity;
- The geotechnical characteristics must be stable, be favourable to the disposal system's stability and help to limit and control settlements;

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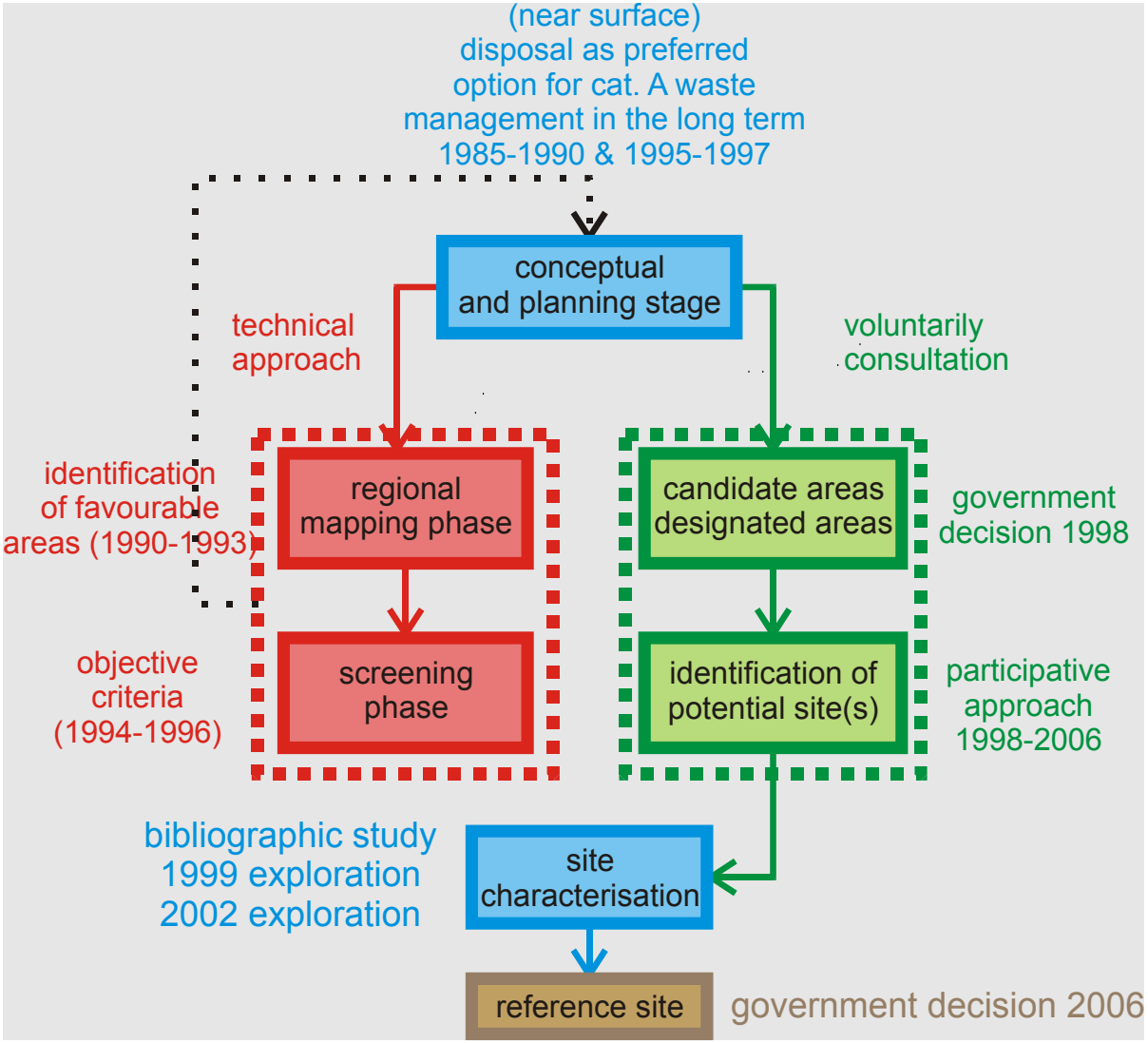
Regulator's guidance (2)

- The geochemical and hydrogeological characteristics must be stable and may not deteriorate the disposal system's components;
- Current or foreseeable human activities in the site's surroundings, including the exploitation of natural resources, may not have the potential to affect the isolation and confinement properties of the disposal system.
- The site and its surroundings must enable appropriate and reliable characterisation and conceptualisation. Among other things, the geology and hydrogeology may not present any spatial heterogeneity such as those which would not enable a reliable understanding and prediction of the transport of radionuclides.
- The site's hydrogeological and hydrological conditions must be such that the area affected by any release of activity is a small as possible.
- The repository may not, under any circumstances, give rise to a contamination of underground water which requires restrictions in use or which is likely to compromise its current or foreseeable use.

The process of selecting a reference site for a near surface repository for category A waste in Belgium – overview.



Decide

Announce

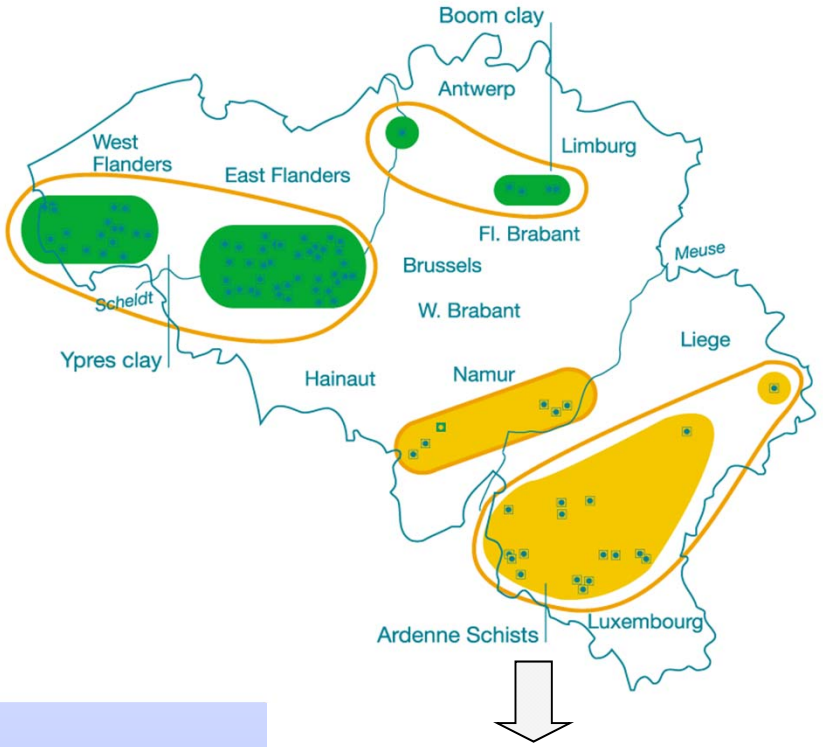
Defend

Engage

Interact

Co-operate

Technial approach: Most favourable sites in Belgium (nation wide survey in early 90's)



Main technical criteria:

- ✓ Low seismicity
- ✓ Geotechnical stability
- ✓ No risk of flooding
- ✓ Simple hydrogeology
- ✓ Absence of natural resources

Rejection by local councils and public

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Participative approach
Local partnerships: STOLA-MONA

- Working groups and members (STOLA-Dessel): 8500 inhabitants

Working groups	Members	Members of an organisation	Individual inhabitants	Experts (NIRAS/ONDRAF, university
Implantation & design	14	7	6	1
Environment & health	13	9	3	1
Safety	18	6	11	1
Local development	15	11	2	2
total	60	33	22	5

- Annual budget: 250 000 €/y for a total of 5 years (+75 000 € for design studies; + 75 000 € for socio-economic studies)
- Partnerships participated in international conferences, workshops, European Platform COWAM (Community Waste Management), field visits (El Cabril, Soulaines, ...)
- Socio-economic development (fund) seems necessary for succes of disposal project (Belgium, Canada, France, Slovenia, ...)

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The governmental decision of 16 January 1998 (translated)

For the management of short-lived low and intermediate level waste (category A waste), on the basis of the information and studies available and with the aim of ensuring cautious economic management with regard to future generations, while at the same time ensuring the best possible level of safety and wide consultation with the relevant authorities and communities, the council

- *chooses, in implementation of the government agreement, a solution that is definitive or likely to become definitive, and one that is progressive, flexible and reversible;*
- *confirms the need to make a technical and economic choice, as soon as possible, between deep and near surface disposal on the basis of comparable conditions of safety and as far as possible protecting the environment;*
- *orders the minister of the economy to instruct the Belgian Agency for Radioactive Waste and Enriched Fissile Materials (ondraf/niras):*
  - ***to limit itself in its exploratory activities, including the necessary area surveys intended to result in a technical choice, to existing nuclear zones and to zones where the local authorities show an interest;***
  - *to develop and finalise, as soon as possible, the near surface disposal concepts, in particular in terms of* ***reversibility and controllability;***
  - *to develop and finalise, as soon as possible, the studies of the feasibility and costs of geological disposal of low-level waste;*
  - *to develop* ***methods, including management and consultation structures, making it possible to integrate a project of this kind at a local level.***

While accomplishing these missions, ondraf/niras shall work in close collaboration with the safety authorities, in particular the Federal Agency for Nuclear Control, concerning all aspects related to the safety of facilities and environmental protection."

Indicators of suitability of a potential near surface disposal site (N/O)

Indicator "availability of grounds"

- *The site should be sufficiently extended in area. In principle, the potential zone selected can be much more extended than the site required for implementation of the project. In a later stage (site characterisation), the exact site location for the project is then determined.*
- *The location may not pose any prohibitive objections regarding environmental planning and ownership, now or in the foreseeable future.*

Safety-related indicators

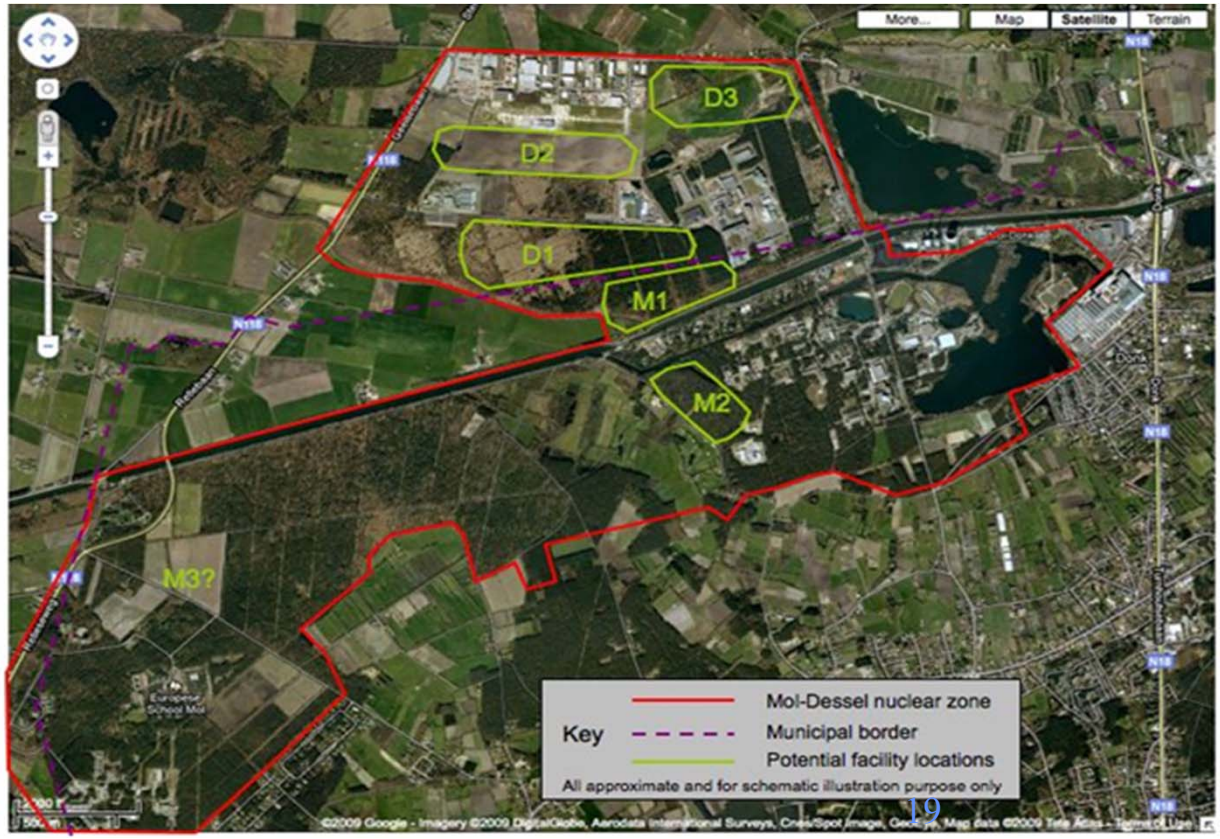
- *Flooding risk - "The site may not be vulnerable to flooding, such that the confinement capability of the engineered barriers shall not be jeopardised"*
- *Soil mechanical stability – "The geological setting of the site must form a sufficiently stable subsoil for the repository, and must provide characteristics favourable for implementing disposal from a technical viewpoint"*
- *Seismic activity – "The site should be located in an area of low tectonic and seismic activity such that the repository's confinement capability is never endangered"*
- *Mineral resources – "Areas in which effective or potential exploitation of natural mineral resources may affect the confinement capability of the repository, should be avoided"*
- *Hydrogeology – "The hydrogeology of the area should be such that detailed characterisation and robust modelling, in the framework of a safety assessment, is possible."*

Site requirements and their evaluation for the disposal site location proposed by STOLA-Dessel

Indicator	Design measures and remarks
Risk of flooding	*Design measure* : design should foresee sufficient elevation underneath the modules; this can be done by placing one or several components between the module and the site ground level.
Soil mechanical stability	*Design measure* : settlements, due to normal load cases, must be evaluated and design measures should foresee that these settlements will not damage the components *Remark:* It should be emphasised that the Mol-Dessel region is known to have soils with adequate bearing capacity.
Seismic activity	*Design measure* : design should take into account the resistance of the disposal facility to reference seismic events (design basis earthquake)
Mineral resources	*Remark* : Mol Sands similar to those on the nuclear zone are exploited by the "Sibelco" company at other locations; the quality of these sands on the site is such that they are not considered suitable for exploitation by Sibelco. Land use restrictions as a means of institutional control will contribute in limiting this risk as a complementary line of defence.
Hydrogeology	*Remark* : characterisation work and robust modelling was successfully carried out during the preliminary project phase.

Considerations from partnerships

The MONA study group considered that:
•the location is preferably situated in the existing nuclear zone;
•the location must meet the basic criteria for near surface disposal as introduced by ondraf/niras;
•the location is preferably situated as close as possible to existing nuclear facilities;
•the location is well situated with regards to supply of both radioactive waste and construction materials;
•the location is not situated on nature reserve;
•an area of 20 to 30 hectares must be available.



The STOLA-Dessel study group also considered that a near surface disposal site were to comply with the indicators set out by ONDRAF/NIRAS

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Site confirmation

- The purpose of the site confirmation stage, prior to the start of construction, is to conduct detailed site investigations at the reference site, in order to:
  - support or confirm the selection; and
  - provide additional site specific information required for detailed design, safety and environmental impact assessment and licensing:
    - Geological, hydrogeological, hydrological data for hydrogeological modelling
    - Geomechanical data to support detailed facility design

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Assessment of the reference site against regulator's guidance

- For each provision specified, a qualitative, and where possible quantitative, assessment is made considering:
  - the positive qualities of the site location,
  - investigations and monitoring or other programmes to prove/assure that these qualities are present;
  - the compensation by engineering for aspects in which the site does not offer an optimum level of protective capacity, such that the total performance of the disposal system meets the guideline; which is in line with the IAEA point of view.
  - overall, this leads to a judgement on the performance of the site, or where relevant the total disposal system, against the FANC requirement.

1. Contribution to the “Isolate & Confine” strategy

The site and its environment must contribute to the long-term “Isolate and Confine” strategy and the implementation of the safety principles that underpin this strategy.

- The main function that the site provides is a **stable and reliable platfom** suitable for the construction and long-term stability of the engineered system, not liable to suffer deleterious events (landslide, flooding...) or changes (climate change):
  - **Subsidence:** total subsidence will be between 2.5 and 5 m over the next 10 000 years
  - **Landslide or weathering:** The site is flat terrain and not subject to extreme temperature cycles or other factors liable to promote weathering
  - **Flooding and drainage:** The site is located relatively far from natural rivers with any significant flooding potential, such as the Witte Nete (at about 1 km).
  - **Erosion**: average annual erosion rate on a vegetated soil in Northern Belgium is small (0.1 mm/year)
  - **Climate change:** Site response to climate changes should therefore not be a criterion to judge the appropriateness of a site, rather should impacts of climate change on the isolation and confine capacity of the facility be evaluated
  - **Dilution and dispersion:** very permeable sand promoting dilution and dispersion

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2. Delay and limitation of release

The site and its surroundings must limit and delay the release of radionuclides into the biosphere. The combination of geochemical and hydrogeological conditions and characteristics must, therefore, be favourable to this purpose.

- The main contribution to limiting and delaying the release of radionuclides into the biosphere comes from the robust waste forms and engineered barriers. The site provides a stable platform for these barriers to function
- Detailed assessments of contaminant migration are carried out in which geochemical characteristics of groundwater and sediments are included. This enables the development of an understanding of their potential contribution of the site to limiting contaminant migration
- Specific features: clay aquitard, sorption onto glauconite rich sands

3. Site does not affect properties of the repository

The site and its surroundings may not affect the isolation and confinement properties of the facility.

- The isolation and confinement properties of the disposal system come mainly from the structural engineered elements and their chemical properties. However, instabilities linked to characteristics of the site may affect the repository's performance.

4.1 Stable geology and low seismicity

The geology and tectonic situation must be stable and the site must present a low level of seismicity.

- The nuclear zone of Mol/Dessel is located within the Campine Basin, which is a sedimentary basin generally lacking large-scale structural features and having quasi-horizontal strata. The nearest signs of tectonic activity that are visible at the surface are at 5 and 7 km to the east of the Dessel/Mol nuclear zone. The Rauw fault was still active in the recent geological past, with a mean movement of approximately one metre per 100 000 years. Trenching did not reveal evidence for faulting events within the last 20 000 years.
- Protection against earthquakes relies, first, on the evaluation of the seismic risk, by defining maps of seismic hazard and vulnerable zones. Secondly, it is necessary to apply this knowledge in the design of structures, such as a disposal facility. Appropriate seismic analyses for the Dessel/Mol nuclear zone are ongoing to determine the level of engineering required to obtain reasonable assurance that seismic events would not compromise the long-term safety functions of the disposal facility. In practice, for the reinforced concrete materials at hand, ONDRAF/NIRAS will seek protection against seismic events by a combination of three design elements, notably concrete mechanical properties, component dimensions, and steel reinforcements.

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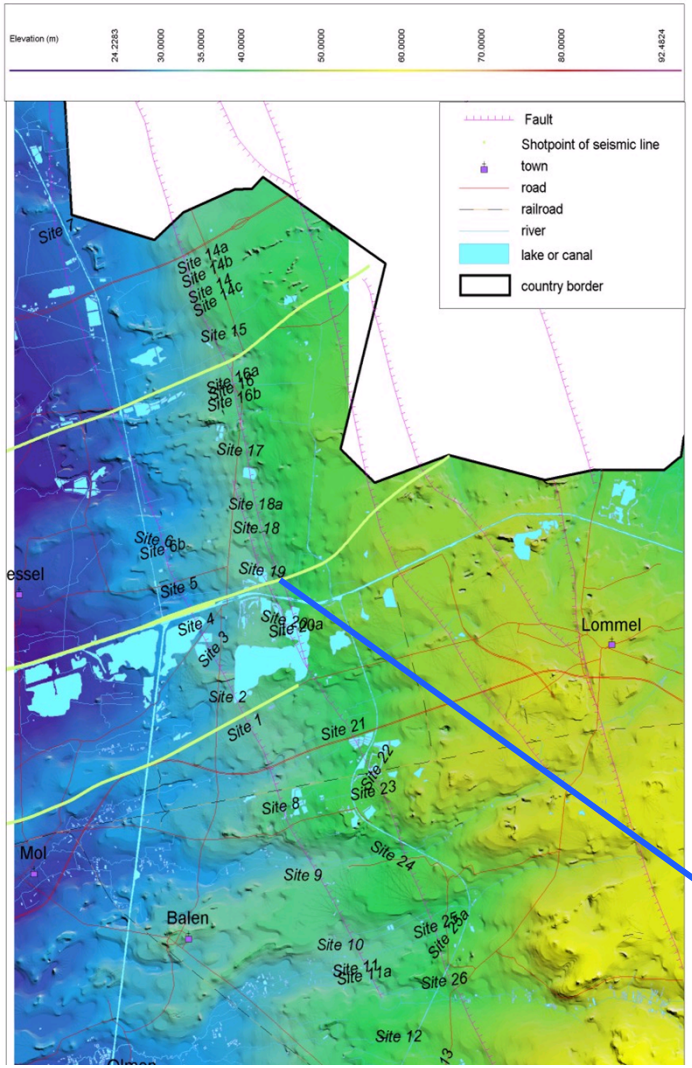
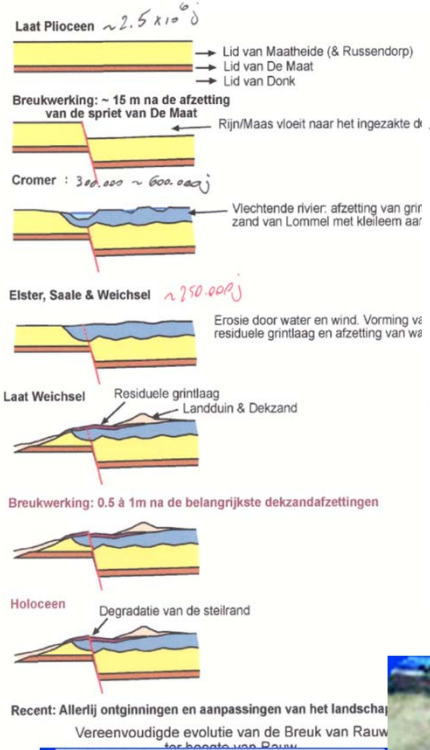
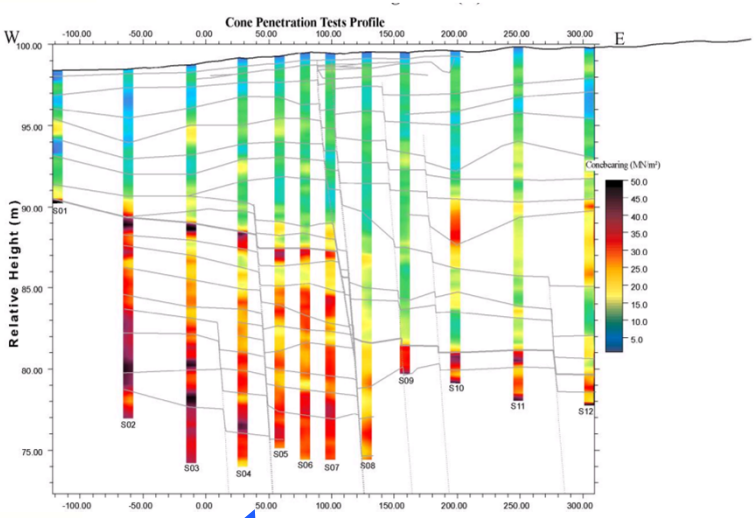
Low seismicity
Analysis of faults activity







4.2 Favourable geotechnical characteristics

The geotechnical characteristics must be stable, be favourable to the disposal system's stability and help to limit and control settlements.

- The site is known to have adequate soil mechanical stability (i.e. load bearing capacity) necessary for long-term stability of the disposal system.
- Additional design measures are defined to ensure the small but unavoidable settlements will not adversely affect the performance of the facility.
- The geotechnical data gained within the scope of the geological campaign were used to evaluate the absolute and differential settlements due to the relatively high distributed repository loads (up to 0.5 MPa) on the underlying soil layers. These indicated that theoretical, maximum absolute settlements of 40 cm could be expected. Thus, constructional adaptations are required to guarantee the normal functioning of the repository and its components allowing for the settlement that is expected (e.g. slope of the drainage system).
- Further large-scale site characterization revealed appropriate soil mechanical properties

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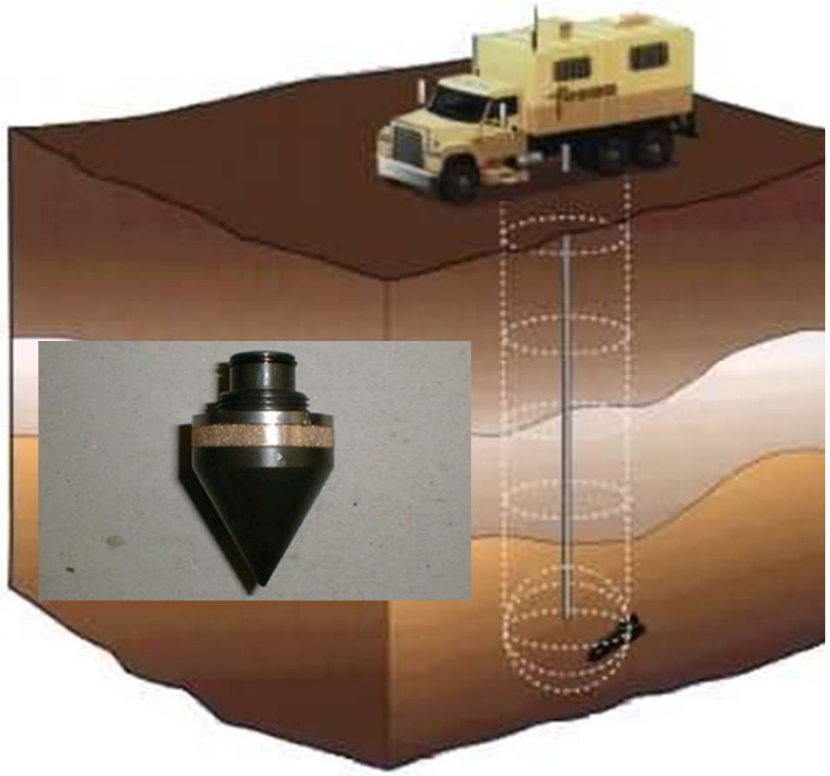
CPT-testing

- Raster of ~ 750 x 750 m in whole catchment.
- Dense network on disposal site (20 per tumulus)
- 180 CPT-E en 20 CPT-U



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Large-scale test programme to determine soil mechanical parameters

4.3 Stable geochemical and hydrogeological characteristics

The geochemical and hydrogeological characteristics must be stable and may not deteriorate the disposal system's components.

- Longevity of engineered barriers is not expected to be negatively affected by the groundwater; the average depth to groundwater at the reference site ranges between 0.85 m (summer) and 1.7 m (winter), based on groundwater level data obtained over nearly 20 y. The near surface disposal facility itself will be constructed on a 2-m high embankment.

- The compatibility of the hydrogeological and geochemical conditions in the area surrounding the repository with the preservation of isolation and confinement properties of the built components of the repository has to be examined in the frame of the safety assessment.

- The embankment will be built on a 0.6-m thick gravel layer whose function is to serve as a capillary break. Under normal conditions capillary rise of groundwater into the embankment should not occur.

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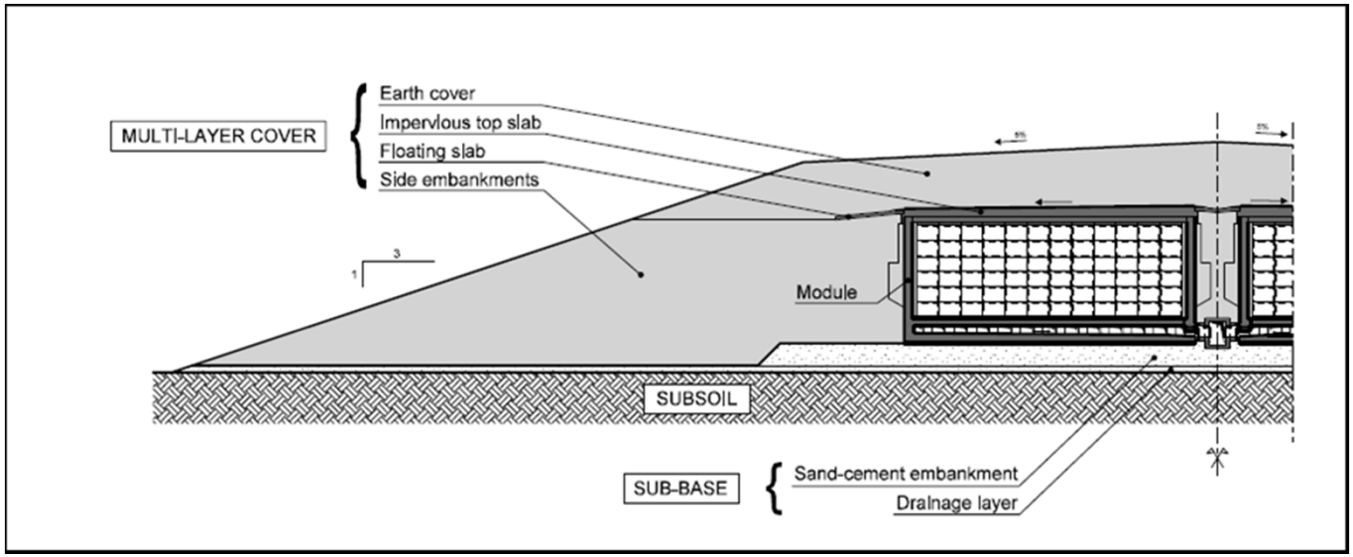
Facility in its final state

Disposal facility cross-section (approx. 2050 ad. onwards)



4.4 Current or foreseeable human activities

Current or foreseeable human activities in the site's surroundings, including the exploitation of natural resources, may not have the potential to affect the isolation and confinement properties of the disposal system.

- Foreseeable human activities: extension of SME zones, sand quarries, increased groundwater pumping,…
- Other human activities, though not "foreseeable", particularly relate to *inadvertent human intrusion* – they are studied in detail in the safety asssessments. It is noted, that they bypass, *by definition*, one or several barriers of the repository, and thus affect confinement and isolation properties.

4.5 Compatibility of repository and hydrogeological and geochemical conditions

- Compatibility of hydrogeological and geochemical conditions near the repository with the preservation of the isolation and confinement properties of the repository SSCs – including an assessment of the influence of possible variations in the groundwater table on the stability of the repository; and
- Influence of the chemical characteristics of the waste and engineered barriers on the transport of radionuclides at the site and its environment. As time progresses and rain water infiltrates into the facility, alkaline water will be released to the groundwater and a pH front will develop. However, this is not expected to happen before complete failure of the module. The anticipated alkaline solutions are rich in dissolved cations (Na^+, K^+, Ca^{2+}) and may be competitors for sorption on the groundwater sediments. The pH front may potentially affect the solubility of contaminants, especially those elements that are known to display amphoteric behaviour. Formation of precipitates along the migration path is not excluded.

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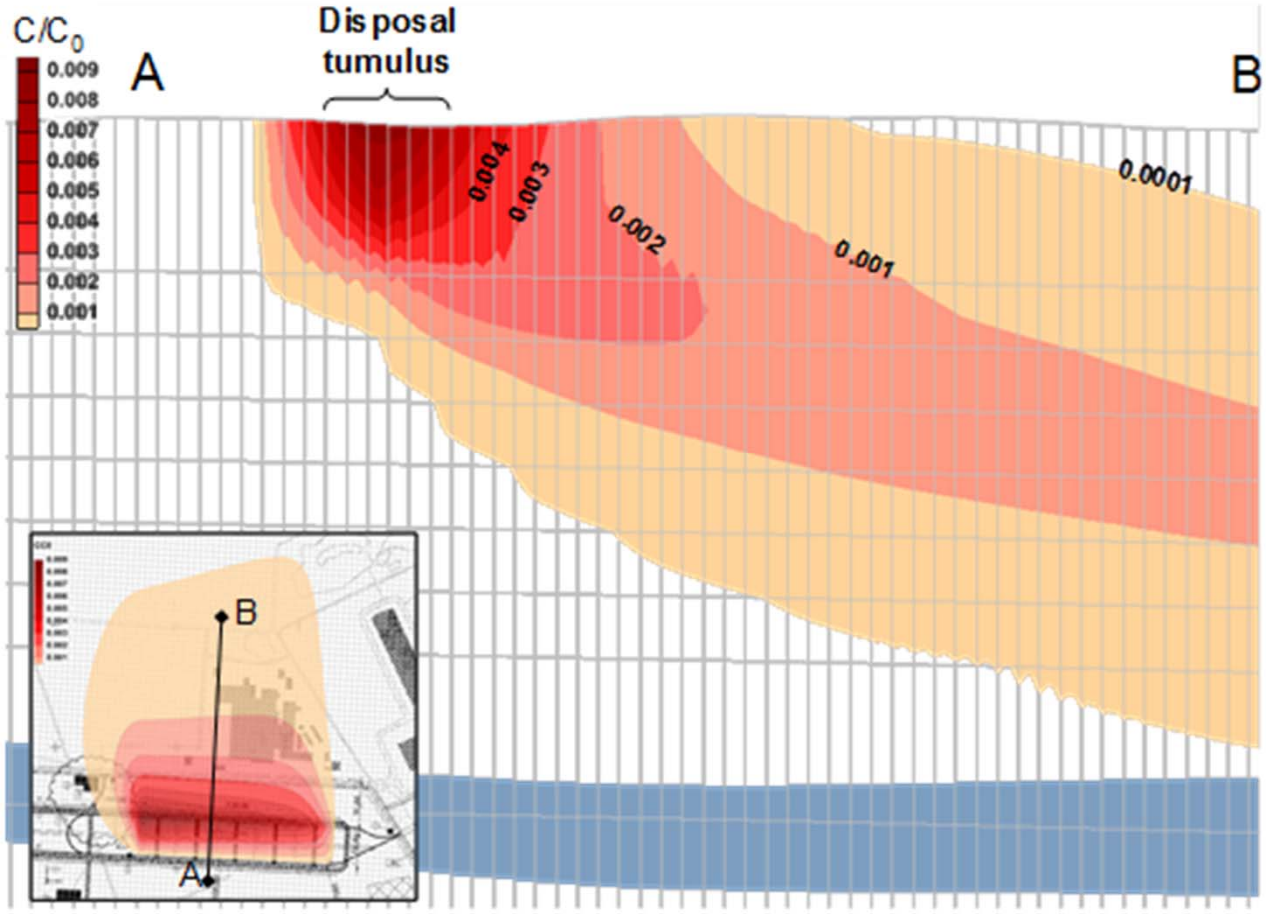
Groundwater dilution



5. Amenable to characterisation and conceptualisation

The site and its surroundings must enable appropriate and reliable characterisation and conceptualisation. Among other things, the geology and hydrogeology may not present any spatial heterogeneity such as those that would not enable a reliable understanding and prediction of the transport of radionuclides.

- Given the dominant role of the engineered barriers in providing long-term safety, **requirements for long-term safety for the geology and hydrogeology of the site can be significantly relaxed**. The requirement for the hydrogeology may then be expressed in terms of the **need for a sufficiently accurate characterisation allowing a defensible assessment of its contaminant migration characteristics**. Thus, a relatively simple geology and hydrogeology would be preferred over a relatively complex one, as the former can be more accurately characterised for its intended purpose by reasonable means, whereas the latter might continue to suffer from uncertainties about its flow and transport properties.
- The FANC guidance on groundwater specifies that a radiological impact implies, among other things, to

  "*acquire an in-depth understanding of the transport process of radionuclides in the site and its surroundings and development of a conceptual model including all of the potential transport routes. These investigations have to include sensitivity studies, aimed notably at identifying the underlying parameters of radionuclide transport.*"

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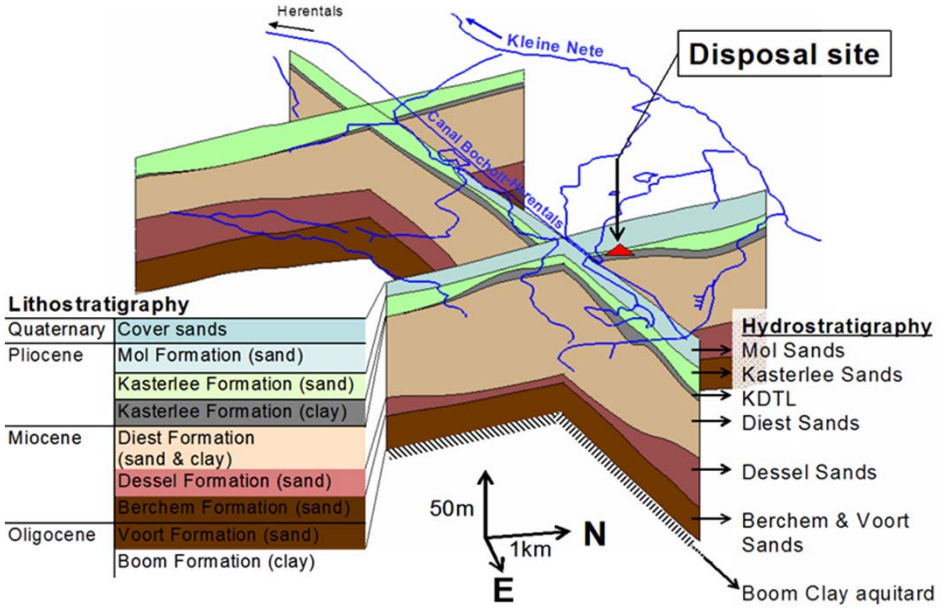
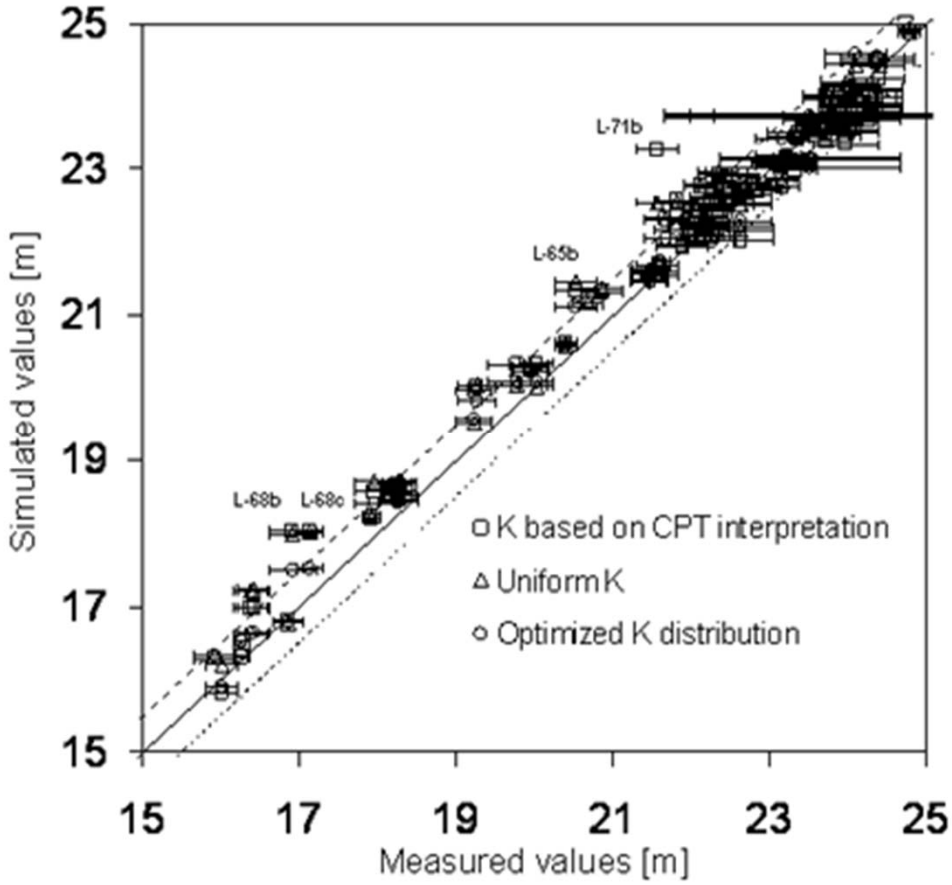
Successful validation of steady-state groundwater flow model





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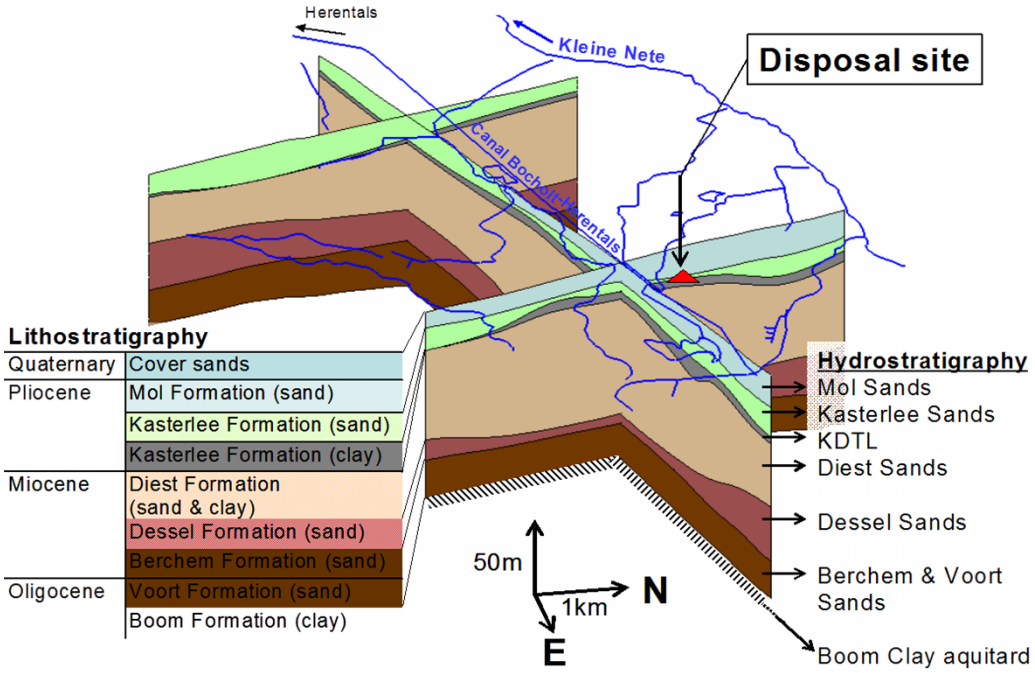
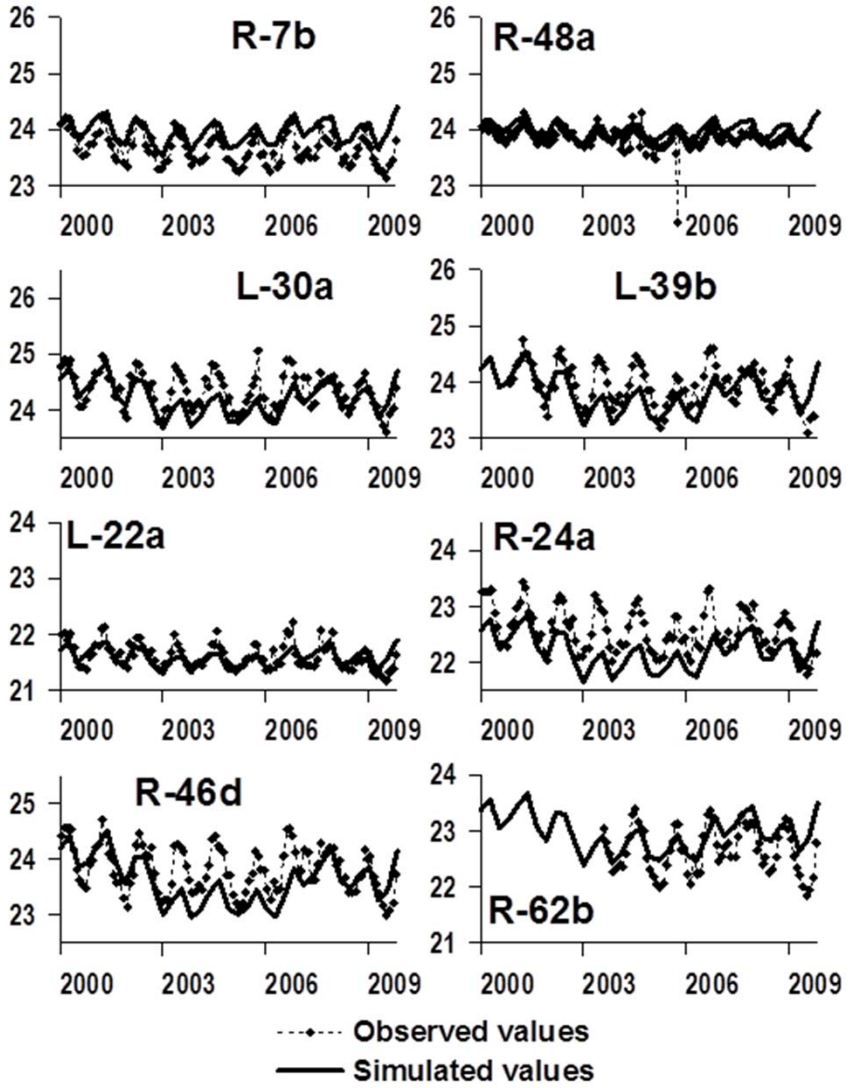
Successful validation of transient groundwater flow model

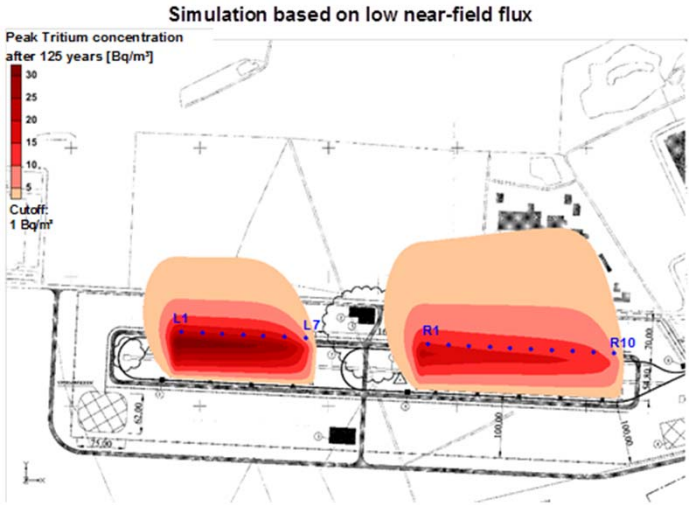


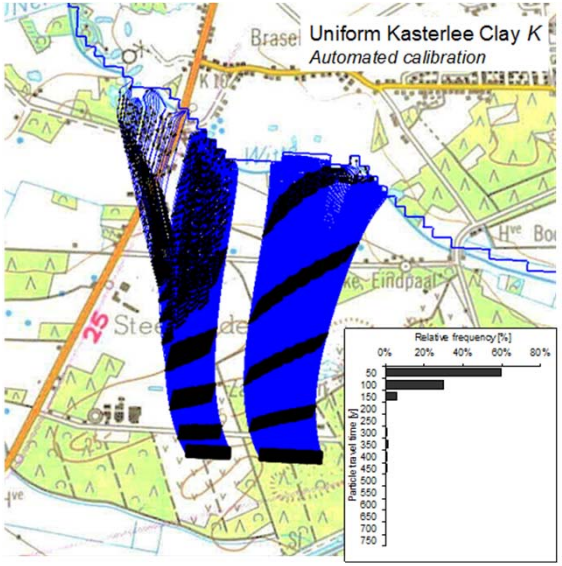


6. Small zone of impact

The site's hydrogeological and hydrological conditions must be such that the area affected by an eventual release of activity is a small as possible.

- The "Isolate and Confine" strategy seeks to minimise release of radioactivity as long as the waste remains hazardous, and the waste form and engineered barriers are the primary contributors to this. Such release as may eventually occur, occurs first to the Mol and Kasterlee Sands of the upper (local) aquifer; the regional Neogene aquifer is largely protected by the Kasterlee Clay. Hence, contamination will be retained primarily in the local area. From the particle tracking analysis it is evident that 95% of particles travel through the upper aquifer and not more than 5% travels through the lower aquifer. The theoretical zone of impact is thus mainly limited to the upper aquifer. Only a few particles travel through the Kasterlee Clay further downwards.





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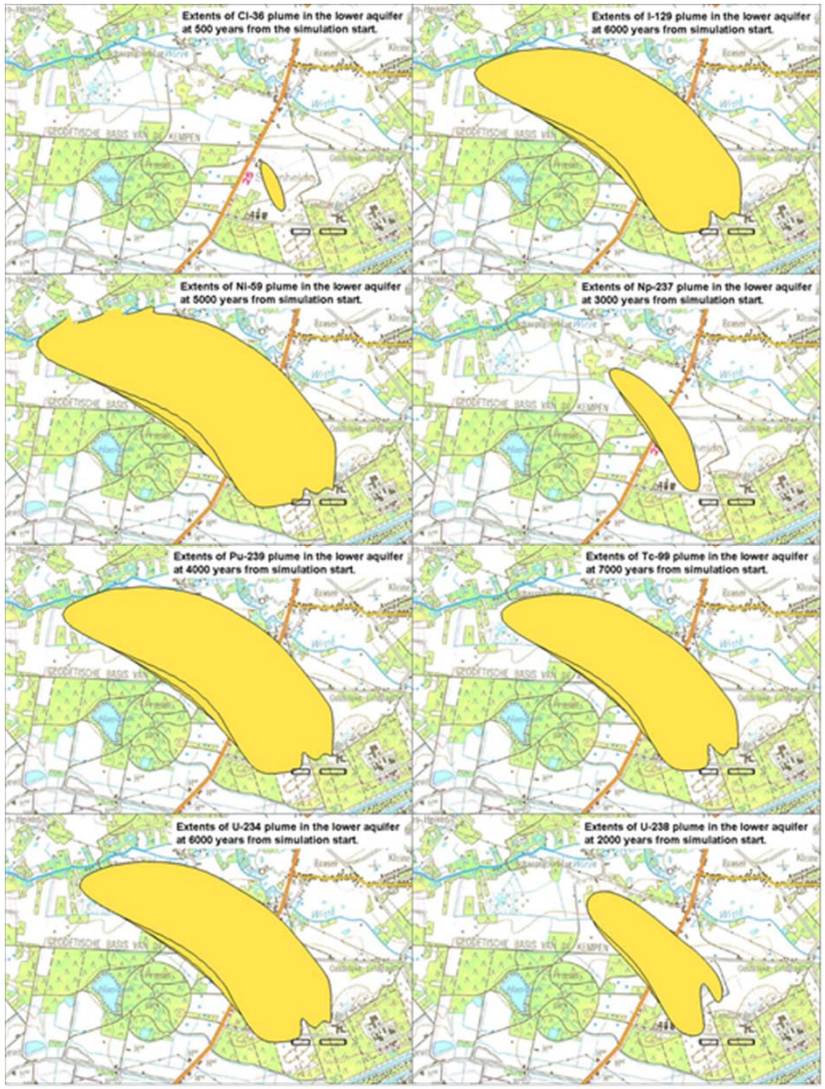
Small zone of impact: Maximum spatial extent of contaminant plume



Defining the zone of contamination will require defining a critical value below which groundwater is considered to be no longer contaminated.

Coloured zones show concentrations that result in an annual dose of 0.1 µSv.

7. Protection of groundwater

The facility may not, under any circumstances, give rise to a contamination of underground water which requires restrictions in use or which is likely to compromise its current or foreseeable use.

- During the period of operations and management control no significant releases of radionuclides to the groundwater are possible, being prevented by the system of inspection and drainage galleries that exist under the disposal modules. Any radioactivity that might appear in the groundwater will be detected in the monitoring wells (if above detection limit), and when needed appropriate remediation measures will be taken.
- Any radioactivity that will appear in the groundwater after release of the site from nuclear regulatory control, must be low enough to keep the radiological impact in case of water use below acceptable limits. This will be demonstrated on the basis of assessment calculations; results from such calculations will also be used to impose/define radiological waste acceptance criteria (site capacity).

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Conclusions

- Site selection and confirmation in Dessel (Belgium) is the result of a relatively long process (1990 – 2010), which in the end resulted in a suitable and safe site. The path that led to this decision took account of:
  - Regulatory guidance
  - IAEA guidance
  - Recommendations from partnerships
  - Recommendations from technical experts.
- *"A suitable disposal site may be chosen either by narrowing the field of candidates from a number of sites or by objectively evaluating a single designated potential site. For either method it is* ***not essential to locate the best possible site, but to provide a waste disposal system which can be convincingly shown to comply with the safety, technical and environmental requirements****. … "* [IAEA, 2008]

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