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REPORT

Conceptual Design Backfill Operation and Dam Construction of StocaMine Toxic Waste Disposal Site

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EXECUTIVE SUMMARY

StocaMine plans to effectively seal the waste disposal site in the mine field of the the former Amelie mine against fluids prior to flooding of the mine. For that purpose several studies were conducted to assess variants of waste removal or total waste inclusion. As a result of the most recent papers, a geomechanical and a hydrogeological study by INERIS, basic conditions and parameters were set for the closure of the waste disposal site.

Following the environmental and industrial legislation as given in Chapter 3 the permit for closure of the disposal site depends on results of studies on storage sustainability and long term consequences as well as environmental impact assessment. Respective studies have been conducted over the last years. Being the basis for a concept of long-term-stable waste inclusion, the INERIS studies /4/ and /5/ were reviewed and summarised in Chapter 4. Mechanical closure due to convergence is expected to be completed in about 100 years. Intruding brine is expected to reach the storage area about 240 years from now and the flooding of the mine is expected to be finished about 305 years from now.

In addition to the summary in Chapter 4 the safety concept "Multi-Barrier System" for the total waste inclusion is presented in Chapter 5. Furthermore the technical conception and basic design for three variants:

- Variant 1: Brine tight dams in access galleries,
- Variant2: Brine tight dams in access galleries and backfilling of the drifts in the sealed area,
- Variant 3: Brine tight dams in access galleries and backfilling of the drifts in the sealed area as well as the storage blocks

to seal the waste disposal site are presented. A total of 12 locations were identified in the storage level, where dams must be constructed in single or double drifts. The backfilling of the drifts would require about 67,700 m³ of filling mortar mixed with brine. Backfilling of the storage blocks would additionally require about 127,500 m³ of filling mortar mixed with brine.

A comparative cost estimation and construction time estimation is given in Chapter 6. Estimated cost and construction time are:

- Variant 1: 50,000,000 EURO and 416 weeks,
- Variant 2: 60,020,000 EURO and 488 weeks,
- Variant 3: 75,540,000 EURO and 635 weeks.

The construction time estimation assumes one crew for dam construction. This time can be considerably shortened by employing several crews simultaneously as long as sufficient hoisting and transportation capacity is provided.

The final Chapter 7 summarises the results and ERCOSPLAN's recommendations. Given the permeability of the geotechnical barrier due to leakages in the existing shaft sealings and the damage of the geological barrier "roof between storage level and lower potash mine level" due to the fire in storage block 15 it is strongly recommended to support the roof, minimise the open void in the storage level and reaching the highest degree of safety by greatest possible exclusion of risk through implementation of Variant 3 – sealing by dams, backfilling of galleries and storage blocks.

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LIST OF ABBREVIATIONS

Abbreviations of physical units/constants used throughout this study are as follows:

g	gram
g/cm^3	gram per cubic centimetre
g/l	gram per litre
H_2O	water
ha	hectare
K_2O	potassium oxide
KCl	potassium chloride
kg	kilogram
km	kilometre
km^2	square kilometre
m	metre
m^2	square metre
m^3	cubic metre
m^3/a	cubic metres per annum
m^3/d	cubic metres per day
m^3/h	cubic metres per hour
m%	percentage by mass
Mg	magnesium
$MgCl_2$	magnesium chloride
mm	millimetre
NaCl	sodium chloride
t	metric tonne
t/a	metric tonnes per annum
t/d	metric tonnes per day
t/h	metric tonnes per hour
t/m^3	metric tonnes per cubic metre
vol. %	percentage by volume
%	percent

1 Background

StocaMine operates an underground waste disposal in the mine field of the former potash mine Amelie near Wittelsheim, where about 42,000 tonnes of waste materials were disposed in storage blocks developed in the rock salt below the potash seam. These wastes mainly consist of industrial ashes, but also material containing heavy metals, cyanides, asbestos, pesticides as well as laboratory wastes and contaminated soils. After a fire occurred in one of the disposal blocks disposal activities in StocaMine ceased in 2002. Subsequently the closure of the waste disposal site was concluded.

The closure of the disposal site has to be planned considering potential water / brine inflow into the abandoned potash mine, which is connected to the disposal site via numerous drifts.

Several studies were conducted to assess variants either of waste removal or of total waste inclusion (e.g. BMG Engineering AG, 2004; ERCOSPLAN, 2008). As a result of the evaluation of these studies by DIRECTION DES RISQUES DU SOL ET DU SOUS-SOL of INERIS, further studies were conducted addressing geomechanical as well as hydrogeological aspects. As result of these studies basic conditions are set for the closure of the disposal site.

StocaMine commissioned ERCOSPLAN Ingenieurgesellschaft Geotechnik und Bergbau mbH (ERCOSPLAN) on the basis of the revised commercial proposal (dated 09 May 2011) on 26 May 2011 with the evaluation of INERIS papers to update the database for assessment of the disposal site closure and development of technical concepts for three closure variants. The technical and economical feasibility as well as the long-term stability of the waste inclusion for each of these variants is to be investigated for a comparison of the variants.

2 Scope of Work

The scope of work was split into the following tasks:

TASK A:

Review and assessment of INERIS documents /4/ & /5/ related to updated geological, hydrogeological and / or rock mechanical data as well as technical conceptions for separation of hazardous waste from remaining parts of StocaMine. ERCOSPLAN will summarize all updated and relevant information for further work (basic conditions).

TASK B:

Basic design for each of the following technical conceptions for separation of hazardous waste from remaining parts of StocaMine as well as Mine Amelie:

1. construction of water / brine tight dams in access galleries to the underground waste disposal,
2. construction of water / brine tight dams in access galleries to the underground waste disposal and additional filling of main galleries in the waste disposal area with an applicable material,
3. construction of water / brine tight dams in access galleries to the underground waste disposal, additional filling of main galleries in the waste

disposal area with an applicable material and filling of remaining cavities in the disposal blocks between or above disposed hazardous waste.

The basic design for each variant additionally will contain a statement on the amount / rate of inflowing water / brine to the waste disposal and an estimation of related capital expenditures (CAPEX) and initial operational expenditures (OPEX) for the remaining time period until the abandonment of StocaMine.

TASK C:

Within the framework of TASK B all abovementioned variants will be assessed by ERCOSPLAN using the following criteria: (i) technical feasibility and (ii) cost-benefit-analysis. Benefit in this case is defined as achievable safety level in terms of influence of possibly developing hazardous solutions on the biosphere.

3 Environmental and Industrial Legislations in France

The initial permit granted by the PREFECTURAL AUTHORISATION OF EXPLOITATION /1/ was approved and delivered to StocaMine on 03 February 1997. At this time, waste storage had to satisfy the current law criteria in France related to:

- CLASSIFIED INSTALLATIONS FOR ENVIRONMENTAL PROTECTION law n° 76-663 of 19 July 1976 and its decree of 21 September 1977,
- DANGEROUS, INSALUBRIOUS OR INCONVENIENT INFRASTRUCTURES, according to a decree dated 20 May 1953 and article 5 of the law of 19 December 1917,
- ELIMINATION AND WASTE RECOVERY, according to the law of 15 July 1975.

3.1 Permit Duration, End of Exploitation

According to the PERMIT ENQUIRY of 19 February 1996, StocaMine was allowed to exploit under certain conditions and reserves stated in the PREFECTURAL AUTHORISATION OF EXPLOITATION of 1997. The permit was valid for a maximum period of 30 years, and afterwards waste had to be recovered in absence of new authorisation extension.

During this period, the owner had to satisfy requirements stated in the authorisation and according to the current laws (applied to underground and surface storage):

- a maximum total amount of 320,000 tonnes of waste stored, with an annual rate of 50,000 tonnes, with approval for waste admissibility and exclusion criteria,
- possibilities of destocking, storage reversibility,
- underground storage supervision schedule (chemical analysis, olfactory measures, temperature control, mechanical surveillance etc.),
- prevention of atmospheric and water pollution, observance of vibration and sound levels according to official standards,
- safety measures, organisation of infrastructure and regular public information.

3.2 StocaMine Closure, Changes in Legislation

On 10 September 2002, a fire occurred in one of the blocks of the StocaMine storage. This fire lasted for three months and led to the closing of StocaMine in September 2003 with a total volume of 44,000 m³ waste stored in the disposal blocks.

The following changes to legislation were made, which changed the objectives for the mine:

- The FRENCH ENVIRONMENTAL CODE /2/ updated on 29 June 2006 stating, according to administrative allowance, that waste has to be destocked after the end of the initial allowance duration or can be extended for unlimited duration after a minimum of 25 years of exploitation and at least one year of activity caesura.
- If unlimited storage duration is envisaged, the allowance will be delivered on the basis of ecological impact assessment studies and alternatives solutions for storage sustainability and long term consequences according to EEC regulations 2003/33/CE /3/ updated from 1999/31/CE, waste classification stated in 2000/532/CE and French transcriptions n°2002-540.

Since September 2003, numerous studies have been performed in order to:

- evaluate the destocking feasibility of StocaMine,
- evaluate the consequences of unlimited storage and resulting potential risks in the long term (several hundred years).

4 Summary of the Technical Studies from INERIS

In December 2010 and March 2011 two studies were carried out, regarding geomechanical and hydrogeological parameters, detailing the expected long term evolution of the mine. Then input data for technical assessment of backfilling area, and especially the consideration of long term sustainability, might have changed. This is the object of the present technical update.

A summary of parameters and conclusions, resulting from the INERIS studies /4/ & /5/, will be presented in the following chapters.

4.1 Geomechanical Study of StocaMine

The GEOMECHANICAL STUDY OF STOCAMINE /4/ was driven by three objectives,

a) The evaluation/assessment of the mechanical stability of the storage site and the corresponding access infrastructures, with detailed studies of accessibility to the site in a medium term, and possibilities of destocking at short or long-term[1].

b) The assessment of creep rate/creep velocity of the different structures (storage areas, galleries, caved stope areas), linked to the problem of impact of the creep rate on the

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[1] Short, medium and long term correspond respectively to a few years, few decades and few centuries.

migration of contaminants, and the possibility of access to the underground site during time.

c) Assessment of damages on the storage roof induced by the Block 15 fire which underlined the question of a possible hydraulic connection through the damaged salt formations.

The important and relevant approaches concluded by INERIS:

a) On mechanical stability:
    - The pillars in the drift galleries are damaged, underlining the problem of stability, sustainability for medium term and accessibility.
    - The contact between the roof and the waste is inevitable and should occur at an average of 30 years after excavation; then destocking is probably impossible.
    - The local stability of the "Stot"[2] is compromised (when width is less than 20 m), suggesting that the impermeable barrier is not assured and the entire Western Sector will be affected during the flooding.
    - The roof, walls and pillars affected by the fire are damaged. The study showed that the damages did not reach the level situated 25 m above, supposing that salt permeability is still low on the upper 13 m.

b) On creep rate of the underground structures:
    - The convergence rate roof/wall is expected to reach 0.9% per year for the storage area and double drifts at 550 m.
    - The storage area (including galleries) is expected to be completely closed after about 100 years (the permeability will still remain non negligible after the closure).
    - A compaction rate of 0.1% per year is expected before flooding.
    - Flexion/buckling phenomenon and residual compaction will have to be considered for the waste/contaminant and brine migrations.

c) On interaction between flexion/buckling and flooding/backfilling:
    - The hypothesis of 5% to 10% residual opening after flooding with 90% of collapsing rate could be justified at depths of 1,000 m, but probably is overestimated for the StocaMine scale. The flooding will probably take place after several centuries. The closure of the structures will be completed by then (still, the permeability will remain high). The diminution of the creep rate would occur during flooding, reaching about 0.01% per year in exploited areas (caved stope), or 1 mm/year which is imperceptible.

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[2] The "Stot" (safety pillar), is a natural barrier which is separating the Western Sector between Marie Louise (Downstream) and Amelie mines (Upstream). This "Stot" must be differentiated from the "Stot" Pillar situated above Blocks 25 and 26.

Important remarks:

- Even if the residual compaction will be very slow in the long term, the creep rate will represent an important source for fluid migration towards the exterior. This phenomenon has to be taken into account for hydrogeological and fluid migration studies.
- The instabilities observed such as slabbing/delaminating on roofs, walls and pillars are supposed to be accentuated/impaired over time. Therefore decisions regarding interventions have to be made quickly.

4.2 Hydrogeological Study of StocaMine

The HYDROGEOLOGICAL STUDY OF STOCAMINE /5/ is complementary to the geomechanical statements. The main objectives and conclusions are presented below:

- The hydrogeological report focuses on the flooding of open areas of the mine, taking into account their compaction rate over time. The report provides solutions regarding floods with barrier infrastructure.

The hydrogeological conclusions, in view of the latest data, are:

a) hypothesis for the overall mine flooding:
  - The flooding study has been done considering the overall Western Sector of the mine, expecting flow communication through the "Stot" separating Marie-Louise mine from Amelie mine.
  - The INERIS consulted several experts regarding different potential inflow or migration origin existing in the overall mine. The conclusions lead to the expectation that the main water inflow will come through the existing plugged shafts (where permeable behaviour was observed). The overall expected initial inflow in the mine has been estimated at about 105,000 m^3 per year through the 15 existing shafts.
  - Taking into account previously determined[3] mechanical parameters, the general inflow of the mine will decrease while the closure and compaction of open volume will progress to reach about 3,000 m^3 per year in the ultimate stage (long-term).
  - The general brine level[4] is expected to reach the storage area after 240 years, taking into consideration that about 7% (2.06 million m^3) of the Western Sector is probably already flooded. The complete mine would be flooded after 305 years[5] (StocaMine and upper levels of Amelie mine).
  - The estimated overall trapped air volume after flooding completion is expected to be 10%.

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[3] General closure rate of about 0.9% for StocaMine, 0.1% compaction rate for non flooded areas and 0.01% compaction rate for flooded areas are taken into account. The mine should be mechanically closed 100 years after excavation.

[4] The brine is estimated to be saturated and in equilibrium with salt formations and potash ore. The density of such brine has been estimated to 1.236 g/cm^3.

[5] The time reference is the year 2010.

b) details of the expected flooding scenario for the storage area in absence of barrier infrastructures:

- The flooding of the mine will be a combination of two potential inflow origins:

  One part of the flood should represent only 2% of the total brine inflow and would percolate from upstream parts of the Western Sector, from the Joseph and Else shafts. The inflow of those shafts is estimated to be very low because those should be plugged according to latest technologies[6]. In absence of dams or other barrier infrastructures, and in light of a closure of the storage area, it has been admitted that StocaMine could be flooded with a small part of contaminant leached during the flow process.

  The main part of the flood should represent the inflowing brines coming from downstream levels and should reach the storage site after 240 years. The site should be mechanically closed but supposing that there is still enough permeability to let the brine flow at about 3 l/s, the scenario would follows 6 steps:

  - The mixed brine, which raises from the lower mine levels spreads first at the 286 level from Amelie II, then breaks through TB2 and flows to the "Atelier Reseaux" (Network Shop).
  - Afterwards, the brine floods the "Atelier Reseaux" and flows through AM1 and AM2 ways.
  - The brine reaches the first waste in Block 21 by AM2, and progressively floods the storage area completely, and is concurrently contaminated.
  - After total filling, the brine flows back up in TB0 and reaches the Joseph Shaft and goes through TB JOS.
  - Then the brine starts to flood the quarters of the lower potash layers and arrives at TB910 and progressively floods neighbouring quarters.
  - The brine floods the whole mining volume and then rises up through inner and outer ring spaces of shafts towards the surface.

  The estimated residual volume of the storage area after flood completion should be about 7,000 m^3 (initial volume of 300,000 m^3). As a perfect long-term hydrogeological barrier for the storage area is difficult to obtain; an expected contaminated flow of about 0.7 m^3 per year could occur. The expected porosity of the waste has been evaluated as 31% in average after flooding completion.

4.3 Summary of the Technical Studies

The results of the technical studies /4/ & /5/ from INERIS are summarised in Figure 1.

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[6] Expected total flow rate of 1,700 m^3 per year for these shafts.

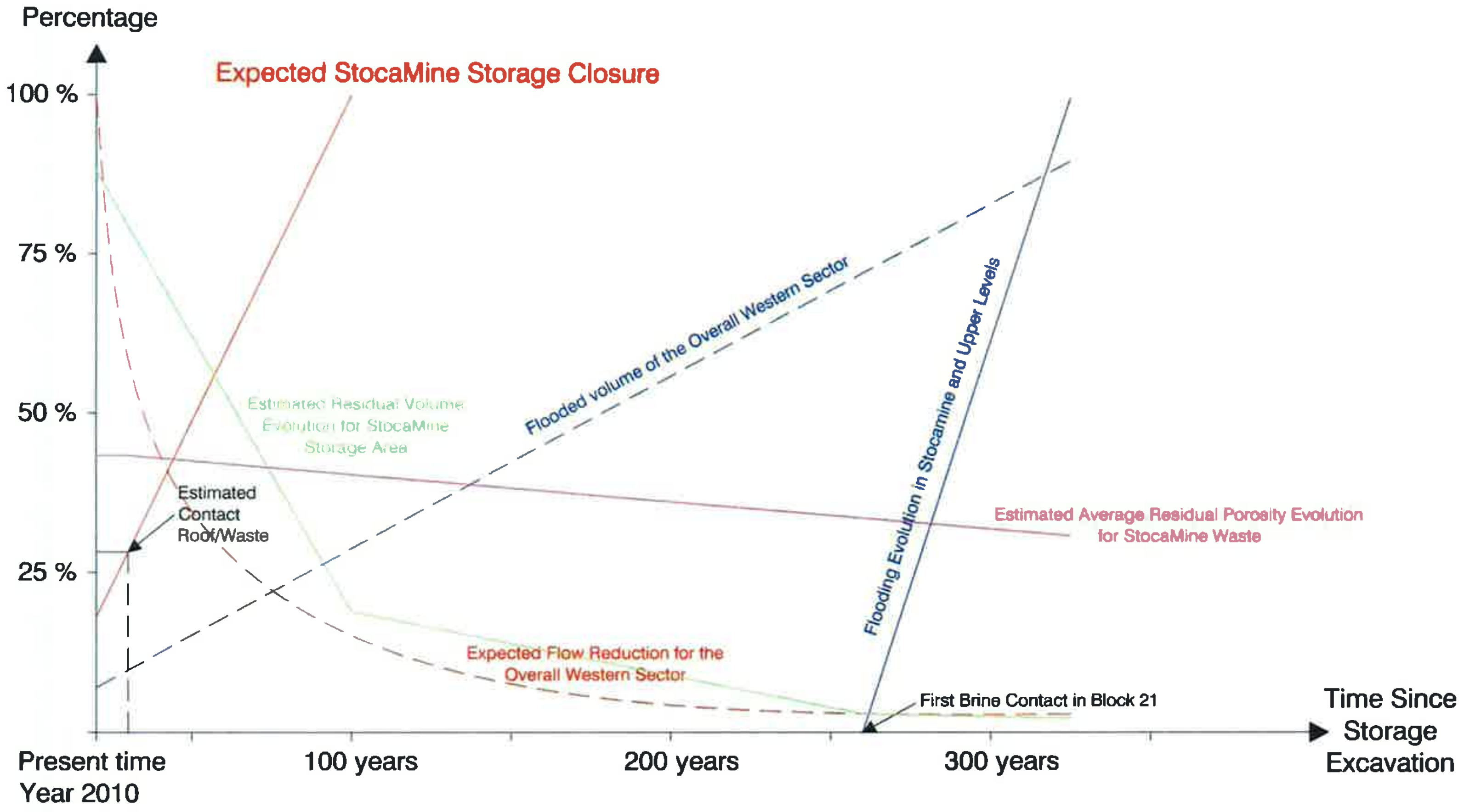

Figure 1 Expected Geomechanical and Hydrogeological Evolution of StocaMine and of the Overall Western Sector

5 Safety Concept "Multi Barrier System" for the Total Inclusion of the Toxic Waste

The required permanent isolation of the deposited waste in StocaMine from the biosphere can only be attained through the total inclusion of the waste in the host rock, rock salt. The outer barrier complex consists of:

- the geological barriers around the Amelie and Marie-Louise mines,

  which comprises the Upper Salt Zone of about 550 m thickness and the Middle Salt Zone of about 300 m thickness. They are impermeable, free of water and contain the marls of the Middle Stampien above the Upper Salt Zone which have a very low permeability.

- the geotechnical barriers,

  which consist of all shaft and surface borehole plugs, which cut across the geological barriers of the outer barrier complex.

- the geochemical barrier,

  which comprises the marls of the Stampien. If any eluted material should reach these marls, the absorbing character of the marl would bind it to these strata.

As this outer barrier complex only functions as a hydraulic barrier due to leaks in the existing geotechnical barriers, whereby the Amelie and Marie-Louise mines are subject to a flooding process, the effective long term total inclusion of the waste has to be effected by an inner barrier complex. This inner barrier complex comprises the following:

- the geological barriers around the waste disposal site,

  which comprises the roof between the waste disposal site and the Lower Potash Layer "CI", the safety pillar around the shafts Joseph and Else and the adjacent Upper and Middle Salt Zone.

- the geotechnical barriers,

  which consist of all the (surface borehole and) drift plugs that were planned in Variant 1, which cut across the geological barriers of the inner barrier complex.

- where applicable, the inner barriers,

  which consists of the filling of the main drifts with applicable material that was additionally planned in Variant 2, in order to reduce the softening of the roof between the waste disposal site and the Lower Potash Layer "CI"

  or

  which consists of filling of the main drifts and the remaining cavities in the storage blocks with applicable material that was additionally planned in Variant 3, in order to reduce the softening of the roof between the waste disposal site and the Lower Potash Layer "CI" and to chemically bind harmful substances in the backfill material.

- the technical barriers,

  which are the vessels, in which the waste material is stored.

A schematic overview of the safety concept "Multi Barrier System" for the underground waste disposal of StocaMine is given in Figure 2.

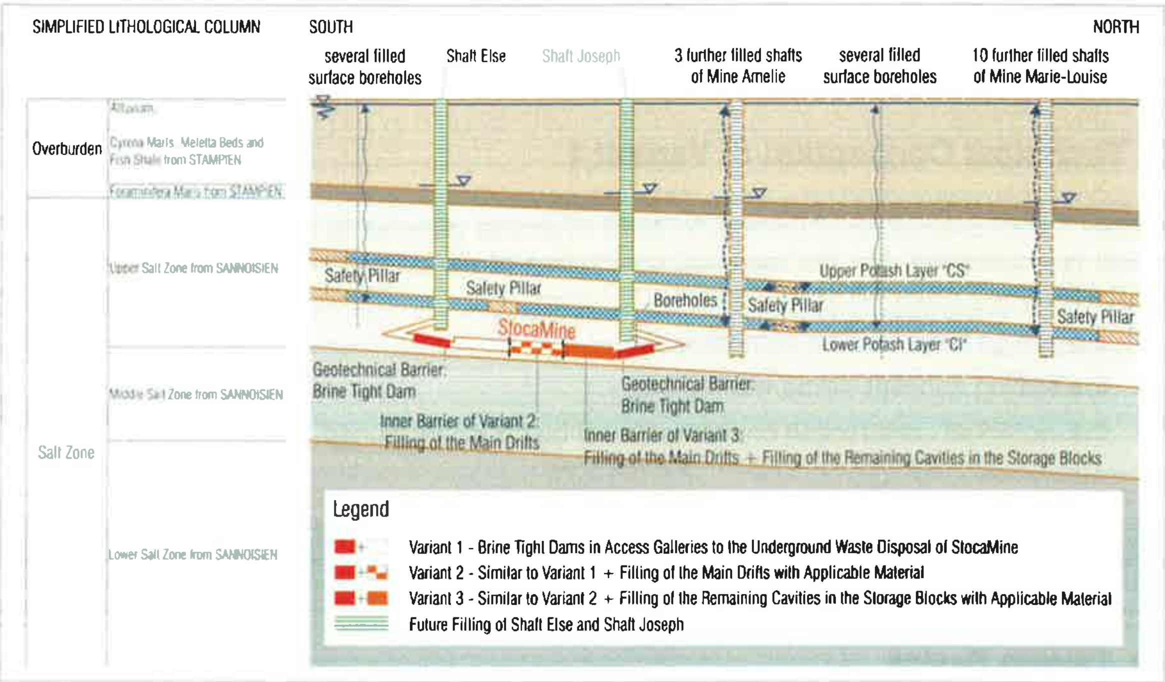

Figure 2 Schematic Overview of the Safety Concept "Multi Barrier System" for the Underground Waste Disposal of StocaMine

In the following sections, the individual components of the effective inner barrier complex for future isolation of the waste from the biosphere will be described. Furthermore, a conceptual design for the geotechnical and inner barriers will be developed.

5.1 Description of the Geological Barriers

The geological barriers around the waste disposal site comprises the roof between the waste disposal site and the Lower Potash Layer "CI", the safety pillar around the Joseph and Else shafts and the adjacent Upper and Middle Salt Zone.

The roof between the waste disposal site and the Lower Potash Layer "CI" is made up of Massive Halite interbedded with laminated Marno-Anhydritic layers from the lower part of the Upper Saliferous Zone. It has been shown that this geological particularity has an importance in the creep rate process.

The average thickness of the layer is about 25 m and it separates the Lower Potash Layer "CI" exploited in Amelie mine from the storage blocks and galleries. It has been declared that the overall permeability of this geological barrier remains low[7]; even for damaged zones such as

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[7] 10^{-21} to 10^{-20} m² for intact zones, locally lower than 10^{-18} m² around damaged zones by extraction and 10^{-17} to 10^{-15} m² for damaged zones by fire.

the zone affected by the Block 15 fire in 2002 or zones affected by the extraction, which only concerns the lower 12 m of the storage roof thickness.

5.2 Technical Conception of Variant 1

In Variant 1 the construction of brine tight dams in access galleries to the underground waste disposal is considered. For the technical conception of the geotechnical barrier (brine tight dam) the following steps will be carried out:

- the design basics will be summarised,
- the sealing concept will be worked out,
- the individual construction components will be pre-dimensioned

and

- the construction design will be illustrated structurally.

5.2.1 Design Basics

The design basics include on one hand all basic data that pertain to the locations of the dams as well as the potential brine intrusion and on the other hand all other constraints from which demands on the construction design can be derived.

5.2.1.1 Basic Data

For the technical conception of Variant 1 the following basic data apply:

a) regarding the dam locations

In order to isolate the storage area from the rest of the mine, drift sealing construction will be constructed at 11 locations. An overview of the locations of the planned constructions can be found in Figure 3 and ENCLOSURE A.

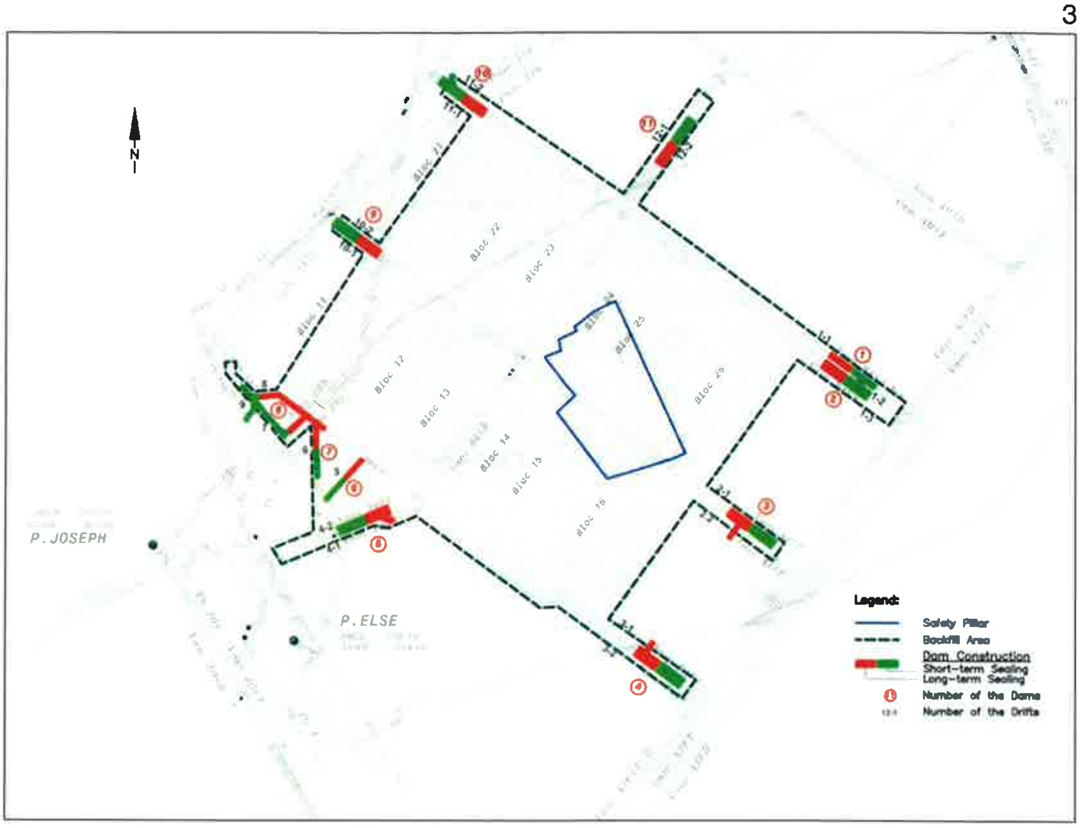

Figure 3 Overview of the Location of the Planned Dams

b) regarding the dimensions of the access galleries

The widths of the dams and pillars at the dam locations have been obtained from the mine plan. It is assumed that for the dams that are to be constructed in double drifts, the intermediate pillar must be removed, and as a result, a very large dam width will result. A height of 3.0 m was assumed for the drifts. An overview of the dimensions of the drifts is contained in Table 1.

Table 1 Dimensions of the Drifts at the Centre of the Planned Dams

Drift ID	**Height in m**	**Width in m**	**Pillar Width in m**	**Drift Type**	**Dam No.**	**Dam Width in m**	**Dam Height in m**
1-1	3.0	5.6		Parallel Drift	1	5.6	3.0
			7.1				
1-2	3.0	3.8					
			3.0	Double Drift	2	10.7	3.0
1-3	3.0	3.9					
2-1	3.0	3.8					
			3.2	Double Drift	3	10.8	3.0
2-2	3.0	3.8					
3-1	3.0	5.5					
			3.2	Double Drift	4	13.7	3.0
3-2	3.0	5					
4-1	3.0	4.8					
			3.2	Double Drift	5	11.8	3.0
4-2	3.0	3.8					
5	3.0	3.8		Single Drift	6	3.8	3.0
6	3.0	3.8		Single Drift	7	3.8	3.0
7	3.0	4.2		Single Drift	8-1	4.2	3.0
8	3.0	3.8		Single Drift	8-2	3.8	3.0
9	3.0	4.3		Single Drift	8-3	4.3	3.0
10-1	3.0	3.9					
			3.2	Double Drift	9	10.9	3.0
10-2	3.0	3.8					
11-1	3.0	3.8					
			3.1	Double Drift	10	10.8	3.0
11-2	3.0	3.9					
12-1	3.0	3.8					
			3.3	Double Drift	11	10.9	3.0
12-2	3.0	3.8					

c) regarding the geological settings at the dam locations

The sealing locations are invariably found in rock salt. The rock mass is assumed to be free of cracks in the intended construction sites. The geological barriers of the inner barrier complex are assumed to be intact. The expansion of the Loosening Zone is conservatively estimated at 0.50 m. It will be removed from the area surrounding the sealing constructions. For the permeability of the trimmed salt rock, a value of $\leq 10^{-18}$ m^2 is estimated. All further considerations are based on a rock temperature of 25°C, as this represents a conservative case with regard to the viscosities.

d) regarding the potential brine intrusion and expected compression load

For the post-closure phase of the StocaMine waste disposal, brine intrusions are predicted. The time of such an intrusion is expected, according to /5/, after 240 years at the earliest. Both a saturated NaCl-solution as well as a solution that is at equilibrium with the host rock (NaCl and KCl saturated brine with marginal amounts of $MgCl_2$) are potential intruding brines. An overview of the basic parameters of the intruding brines at 25°C rock temperature is contained in Table 2.

Table 2 Calculation Parameters of the Intruding Brines at 25°C

Intruding Brine	**Density ρ in g/cm^3**
NaCl saturated brine	1.197
NaCl and KCl saturated brine with marginal amounts of $MgCl_2$	1.236

The maximum expected fluid pressure amounts to up to 7.3 MPa[8]. According to /5/, the sealing constructions will be worn out after 240 years at the earliest.

5.2.1.2 Basic Conditions

The following mining-related basic conditions have an influence on the design:

a) shaft hoisting capacity

Hoisting equipment capacity available in existing shafts:

- 5.0 tonnes capacity hoisting cage in Joseph Shaft (driven by « Köpe » pulley) with convertible imbalance system at the balancing pole,
- 4.5 tonnes capacity hoisting cage (taking into account its volume) in Else Shaft.

b) available mechanical equipment

For Halite ore extraction, a reserve area near the storage is ready to produce required amount for dam construction. Underground equipment such as continuous miner "PAURAT E 195" and smaller longwall equipment "JOY 15 RU" cutter, in running condition, are available for operations.

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[8] Conservative approach, which assumes that the water column reaches up to the surface.

c) useable area

An analysis of the mine plan shows that there is only limited space for the storage of construction materials etc. available.

Additionally the following basic conditions required by INERIS /6/ apply:

a) regarding the operating life of the sealing constructions

The sealing constructions should be designed to have an operating life of 10,000 years.

b) regarding the materials of the sealing elements

Preferably, bentonite should be used as the material for sealing elements as it possesses not only the required sealing properties but also an absorbing effect on heavy metals.

c) regarding the permeability-length-relationship of the sealing elements

For a pre-dimensioning of the sealing elements, the permeability-length-relationship from equation (5.1) was used.

- $$\frac{K}{L^2} < 10^{-21} \qquad (5.1)$$

with: K Intrinsic Permeability of the Sealing Element [m²]

L Length of the Sealing Element [m]

5.2.2 Design of the Brine Tight Dams

5.2.2.1 Engineering Design Principles

The planning of the long term stability of sealing constructions in salt rock is based on the following engineering design principles /7/, /8/:

- classification of the sealing elements into elements with a sealing function and elements with a static function,
- redundancy in the arrangement of the sealing elements, i.e. many similar sealing elements are placed consecutively,
- diversity in the arrangement of the sealing elements, i.e. many sealing elements that are made from different materials are placed consecutively,

whereby a increasing safety standard over time is targeted for the whole system.

5.2.2.2 Construction Materials that are stable in the Long Term

The dam constructions in the access galleries to the underground waste disposal must be designed for an operating life of 10,000 years. Essentially, the following materials that are stable in the long term for the sealing of a drift cross-section against the expected brine intrusion are available:

- Bitumen / asphalt,
- Clay / bentonite / mineral mixtures,
- salt grit / salt debris

and

- salt-concrete / slurry backfill as salt-like materials.

The material groups of bitumen and asphalt as well as clay, bentonite and mineral mixtures have to be positioned over the abutment in the sealing cross-section in order to guarantee their sealing function. Only materials belonging to the salt-concrete and slurry backfill group can be considered for use under the basic conditions applicable here. Normal concretes and also concretes mixed with brine are subject to corrosive processes, such that their material properties will change significantly during the reference period. Abutments made of seamless masonry made from natural stone, which possess long term stability, are theoretically possible, but for the quantity required here, it would not be feasible due to economic and technical reasons.

The salt grit and salt debris material group as well as the salt-like materials made from salt-concrete and slurry backfill will only develop a complete sealing effect after a time lag, after excess pressure increases contact between construction and rock as a result of accruing convergence, i.e. after a so called “prologue phase”.

5.2.2.3 Technical Conception of the Brine Tight Dams

The technical conception is mainly based on the separation of the sealing construction in a long-term effective and a short-term effective structural component. The long-term effective drift seal should be a combined abutment-sealing element made of salt-concrete. This kind of construction takes credit from a prologue phase, for which, due to the high creep rate (cf. Section 4.1), a time of maximum 500 years is assumed. Since according to the HYDROGEOLOGICAL STUDY OF STOCAMINE /5/, the earliest possible intrusion can already occur after 240 years, i.e. at a point at which the functionality of this construction component is not completely verifiable, an additional component with an instantaneous effect must be placed at the side where the brine intrusion is expected. This component will be made out of 2 redundantly arranged bentonite sealing elements as well as 1 mastic asphalt sealing element that is positioned diversely from the bentonite elements. The sealing elements will be positioned between abutments made of concrete mixed with brine in the drift (cf. Figure 4).

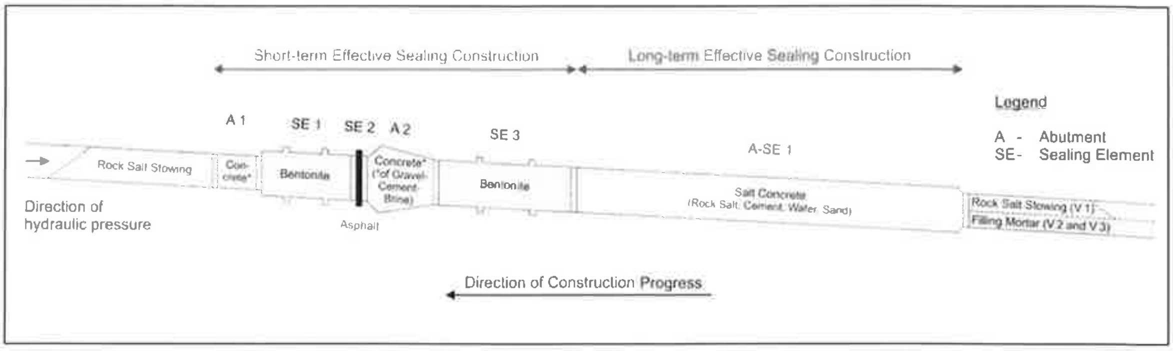

Figure 4 Derived Construction Design for the Drift Sealing Constructions

The basic construction of the dam as well as the function of the individual construction components can be described as follows:

- **Rock Salt Stowing**

  In order to harmonise the stiffness transitions between the outer abutments and the drift cross-section that is to be left open, an approx. 15 m long stowing made of rock salt debris will be placed in front of every dam construction. The rock salt debris should be installed level to the roof.

- **Abutment (A 1)**

  Abutment 1 has a short-term function and will act as a block dam. It will absorb the swelling pressure from Sealing Element 1. The drift contour will not be extended in this area but only trimmed. For this temporary abutment, the use of a gravel-cement-salt-concrete mixture is planned. The duration of the functioning of the concrete constructions can be specified as up to 1,000 years. The construction of comparable structures represents a technology that has been tried and tested for many years in the German potash industry.

- **Sealing Element (SE 1)**

  Sealing Element 1, which is made out of bentonite moulded bricks has a short-term function and insulates against the intruding brines over a longer period of time. SE 1 will be equipped with circumferential sealing trenches. In order to increase the initial permeability in the central section as opposed to that in the outer section (contact between sealing element / rock) as well as to achieve an optimal building up of swelling pressure “from within” to the contours, filter stones (Korund-LS-stones) will be fitted in the centre of the first two frames on the pressure side. In the region of the sealing element, the removal in the Loosening Zone (LZ) in the joints as well as in the roof and the floor should be carried out carefully. The depth of LZ where removal is to be carried out is estimated at 0.50 m and should be determined in the course of construction by means of permeability measurements.

- **Sealing Element (SE 2)**

  Sealing Element 1 is followed by the diverse Sealing Element 2, which is made out of mastic asphalt bricks that cut into the rock circumferentially. The circumferential trenches should have a depth of 0.50 m and a width of 0.50 m.

- **Abutment (A 2)**

  Abutment 2 has a short-term function and will be designed to be in the shape of a truncated cone as well as to be low friction. The drift will be widened for the construction of the truncated cone shaped geometry using a part-face heading machine, which is rock-sparing. Abutment 2 takes over the axial load transmission during brine intrusion. Like Abutment 1 a gravel-cement-salt-concrete mixture is planned to be used as construction material for Abutment 2.

- **Sealing Element (SE 3)**

  Sealing Element 3, which is also made of bentonite moulded bricks, has a redundant insulating function for Sealing Element 1. In the section of Sealing Element 3, the removal in the Loosening Zone (LZ) in the joints as well as in the roof and the floor should be carried out carefully. The depth of LZ where the removal is to be carried out is estimated at 0.50 m and should be determined in the course of construction by means of permeability measurements.

- **Combined Abutment-Sealing Element (A-SE 1)**

  The Combined Abutment-Sealing Element 1, which is made of salt-concrete, has a long term function, and after a prologue phase of a maximum of 500 years, exclusively takes over the insulation of the drift cross-section over the reference period. Such an arrangement is possible because as a result of convergence, deformation processes will be inducted, which then lead to a conclusive bonding between salt-concrete and the surrounding rock. In the region of the Combined Abutment-Sealing Element 1, the removal in the Loosening Zone (LZ) in the joints as well as in the roof and the floor should be carried out carefully. The depth of LZ where removal is to be carried out is estimated at 0.50 m and should be determined in the course of construction by means of permeability measurements.

- **Rock Salt Stowing (only if Variant 1 is chosen)**

  In order to harmonise the stiffness transition between the long-term stable Combined Abutment-Sealing Element 1 and the drift cross-section that is to be left open, an approx. 15 m long stowing made of rock salt debris will be placed in front of every dam construction. The rock salt debris should be installed level to the roof.

5.2.3 Pre-Dimensioning of the Individual Structural Components

In the following sections, the abutments as well as the sealing elements are pre-dimensioned. The pre-dimensioning does not substitute the load-bearing capacity or the serviceability checks for this construction. It merely serves as a guide to the dimensions of the structural components.

5.2.3.1 Pre-Dimensioning of the Abutments A1 and A2

According to SITZ /7/, for the pre-dimensioning of parallel, interlocked and truncated cone shaped dams, verifications based on the equations (5.2) and (5.3) are necessary.

- Shear Stress Analysis: $$L_1 = \frac{p\cdot A}{Pe\cdot\tau\cdot 0{,}7} \tag{5.2}$$

with:	L_1	Required Length of the Abutment [m]
	p	Hydrostatic Pressure of the Fluid [N/cm²]
	A	Cross-Sectional Area of the Drift [m²]
	Pe	Perimeter of the Drift [m]
	τ	Permissible Shear Stress of the Construction Material [N/cm²]

- Flexural Tension Analysis: $$L_2 = \sqrt{\frac{p\cdot d^2}{6\cdot\sigma_z}} \tag{5.3}$$

with:	L_2	Required Length of the Abutment [m]
	p	Hydrostatic Pressure of the Fluid [N/cm²]
	d	Shorter Drift Dimension [m]
	σ_z	Permissible Flexural Tension of the Construction Material [N/cm²]

The maximum hydrostatic pressure should be 7.3 MPa. The drift dimensions, which form the basis of the pre-dimensioning, can be found in Table 1. Concrete mixed with brine should be used as construction material for Abutments 1 and 2. For this construction material, the following values apply to the C25/30 strength category:

- Permissible shear stress τ: 170 N/cm²,
- Permissible flexural tension σ_z: 110 N/cm²,

The dimensions of the abutments based on these values can be found in Table 3 and Table 4.

Table 3 Pre-Dimensioning of the Abutments in Single Drifts

Abutment	Required Length L_1	Required Length L_2	Chosen Length of the Abutment
A 1	5.1 m to 6.0 m	3.1 m	6.0 m
A 2	6.7 m to 7.6 m	4.2 m	8.0 m

Table 4 Pre-Dimensioning of the Abutments in Double Drifts

Abutment	Required Length L_1	Required Length L_2	Chosen Length of the Abutment
A 1	6.9 m to 7,3 m	3.1 m	7.5 m
A 2	8.8 m to 9.3 m	4.2 m	9.5 m

5.2.3.2 Pre-Dimensioning of the Sealing Elements

The pre-dimensioning of the required sealing elements was calculated based on the permeability-length-relationship (cf. Equation (5.1)) given by INERIS /6/. For the intrinsic permeability, the following values were assumed:

- for bentonite bricks: $5 \cdot 10^{-20}$ m² /6/,
- for salt-concrete: 10^{-18} m².

The results are summarised in Table 5.

Table 5 Pre-Dimensioning of the Sealing Elements

Sealing Element	Sealing Material	Required Length of the SE	Chosen Length of the SE
SE 1	Bentonite Bricks	7.0 m	8.0 m
SE 3	Bentonite Bricks	7.0 m	12.0 m
A-SE 1	Salt Concrete	31.6 m	35.0 m

5.2.3.3 Resulting Dam Lengths

Based on the pre-dimensioned lengths for the abutments and sealing elements, the lengths for the drift sealing constructions[9] were calculated. The results are presented in Table 6. In this case, it can be differentiated between 3 types of constructions:

- Dam Type 1: dams in single drifts,
- Dam Type 2: dams in double drifts

and

- Dam Type 3: a connected special construction (Dam 8), which stretches out across several single drifts.

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[9] For the lengths contained in Section 5.2.3.3, the approx. 15 m long dam stowing made of rock salt debris was not considered. If Variant 1 was chosen, this dam stowing would be placed on both sides and if Variant 2 or 3 was chosen, it would be added on the side at risk of brine intrusion.

Table 6 Resulting Dam Lengths According to the Pre-Dimensioning

Construction Components		**Length in m**	
	Dam Type 1	**Dam Type 2**	**Dam Type 3**
Abutment (A 1)	6.0	7.5	Special Construction
Sealing Element (SE 1)	8.0	8.0	
Sealing Element (SE 2)	0.5	0.5	
Abutment (A 2)	8.0	9.5	
Sealing Element (SE 3)	12.0	12.0	
Combined Abutment-Sealing Element (A-SE 1)	35.0	35.0	
Formwork walls (7 units á 0.5 m)	3.5	3.5	
Dam length[9]	**73.0**	**76.0**	**~270.0**[10]

An example of the construction design for a sealing construction of Dam Type 1 can be found in ENCLOSURE B.

5.3 Technical Conception of Variant 2

With Variant 2 a sealing concept is pursued in which, apart from the construction of long-term stable drift sealing constructions in the access drifts to the waste disposal area, an additional filling of the main drifts in the disposal site is planned. With this additional inner barrier that is placed in addition to the geotechnical barrier (drift sealing), the reactive voids in the main galleries should be reduced so that the long-term deformation processes are reduced and the associated weakening of the barrier between the waste disposal and the lower potash layer "CI" can be avoided. With this backfilling measure, the integrity of the geological barrier "Roof between Waste Disposal and Lower Potash Layer" can be maintained.

5.3.1 Design Basics

For the technical conception of Variant 2, apart from those mentioned in Section 5.2.1, the following basic data and basic conditions also apply:

a) regarding the location of the main galleries

The location of the main drifts that are to be backfilled is illustrated in Figure 5 and in ENCLOSURE C.

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[10] The required length of the construction was determined based on the mine plan.

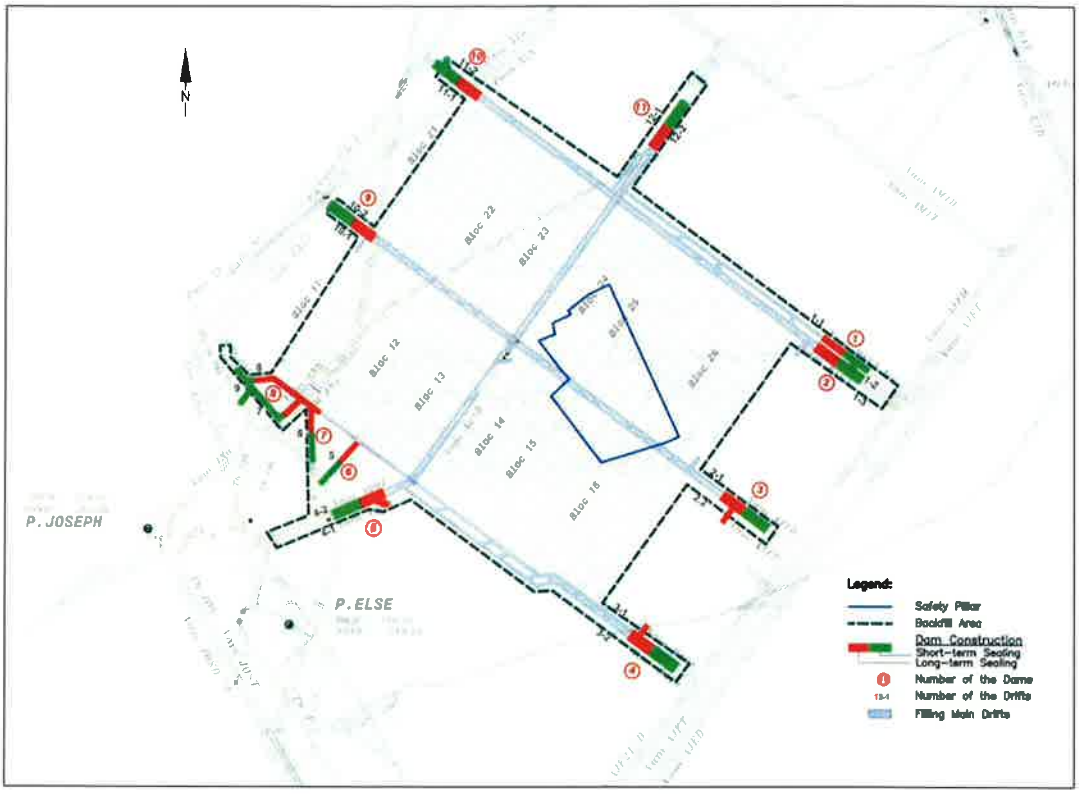

Figure 5 Overview of the Location of the Planned Dams as well as the Main Drifts that are to be Backfilled

b) regarding the dimensions of the main galleries

The dimensions, i.e. the lengths and widths of the drifts that are to be backfilled were taken from the mine plan. The height of the drift was estimated uniformly at 3 m. The volume of the voids in all 4 main drifts was calculated based on this data and can be found in Table 7.

Table 7 Cavity Volume of the Main Drifts

Name of the Drift	**Drift System Cavity Volume in m³**
Vam RAS2 bis & Vam RAS2	19,913.7
Vam AJ1D & Vam AJ1T	15,351.9
Vam RAS1 & Vam RAT1	16,247.1
Vam AQ0T & Vam AQ0D	16,185.0
Total	**67,697.7**

c) regarding the geological settings of the main drifts

The main drifts are all found in the Lower Rock Salt Layer (Upper Salt Zone of Sannoisien).

5.3.2 Backfill Material

For the backfilling of the main drifts the following backfill materials can be considered based on the basic conditions (host rock: rock salt, chemistry of the potential intruding brines: NaCl saturated brine or NaCl and KCl saturated brine with marginal amounts of $MgCl_2$):

- rock salt debris,
- salt-concrete

and

- filling mortar (mixed with brine).

For the use of rock salt debris, a new extraction field for rock salt must be designed. The possibility of obtaining a new extraction permit will have to be examined. Alternatively, the debris could be purchased from another mine. However, the transport of the purchased debris will be very time-consuming due to the limited shaft hoisting capacity (cf. Section 5.2.1.2).

Both the alternatives of salt-concrete and filling mortar could be pumped underground from the surface so that a continuous stream of construction materials can be ensured. This stream would only be dependent on the design / dimensioning of the backfill mixing plant as well as the dimensioning of the pipelines for the construction material.

Since there are no demands on the inner barrier of the multi-barrier-system with regard to the permeability as well as the long-term stability of the construction material, because the task of isolating the waste disposal area is entirely taken over by the geotechnical barriers "brine tight dams" and the inner barrier mainly serves the purpose of reducing the reactive void, filling mortar[11] (mixed with brine) should be used as backfill material. In terms of cost-effectiveness, this is the best alternative.

5.3.3 Backfill Technology

The backfill process includes the following steps:

- delivery and storage of the components of the backfill material,
- transport of the components to the backfill mixing plant,
- preparation of the backfill material in the mixing plant,
- transport of the backfill material to the prepared open cavities

and

---

[11] e.g. filling mortar DM 1.25 from QUICK-MIX (www.quick-mix.de)

- filling of the open cavities.

Due to the limited floor space underground, the mixing plant for the construction material should be constructed on the surface. This would also be advantageous because

- no underground installations are needed except pipelines

and

- geodetic height differences in the shaft can be used for transporting the backfill material to the backfill site underground.

The position of the backfill mixing plant depends on the required space and the maximum possible transportation distance for the prepared backfill material.

The mixed backfill material is pumped down to the prepared open cavities via pipelines. The backfilling will be carried out in sections, whereby the individual sections should be separated by formwork walls. The backfill material can be stored intermediately in a tank underground for effective distribution to the blocks over short distances (cf. Figure 6).

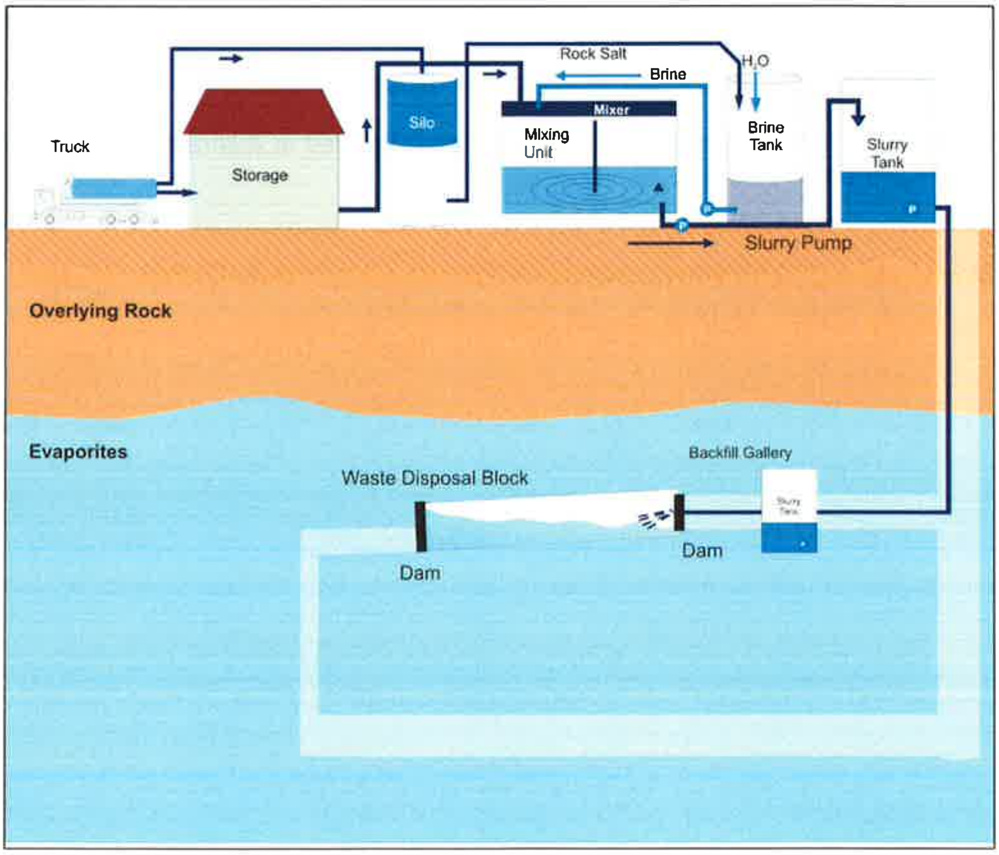

Figure 6 Backfill Technology with the Backfill Plant at the Surface

To reduce remaining open cavities, the backfill material must be inserted at the geodetically highest point of the section to be backfilled.

A total of approx. 67,700 m³ filling mortar mixed with brine (e.g. DM 1.25 from Quick-Mix or similar material) should be brought into the main galleries.

5.4 Technical Conception of Variant 3

Variant 3 is similar to Variant 2 with an additional filling of the remaining cavities in the disposal blocks between or above the waste. The objective of this backfilling alternative is the reduction of the reactive voids in order to maintain the integrity of the geological barrier "Roof between Waste Disposal Area and Lower Potash Layer "CI".

5.4.1 Design Basics

For the technical conception of Variant 3, apart from those mentioned in Section 5.3.1, the following basic data and basic conditions apply:

a) regarding the location of the storage blocks

   The location of the storage blocks that are to be backfilled is illustrated in Figure 7 and ENCLOSURE D.

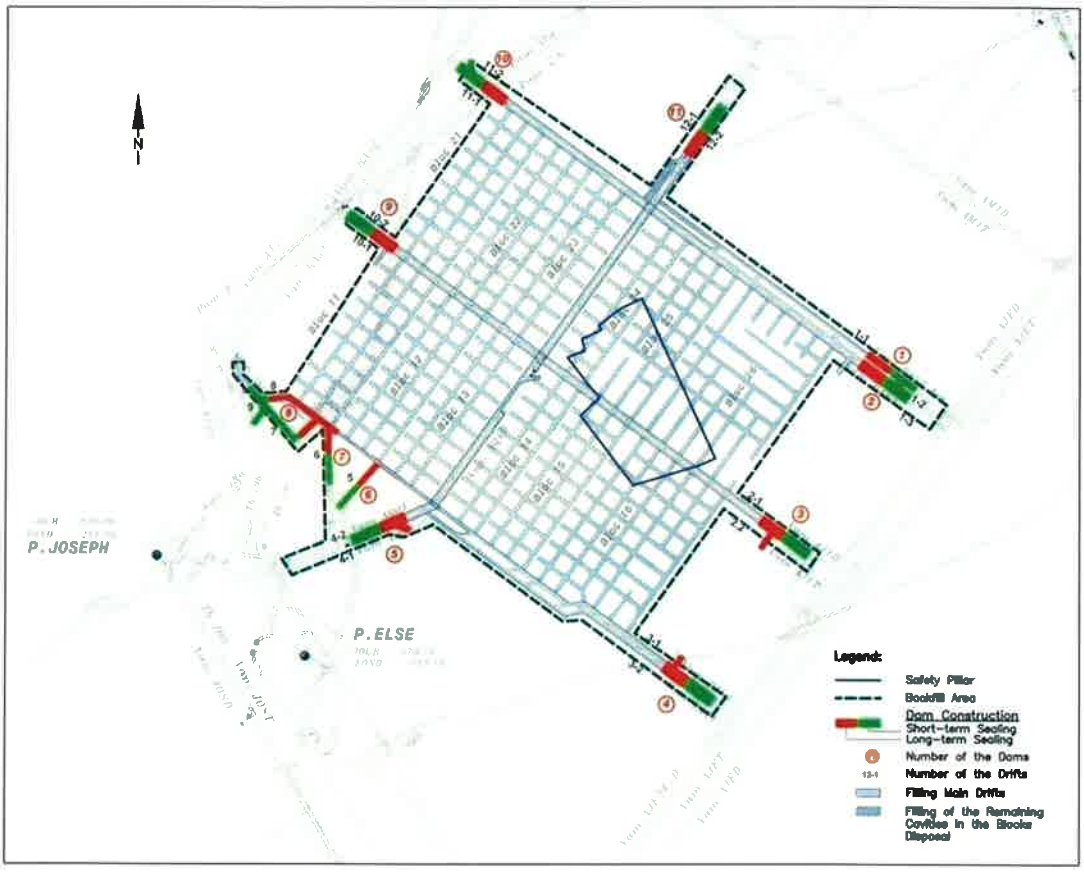

Figure 7 Overview of the Location of the Planned Dams as well as the Main Drifts and Voids to be Backfilled in the Storage Blocks

b) regarding the remaining cavity volume of the storage blocks

The dimensions of storage blocks that are to be backfilled were taken from the mine plan. The height of the drifts was uniformly estimated at 3 m. For the estimation of the deposited waste, it was assumed that approx. 70% of the open cavities in the storage blocks are filled with waste. The remaining cavity volume that was calculated based on this data is contained in Table 8.

Table 8 Remaining Cavity Volume of the Storage Blocks

Block Number	**Open Volume before the Storage in m³**	**Volume of the Waste in m³**	**Remaining Cavity Volume in the Blocks in m³**
11	18,222.0	12,755.4	5,466.6
12	18,680.7	13,076.5	5,604.2
13	15,746.1	11,022.3	4,723.8
14	13,743.9	9,620.7	4,123.2
15	18,639.3	3,639.3	15,000.0
16	34,834.5	-	34,834.5
21	18,579.3	13,005.5	5,573.8
22	18,717.9	13,102.5	5,615.4
23	15,702.9	10,992.0	4,710.9
24	13,493.1	9,445.2	4,047.9
25	16,797.9	-	16,797.9
26	27,579.9	-	27,579.9
Total	**230,737.5**	**96,659.4**	**134,078.1**

5.4.2 Backfill Material

The only backfill material that can be used under the given basic conditions:

- substratum: rock salt,
- potential intruding brines (cf. Section 5.2.1.1): NaCl saturated brine or NaCl and KCl saturated brine with marginal amounts of $MgCl_2$

and

- inaccessible remaining cavities in the storage blocks

is filling mortar. This backfill material is largely self-levelling and very capable of flowing, such that it can thoroughly penetrate the remaining cavities. When filling mortar is mixed with saturated NaCl brine, the material is not potentially soluble in the substratum.

5.4.3 Backfill Technology

The backfill technology is the same as described in Section 5.3.3.

For the backfilling of the remaining cavities in the storage blocks, approx. 127,500 m³ of filling mortar (e.g. DM 1.25 from Quick-Mix or similar material) mixed with brine will be required. This estimation is based on the assumption that a maximum of 95% of the remaining cavity can be filled because "backfill shadows" (remaining open voids under the roof) will be inevitably created within the backfilled sections due to the cavity geometry in the roof area.

6 Estimation of Costs and Construction Time

The cost estimations for the implementation of Variants 1 to 3 concerning the separation of hazardous waste from remaining parts of Amelie mine are based on:

- the schematic construction draft for the drift dams (ENCLOSURE B) and the backfilling concepts as shown in ENCLOSURE C and ENCLOSURE D respectively,
- corresponding, estimated quantity determinations

as well as

- reference prices, which were determined by examining comparable projects, budgetary quotations and price databases.

The accuracy of the cost estimations for each individual backfilling alternative is about 35%. All construction costs are estimated and given in net prices.

6.1 Cost Estimation of Variant 1

The net prices for the construction of brine tight dams in access galleries to the underground waste disposal are shown in Table 9 and include the following items:

- site installation, maintaining the site, establishment and operation of the necessary auxiliary ventilation and the clearing of the site,
- all preliminary and extra works under/above ground, e. g. smaller developments for infrastructural facilities etc.,
- scaling works, e. g.
    i. Trimming of the Loosening Zone (LZ),
    ii. Establishment and smoothing of the abutment profile for A 2,

  as well as

    iii. milling of the sealing trenches of the Sealing Elements,
- walling and cleaning works, including the delivery and fitting in of lime sand bricks in order to install the frame walls, including the plastering of these walls and the spreading with e.g. IMBERAL® sealing compound

and

- the delivery / transport of
    i. rock salt debris with required grain sizes,
    ii. concrete mixed with brine,

iii. bentonite,

iv. mastic asphalt stones, including the sealing compound

as well as

v. salt-concrete

to the individual dam construction site and fitting into the particular construction components.

Table 9 Cost Estimation of Variant 1 – Dam Constructions in Access Galleries

Item	Short Description	Construction Costs
1	Site Installation	9,599,500 EUR
2	Preliminary and Extra Works	2,870,700 EUR
3	Scaling Works	2,158,700 EUR
4	Dam Stowings	2,308,200 EUR
5	Walling and Cleaning Works	1,808,900 EUR
6	Concrete and Sealing Works	28,016,800 EUR
7	Technical Engineering: Supervision, Preservation of Evidence, Documentation, Building Materials Testing	849,300 EUR
Subtotal		47,612,100 EUR
5.00%	Contingencies	2,380,605 EUR
Total		**49,992,705 EUR**

According to these calculations, the construction of brine tight dams in access galleries to the underground waste disposal will cost about **50,000,000 EURO**.

6.2 Cost Estimation of Variant 2

The net prices for the construction of brine tight dams in access galleries to the underground waste disposal and the additional filling of the main galleries in the storage area with applicable material are shown in Table 10 and include the following items:

- the complete implementation of Variant 1,
- the installation (and subsequent de-installation) of a mixing- and pumping station for the construction material, including storage silo and tanks at the surface, a brine mixing unit, a backfill mixing unit, a shaft pipeline, underground pipelines, a system control unit and auxiliary equipment,
- the sealing of the disposal blocks and the cross sectional area in between the particular plugging sections with corresponding formwork panels

and

- the complete filling of the main galleries with filling mortar.

Table 10 Cost Estimation of Variant 2 – Dam Constructions in Access Galleries and Additional Filling of the Main Galleries with Filling Mortar

Item	Short Description	Construction Costs
1	Installation/De-installation of the Backfill Mixing Plant	
1.1	Backfill Mixing Plant	4,021,000 EUR
1.2	Installation	1,137,000 EUR
1.3	De-installation	380,000 EUR
2	Filling of Main Galleries	
2.1	Backfill Material	1,790,500 EUR
2.2	Backfilling	2,685,800 EUR
3	Implementation of Variant 1	50,000,000 EUR
Total		**60,014,300 EUR**

According to these calculations, the construction of brine tight dams in access galleries to the underground waste disposal with an additional filling of applicable material in the main galleries of the storage area will cost about **60,020,000 EURO**.

6.3 Cost Estimation of Variant 3

The net prices for the construction of brine tight dams in access galleries to the underground waste disposal and the additional filling of the main galleries in the storage area as well as of the remaining cavities in the disposal blocks between or above the waste are shown in Table 11 and include the following items:

- the complete implementation of Variant 2,
- the sealing of the particular plugging sections with corresponding formwork panels

and

- the best possible plugging of the remaining cavities in the disposal blocks between or above the waste with filling mortar (mixed with brine).

Table 11 Cost Estimation of Variant 3 – Dam Constructions in Access Galleries and Additional Filling of the Main Galleries and Remaining Cavities in the Storage Blocks with Filling Mortar

Item	Short Description	Construction Costs
1	Installation/De-installation of the Backfill Mixing Plant	
1.1	Backfill Mixing Plant	4,021,000 EUR
1.2	Installation	1,137,000 EUR
1.3	De-installation	380,000 EUR
2	Filling of the Main Galleries and the Remaining Cavities in the Storage Blocks	
2.1	Backfill Material	14,001,000 EUR
2.2	Backfilling	6,000,600 EUR
3	Implementation of Variant 1	50,000,000 EUR
Total		**75,539,600 EUR**

According to these calculations, the construction of brine tight dams in access galleries to the underground waste disposal with an additional filling of applicable material in the main galleries of the storage area as well as the filling of remaining cavities in the disposal blocks between or above the disposed hazardous waste will cost about **75,540,000 EURO**.

6.4 Preliminary Estimation of the Construction Time of the Backfill Works

The individual backfill variants can be realised within the estimated construction periods shown in Table 12. The construction time of 416 weeks for the dams assumes one crew in single-shift operation. This time can be considerably shortened by employing several crews simultaneously as long as sufficient hoisting and transportation capacity is provided.

Table 12 Preliminary Estimation of the Duration of the Backfill Works

Item	**Time in Weeks**		
	Variant 1	**Variant 2**	**Variant 3**
Installation/De-installation of the Backfill Mixing Plant			
Installation		22	22
De-installation		5	5
Filling of the Remaining Cavities in the waste disposal site			
Backfill Material			
Backfilling		45	192
Implementation of Variant 1			
Material / Construction (all dams)	416	416	416
Building Site Equipment & Supervision			
Total	**416**	**488**	**635**

7 Recommendations and Conclusions

The abovementioned Variants 1 to 3 were assessed by using a cost-benefit-analysis. Benefit in this case is defined as achievable safety level in terms of influence of possibly developing hazardous solutions on the biosphere.

According to the safety concept described above (cf. Chapter 5) the waste can only be isolated from the biosphere on a long term basis through a multi-barrier-system within the host rock. This system consists of an outer and an inner barrier complex.

Due to leakages in the existent geotechnical barriers (shaft and surface drill hole plugs) the outer barrier works only as a hydraulic retardant, which leads to a flooding of the Amelie and Marie-Louise mines. According to the HYDROGEOLOGICAL STUDY OF STOCAMINE /5/ the cavities of the mines will be flooded at the earliest in 240 years from now, such that the level of brine will reach the storage area. Due to the fact that the outer barrier complex represents an open system (hydraulic connection with aquifers) the required isolation of the waste from the biosphere (cf. Chapter 3) can only be achieved by using an additional inner barrier complex. An essential component of this complex is the geological barrier “roof separating the waste disposal site and the Lower Potash Layer” with a thickness of about 25 m. Due to the fire in 2002 within Storage Block 15 the roof has been damaged, which leads to the assumption, that its sealing function inside this zone is unaffected only in the upper 13 m (GEOMECHANICAL STUDY OF STOCAMINE /4/). In order to guarantee the integrity in the long term, the reactive cavity inside the storage area has to be reduced to a minimum. Therefore this report also considers the possibility of installing additional inner barriers (Variant 2 & Variant 3) besides the necessary geotechnical barriers (“brine tight dams”, Variant 1). There are no requirements for the inner barriers regarding their sealing effects and long-term stability. Their objective is to minimise long-term deformation processes and the resulting softening of the roof formations between the storage area and the lower potash beds “CI”. These deformation processes are enhanced in the areas of the Storage Blocks 14, 15, 16, 24, 25 and 26 due to a safety pillar in the zone of the Lower Potash Layer, which causes a roof softening before the reactive cavity can actually be backfilled. Although the inner barriers have no requirements regarding their sealing function and long-term stability, they form a homogeneous back stowing area, which inhibits the leaching of harmful substances in case of a potential brine intrusion through pathways within the roof.

The required geotechnical barriers (“brine tight dams“) of all three variants are constructions that require sophisticated, structurally engineered implementation. In particular the dams which will be arranged in double drift systems will have widths of up to 14 m due to the fact that the intermediate pillar as well as the Loosening Zone have to be removed in this area. There is no comparable reference project in the world where a functional drift sealing is realised on this scale. Furthermore the high number of drift sealing constructions has to be taken into account, which would result in stringent requirements for the quality assurance during the installation of individual construction components. In general the implementation of any of the abovementioned closure options is evaluated as technically feasible.

However, in this case safety is the greatest asset and therefore, regardless of the technical effort and economic expenditure necessary, Variant 3 must be recommended as the most economically sound alternative. Variant 3 is strongly recommended because it offers the greatest possible exclusion of risks and therefore also the highest degree of safety in case of the decision that the waste is not to be removed from the site. An important point to consider is that if the waste has to be moved to another site, it will be subject to the same kinds of risks already faced currently.

REFERENCES

/1/ Arrêté Préfectoral n°970157 du 03.02.1997 délivré par le Préfet du Haut-Rhin et portant autorisation d'exploiter au titre des exploitations classées, 38 pages.

/2/ Article L-515-7 du Code Français de l'Environnement du 29 Juin 2006, sur la base d'ancienne loi n°76-663 du 16 Juillet 1976 relative aux installations classées pour la protection de l'environnement (modifié par la loi n°92-646 du 13 Juillet 1992, art6 JORF 14/07/92).

/3/ EEC 2003/33/CE, Journal Officiel des Communautés Européennes, Décision du Conseil du 19 décembre 2002 établissant des critères et des procédures d'admission des déchets dans les décharges, conformément à l'article 16 et à l'annexe II de la directive 1999/31/CE.

/4/ Rapport d'Etude DRS-10-108-130-14273A du 23/12/2010, « Etude Géomécanique du stockage de StocaMine », INERIS, 2011, 116 pages.

/5/ Rapport d'Etude DRS-10-108-130-12810B du 09/03/11, « Stockage Souterrain de STOCAMINE (68), Etude Hydrogéologique de l'Ennoyage du Site », INERIS, 2011, 190 pages.

/6/ INERIS (2011): Rappel des précédents résultats de l'étude d'impact sur la nappe. - présentation PowerPoint, INERIS, 23.05.2011.

/7/ Sitz, P. (1982): Querschnittsabdichtungen untertägiger Hohlräume durch Dämme und Pfropfen. – Freiberger Forschungsheft A 643, 151 Seiten, VEB Deutscher Verlag für Grundstoffindustrie, Leipzig, 1982.

/8/ TU BAF (2009): Diversitäre und redundante Dichtelemente für langzeitstabile Verschlussbauwerke. - Abschlussbericht zum mit Mitteln des BMBF unter 02C1124 geförderten Forschungsvorhaben, 307 Seiten, Freiberg, 2009.

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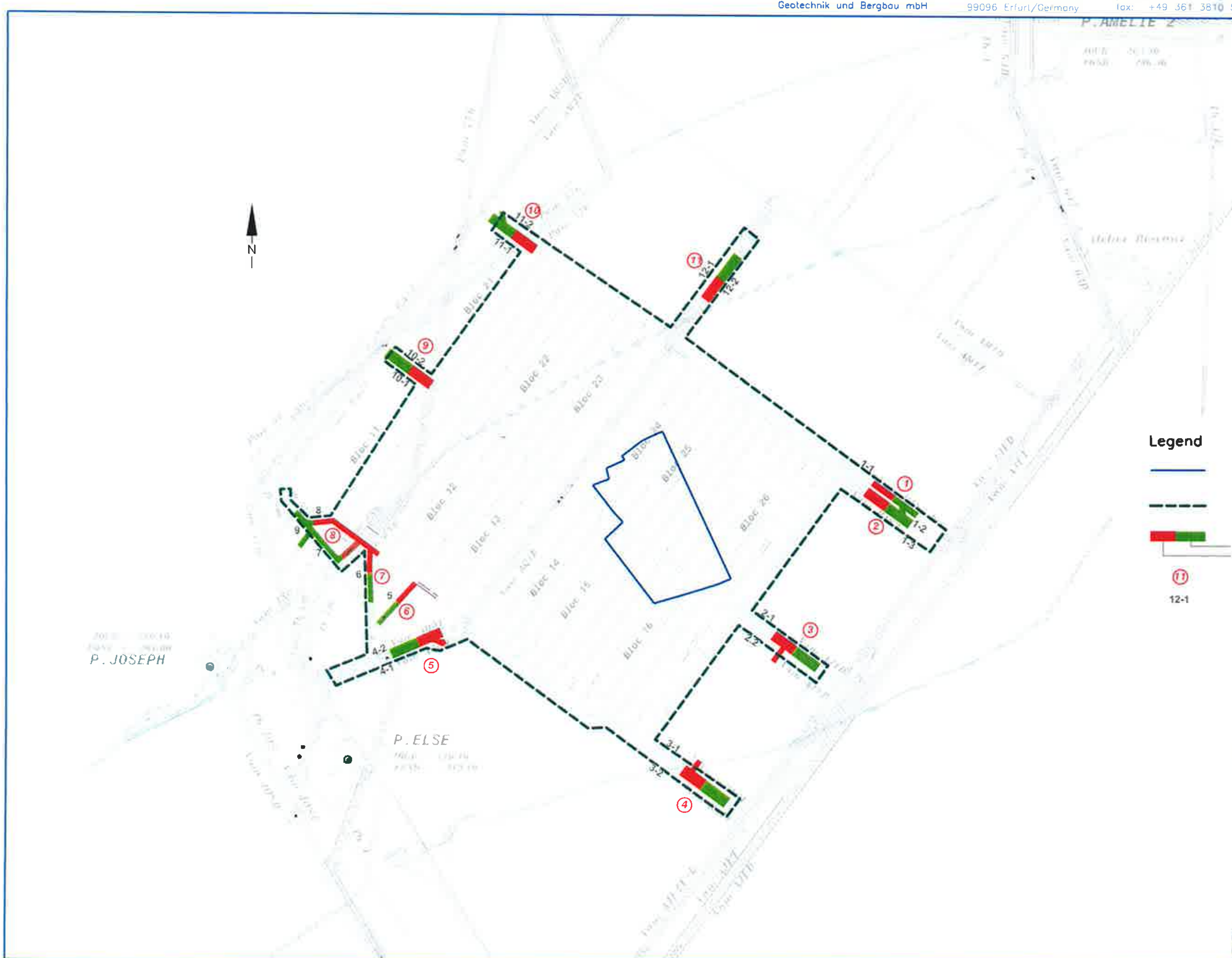

Conceptual Design
Backfill Operation and Dam Construction
of StocaMine Toxic Waste Disposal Site

ENCLOSURE A

General Plan of the StocaMine Waste Disposal Site and the Recommended Dam Positions

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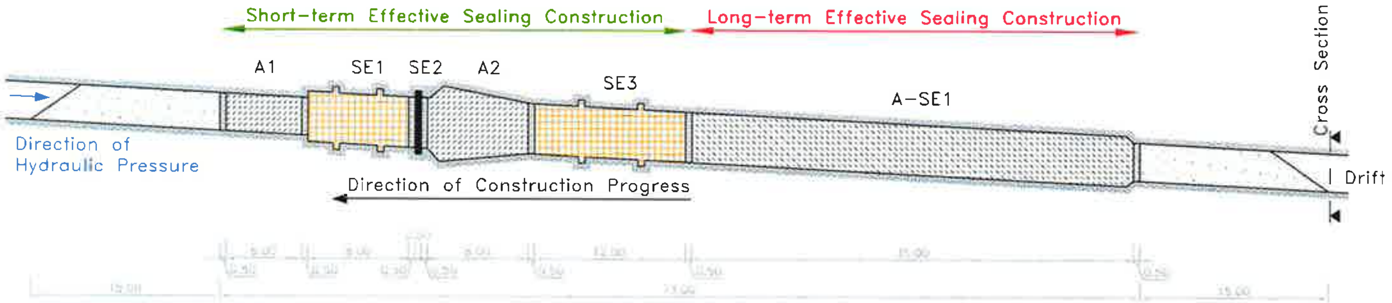
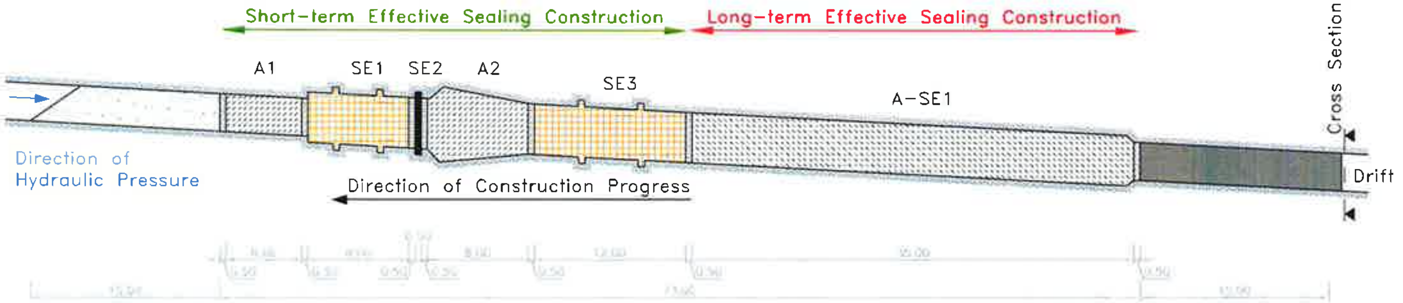
Sealing Construction (V1)

Scale 1:400



Sealing Construction (V2 and V3)

Scale 1:400

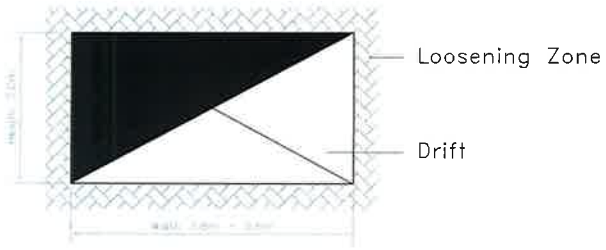


Legend

▨	Loosening Zone (LZ)
☐	Rock Salt Stowing
▨	Concrete of Gravel-Cement-Brine
▨	Bentonite
▨	Salt-Concrete (Rock Salt, Cement, Water, Sand)
■	Filling Mortar
|	Mastic Asphalt
A	Abutment
SE	Sealing Element

Cross Section of Drift (Schedule)

Scale 1:100



Conceptual Design
Backfill Operation and Dam Construction
of Slocomine Toxic Waste Disposal Site

ENCLOSURE B

**Cross Section of the
Brine Tight Dams**

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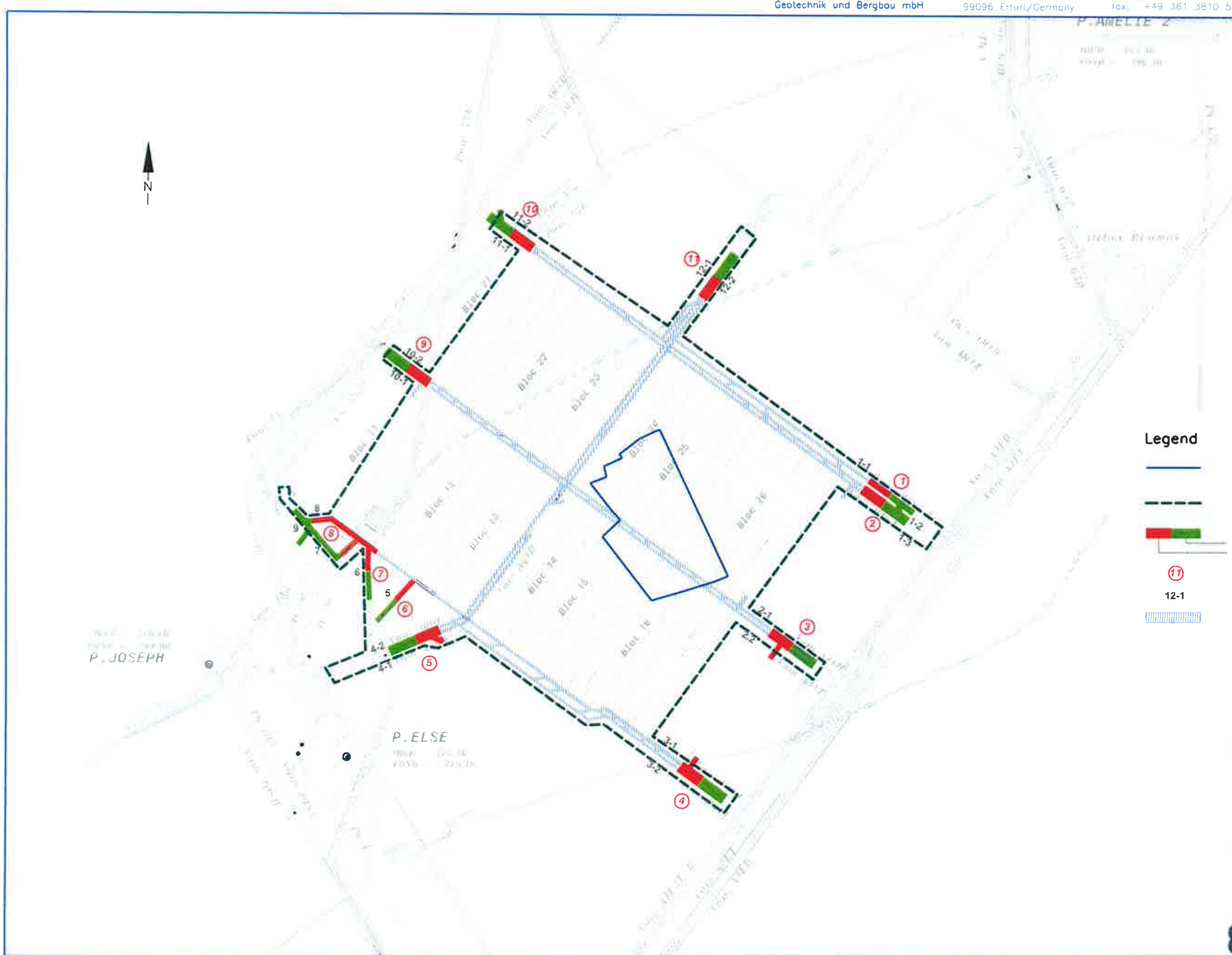

Legend

━	Safety Pillar in Lower Potash Level
╍╍	Backfill Area
🟥🟩	<u>Dam Construction</u> Short−term Sealing Long−term Sealing
⑪	Number of the Dams
12-1	Number of the Drifts
▥	Filling Main Drifts

Conceptual Design
Backfill Operation and Dam Construction
of StocaMine Toxic Waste Disposal Site

ENCLOSURE C

General Plan of the StocaMine Waste Disposal Site, the Dam Positions and the Filling Area of Variant 2

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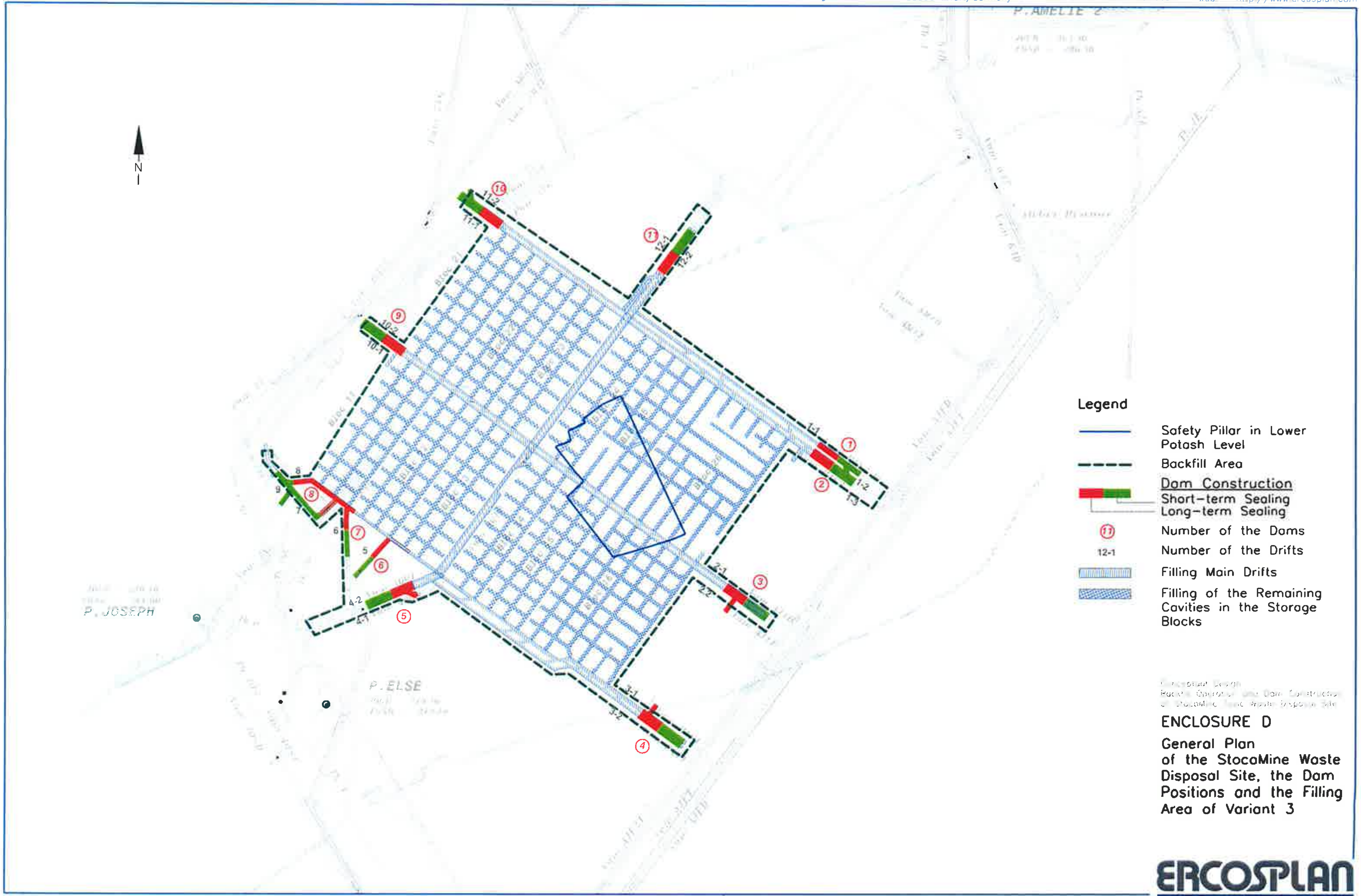

Conceptual Design
Backfill Operation and Dam Construction
at StocaMine Toxic Waste Disposal Site

ENCLOSURE D

General Plan
of the StocaMine Waste
Disposal Site, the Dam
Positions and the Filling
Area of Variant 3

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