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Follow-Up Report

Conceptual Design for Dam Constructions and Partial Backfill for the Isolation of the StocaMine Underground Waste Disposal Site

Client: **StocaMine**
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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

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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 the Direction des Risques du Sol et du Sous-sol of INERIS, further studies were conducted addressing geomechanical, hydrogeological and chemical aspects. As result of these studies frame conditions were set for the closure of the disposal site.

StocaMine has contracted ERCOSPLAN for the evaluation of INERIS papers to update the database for assessment of the disposal site closure and development of a technical concept for the closure by partial backfill and dam construction.

In a meeting held in September 2011 at the StocaMine site, the scope of work was discussed to incorporate latest results of INERIS and develop a technical concept for closure of the waste disposal site based on fixed assessment criteria. This scope of work has been revised during the year 2012 according to discussions of the best option concerning the site conditions. The technical concept as fixed in a meeting in February 2013 is to be delivered in form of a follow-up report.

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2 Scope of Work

The technical concept for the closure of the waste disposal site will be developed comprising the conceptual design of dams and partial backfill meeting the requirements of assessment criteria given by INERIS as well as considering the specific conditions of the waste disposal site, the estimation of construction time and cost of the closure and recommendations to an implementation of the concept.

The scope of work was split into the following subtasks:

- Explanation of the legal environmental and industrial basis and derivation of safety objectives,
- Summary of the site-specific boundary conditions (geology, hydrogeology, rock mechanics),
- Summary of the technical requirements for the dam constructions as provided by INERIS,
- Conceptual design of the dam constructions, including:
  - (i) Description of the current scientific knowledge and technology of the construction of drift sealing systems for underground waste deposits,
  - (ii) Creation of an utilisation plan for the drift sealing system,
  - (iii) Compilation of a list of potential construction materials,
  - (iv) Design of the dam construction,
  - (v) Pre-dimensioning of individual components,
  - (vi) Description of the construction method,
  - (vii) Estimation of the construction time,
  - (viii) Rough estimation of quantities,
  - (ix) Cost estimation with an accuracy of ± 35%,
- Conceptual design of the partial backfilling of the disposal site, including:
  - (i) Compilation of a list of potential backfill materials,
  - (ii) Design of the partial backfilling of the waste disposal site,
  - (iii) Description of the backfill operation,
  - (iv) Estimation of the backfill operation time,
  - (v) Rough estimation of quantities,
  - (vi) Cost estimation with an accuracy of ± 35%,

as well as

- ERCOSPLAN's recommendations for further course of action.

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3 Legal Environmental and Industrial Basis for the Stocamine Waste Disposal Closure

The initial permit granted by the PREFECTURAL AUTHORISATION OF EXPLOITATION (1997, /2/) 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 stored waste.

After this incident the following changes to legislation were made:

- The FRENCH ENVIRONMENTAL CODE (2006, /3/), 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 (2003, /4/) 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 as well as to evaluate the consequences of unlimited storage, and resulting potential risks in the long-term (several hundred years). As a result of this evaluation the decision was made in December 2012 to close StocaMine by partial destocking of one waste type, the unlimited storage of the remaining waste and the sealing of the StocaMine waste disposal site by partial backfill and dam construction. By sealing of the waste disposal site it has to be ensured, that in the long-term pollution of the environment, and especially the groundwater, is prevented or kept at minimum level.

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4 Summary of the Technical Studies from INERIS

In December 2010, March and November 2011 three studies were carried out, regarding geomechanical, hydrogeological and chemical parameters, detailing the expected long-term evolution of the mine. Input data for the technical assessment of the isolation of the waste disposal site, and especially the consideration of long-term sustainability, have been revised by these studies.

The important parameters and conclusions, resulting from the INERIS assumptions (INERIS 2010, /7/; 2011, /10/; 2011, /8/), will be presented in the following chapters.

4.1 Geomechanical Study of StocaMine

The ETUDE GÉOMÉCANIQUE DU STOCKAGE DE STOCAMINE (INERIS 2010, /7/) 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, drifts, caved stope areas), linked to the problem of impact of the creep rate on the 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 intermediate pillars of the double drifts 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 and pillars affected by the fire are damaged. The study showed that the damages, reaching about 12 m into the roof, did not reach the potash level 25 m above, supposing that salt permeability is still low on the last 13 m.

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

[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” should be differentiated from the “Stot” Pillar situated above Blocks 25 and 26.

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 drifts) 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 closure could be justified at depths of 1,000 m, but might probably be 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, reaching about 0.01% per year in exploited areas (caved stope), or 1 mm / year which is imperceptible.

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 and pillars are supposed to be accentuated over time. Therefore decisions regarding interventions have to be made quickly.

4.2 Hydrogeological Study of StocaMine

The ETUDE HYDROGÉOLOGIQUE DE L'ENNOYAGE DU SITE (INERIS 2011, /10/) 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.
   - 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

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behaviour was observed). The overall expected initial inflow in the mine has been estimated at about 105,000 m³ per year through the 15 existing shafts.

- Taking into account previously determined[3] mechanical parameters, the general inflow of the mine will remain constant until flooding is completed while the closure and compaction of open volume in the western sector will progress to reach about 3,000 m³ per year in the ultimate stage (in the long-term). This volume of 3,000 m³ corresponds to the volume of brine which is expulsed through the shafts into the aquifer every year. At the same time a volume of 0.7 m³ of contaminated brine will migrate from the StocaMine waste disposal area into the flooded mine every year where it will be diluted.
- The general brine level[4] is expected to reach the storage area after 240 years, taking into consideration that about 7% (2.06 million m³) of the Western Sector is probably already flooded. The complete mine would be flooded after 305 years[5] (StocaMine and upper levels from Amelie mine).
- The estimated overall trapped air volume after flooding completion is expected to be 10%.

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 come 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 flows through TB2 up to the “Atelier Reseaux” (underground workshop).
  - Afterwards, the brine floods the “Atelier Reseaux” and flows through AM1 and AM2 ways.
  - The brine reaches the peripheral storage area (outside the dams) by AM2, and progressively floods the storage area completely, and is concurrently contaminated.

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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. 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/cm³.

5 The time reference is the year 2010.

6 Expected total flow rate of 1,700 m³ per year.

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- 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 intrados and extrados of shafts towards the surface.

Important remarks:

- The estimated residual volume of the storage area after 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 / year could occur. The expected porosity of the waste has been evaluated as 31% in average after flooding completion.

4.3 Source Term Study for Unlimited Storage Time of StocaMine

The EVALUATION DU TERME SOURCE DANS LE SCÉNARIO DU STOCKAGE ILLIMITÉ (INERIS 2011, /8/) is complementary to the geotechnical and geomechanical statements. The main objectives and conclusions are presented below:

- This reports aim is to establish from the interpretation of available information and data collected over the entire waste stocking operation period between 1999 (commencement of operations) and 2002 (cessation of the operation) the amount of contaminants present in the storage as well as the potential concentrations of these in brines flooding the disposal area and their possibility to move, and in the air in equilibrium with these concentrations.

The important and relevant approaches concluded by INERIS, according to two separate flooding scenarios (absence of and presence of barriers) are:

a) The amount of contaminants present in the storage,
    - The results from BMG indicate that the quantities of contaminants stored vary widely for the same waste. The quantities of contaminants stored were recalculated using the weights stored by preliminary acceptance certificate (PAC) and the average content of contaminants derived from the analysis of stored batches (corrected for containers and added plaster) with the weight of the batches. The results of BMG are confirmed (despite some minor differences) by INERIS. Computed quantities of contaminants are usable and could be finally resolved by the seizure of the masses by lot.
b) The concentrations of these contaminants in the flooding brine and their solubility,
    - The Solubility of contaminants stored calculated by geochemical equilibrium leads to the equilibrium concentrations of around 1 mg/L for Cd, between 10 and 100 mg/L Cr, Hg and Sb for the scenario in the absence of barriers (diluted in 6.2 million m^3 of brine) and at concentrations of 1 mg/L for Cd, between 1 and

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10 g/L Cr, Hg and Sb for the scenario in the presence of barriers (diluted in 7,000 m^3 of brine).

c) The gas in the underground atmosphere,

- The current levels in the atmospheric air storage showed no traces of biological activity but indicated slight chemical activity signs. As concluded by BMG, the emission of compounds created in a reducing atmosphere (AsH_3, Hg°) after flooding is unlikely. Hydrocyanic acid concentrations after flooding HCN_g, estimated from free cyanide, pH of the storage and complexation by metals, reach between 10^{-3} and 10^{-6} mg/m^3.

Important remarks:

- Concentration of contaminants in the brine in the StocaMine area could reach considerable high levels but would be diluted in the brine volume flooding the entire mining sector.
- The contamination of aquifers by expulsion of contaminated brine trough the shafts as possible connection would be marginal and well below permissible limits.

4.4 Summary of the Technical Studies of INERIS

The results of the technical studies regarding geomechanical and hydrogeological aspects from INERIS (2010, /7/ and 2011, /10/) are summarised in Figure 1. Main aspects shown are the expected closure of the storage blocks and drifts after about 100 years and the flooding of the storage area starting after about 240 years and ending after about 300 years. The concentration of pollutants in possibly contaminated brine will be diluted if the brine is expulsed out of the storage area into the surrounding mining sector. This diluted brine would be further diluted if it came into contact with groundwater in aquifers.

Taking into account the isolation of the waste disposal area by a combination of backfilling and dam construction, the situation is estimated to be even more favourable than described above.

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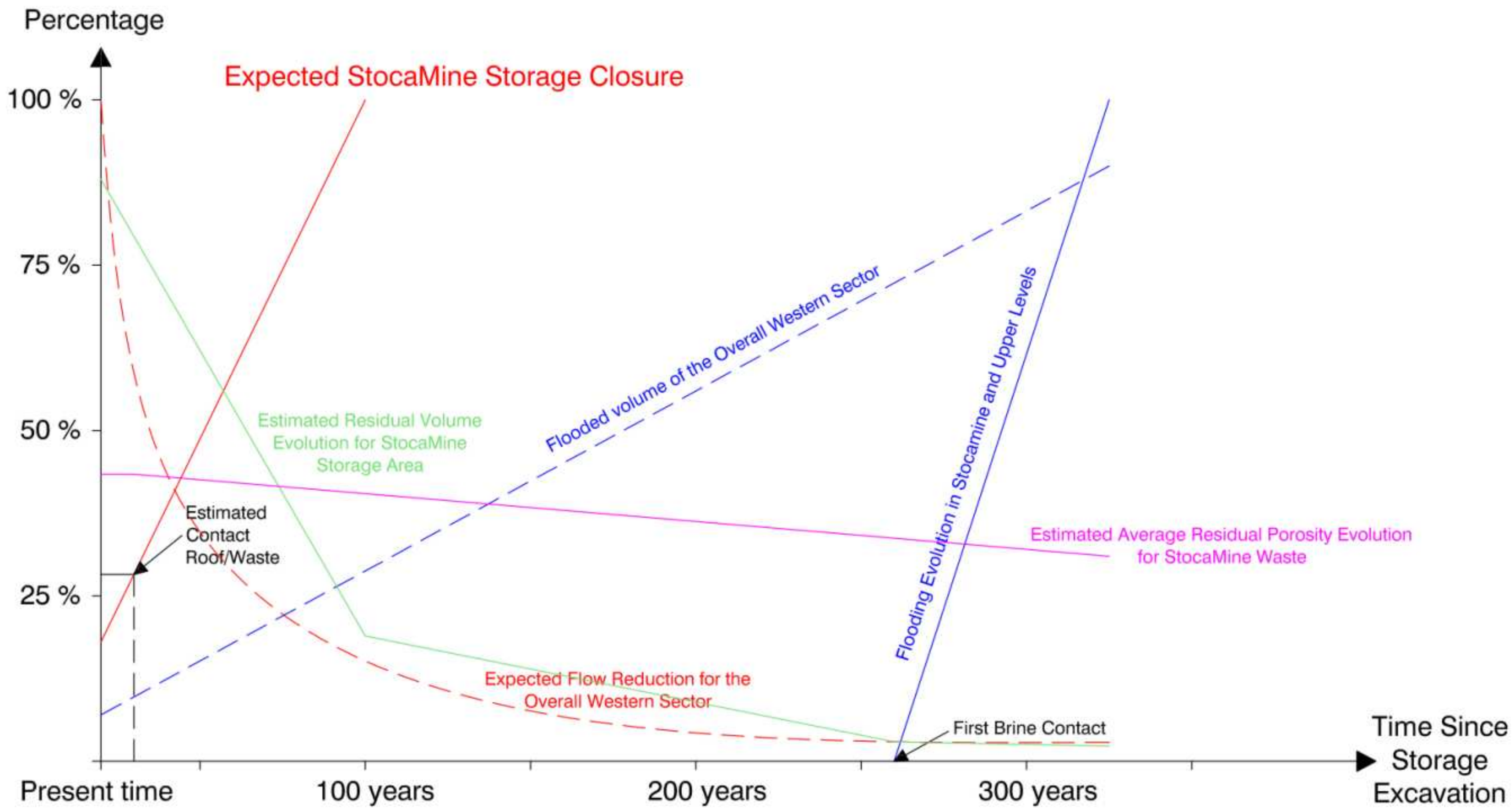

Figure 1 Expected Geomechanical and Hydrogeological Evolution of StocaMine and of the Overall Western Sector

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5 Sealing Concept for the Permanent Isolation of the Deposited Waste in StocaMine

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 (in this case rock salt) taking into account a Multi Barrier System. The outer barrier complex consists of:

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

  which comprise 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.

This outer barrier complex only functions as a hydraulic barrier due to the leaks in the existing geotechnical barriers and because the Amelie and Marie-Louise mines are subject to a flooding process. The efficient long-term 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 comprise the roof beam of rock salt 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 borehole plugs and drift sealing systems, which cut across the geological barriers of the inner barrier complex.
- 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.

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 barrier “Drift Sealing Dam” and for the partial backfilling of the waste disposal site will be developed.

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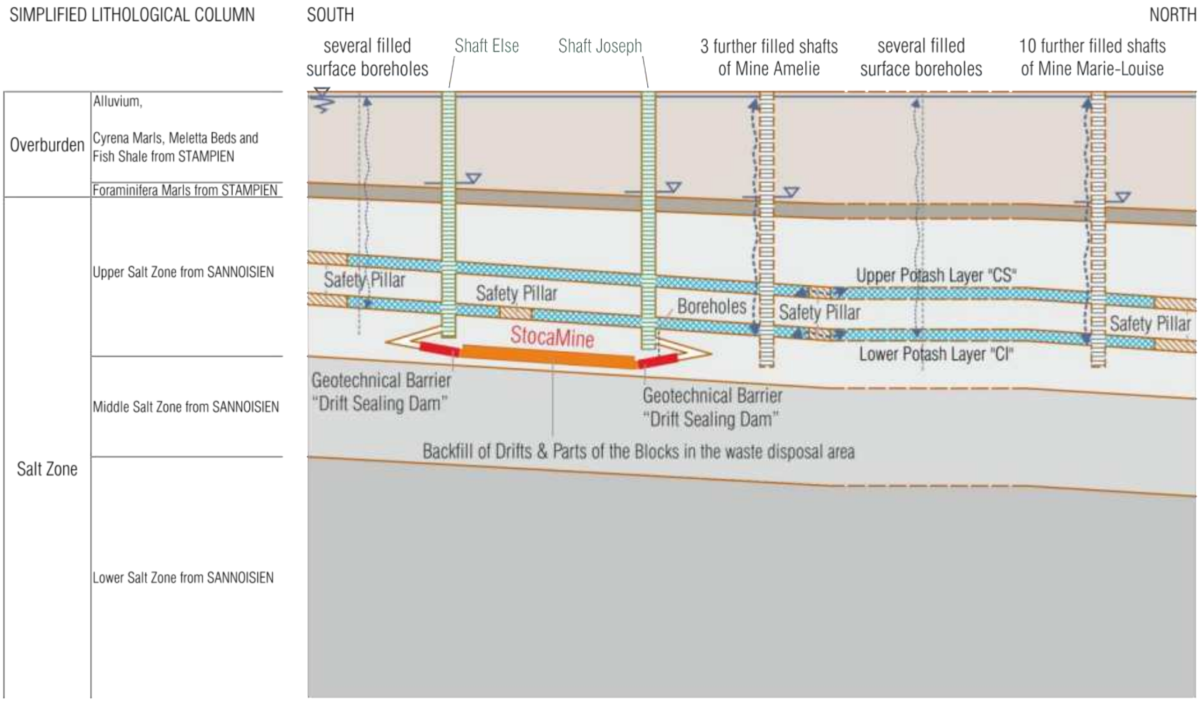

Figure 2 Schematic Overview of the Safety Concept “Multi Barrier System” for the Underground Waste Disposal of StocaMine

5.1 Description of the Geological Barriers

The geological barriers around the waste disposal site comprise the roof beam 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 beam 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 roof beam is about 25 m and it separates the Lower Potash Layer “CI” exploited in Amelie mine from the storage blocks and drifts. INERIS assumes in its ETUDE GÉOMÉCANIQUE DU STOCKAGE DE STOCAMINE (2010, /7/) that the overall permeability of this geological barrier remains low[7], even for damaged zones such as the zone affected by the fire in Block no. 15 in the year 2002 or zones affected by the extraction, which only concerns the first 12 m of the storage roof thickness.

For the sealing of the disposal site, the geological barriers (apart from the geotechnical barriers) are the decisive safety elements in the long-term and their integrity must remain intact during the entire period covered by the safety assessment. Salt rocks are only impervious to liq-

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

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uids and gases under undisturbed rock conditions, since no connected pore space exists in the salt rocks under these conditions.

The task of certifying the integrity of the salt barriers is not part of the services that StocaMine has commissioned ERCOSPLAN with. However, this should be part of the certification of the long-term isolation of the waste in the StocaMine underground waste disposal site.

5.2 Conceptual Design of the Geotechnical Barrier "Drift Sealing Dam"

The conceptual design of the geotechnical barrier "Drift Sealing Dam" comprises the following steps:

- Description of the current scientific knowledge and technology of the construction of drift sealing systems for underground waste disposals,
- Specification of the technical requirements provided by INERIS,
- Summarization of the design basics,
- Creation of an utilisation plan for the drift sealing dams,
- Design of the dam constructions,
- Pre-dimensioning of the individual components,
- Description of the construction method and technology,
- Estimation of the construction time

as well as

- Rough estimation of quantities and construction costs.

5.2.1 State-of-the-Art Technology in Designing Sealing Constructions in Horizontal Salt Mine Openings

During the last decades several research and development (R&D) projects dealing with long-term stable drift sealing constructions in salt deposits were conducted. These R&D projects were conducted against the background of long-term sealing of underground waste disposals, underground reutilisations or repositories from the biosphere. These projects were carried out in cooperation with research institutes and mine operators (e. g. TU BERGAKADEMIE FREIBERG 2003, /15/; 2009, /16/; K+S, 2002, /11/; GTS, 2008, /5/). The major aim was the compilation and analysis of state-of-the-art technologies used for previous sealing constructions. Due to the development of these technologies, it was possible to collect information of the successfully tested construction principles and to further develop existing concepts. Another example of a successful sealing construction is given in HANDKE (2002, /6/) and SANDIA NATIONAL LABORATORIES (1995, /12/).

It can be stated that the hydraulic sealing of drifts in rock salt is feasible, at least for several centuries, if the installation horizons are long enough to protect against corroding fluids, which

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are fully saturated in the rock salt stowing, in comparison to the surrounding rock, and consequently there will be no more chemical reaction with rock salt. Therefore the intruding brine is not able to dissolve more material, and no dissolution of roof and pillars could take place even at higher pressures (to protect the EDZ against corroding fluids, saturated brine).

Based on the existing technology in sealing construction design within salt deposits, it is essential to have information about the foundation, the surrounding rocks and the expected, time-dependent stresses to be exerted on the dam-rock-system.

5.2.1.1 Planning prerequisites

Before entering the planning phase the following site-specific geological / mineralogical, hydraulic and mine technical information must be known / determined for the target locations:

- Year and type of mine construction,
- Depth of the drifts,
- Geometric dimensions of the mine including roof and wall heights,
- Description of the geology, mineralogy and economic geology of the locations regarding outcropping salts, distribution, depositional style, vertical and horizontal distances to other excavation levels above/below/beside, geological anomalies e. g. cleavages, cross sections etc.,
- Permeability of the excavation disturbed zone (EDZ) within disturbed and undisturbed rock,
- Depth of the EDZ surrounding the drift (walls, roof, floor)

as well as

- Convergence and stress within the relevant rock parts.

In order to develop a structural design for the dam construction, it is necessary to gain the following information about the expected, time-dependent influences and stresses on the dam-rock-system:

- Chemistry / mineralogy of the inflowing brines and their time-dependent interactions with the surrounding rocks,
- Direction of brine inflow with regards to the dam (mono- or two-directional),
- Expected fluid pressure (hydrostatic pressure for brines within open systems and petrostatic pressure for solvents within closed systems)

as well as

- Chronological sequence of the exerted stress on the dam-rock-system.

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5.2.1.2 Design Principles

Regarding the existing knowledge about dams in salt deposits, the following specific requirements / construction principles have to be considered:

- Separation of the construction elements into elements with static or sealing function (short- and long-term sealing elements),
- Redundancy in the arrangement of the sealing elements, i.e. several similar sealing elements are placed consecutively,
- Diversity in the arrangement of the sealing elements, i.e. several sealing elements that are made from different materials are placed consecutively,

whereby an increasing safety standard over time is targeted for the whole system. The aims of redundancy and diversity are addressed with the combination of backfilling of the access drifts in the storage area and the isolation of this area by dams for the sealing of the drifts comprising concrete and Bentonite elements. This is supported by the injection of the contact zone between the abutment and the host rock providing supplemental sealing functionality by the abutment. In addition the following design principles apply:

- Use of construction materials that reliably fulfil their static or sealing function within the required time span or longer,
- Careful cutting of the EDZ surrounding drifts in the vicinity of dam elements with sealing function, except for stable / leak-proof rock,
- Use of sealing material that has a hydraulic conductibility against salt brine in the magnitude of the hydraulic conductibility of the host rock,
- Sealing of the contact joint between rock and sealing material – in order to avoid the formation of a preferred flow path,
- Adjustment of the mechanical features of the sealing construction according to expected loads,
- In order to increase the safety level of the whole system, it is advisable to construct the sealing element in such a way that allows it to bear part of the load distribution

as well as

- Securing the function of the drift sealing dams by applying appropriate technical measures and choice of location respectively, such that the inflowing brines are saturated and therefore no dissolution takes place.

Drift sealing constructions are to be constructed such that they are generally maintenance-free, robust and can be erected cost effectively using existing / proven processes.

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5.2.1.3 Long-term Stable Construction Materials

The following potential construction materials for dam elements with a sealing function providing a stability of >100 years, as demonstrated by natural analogues, were tested or used in different R&D projects or in drift sealing constructions that were implemented in the past:

- Bitumen / asphalts and asphalt concretes,
- Clays / Bentonites,
- Mineral aggregates

as well as

- Salt grit / crushed salt.

Bitumen / asphalts, clays, Bentonites and mineral aggregates are materials that are immediately effective, i. e. they work once they are built in the structure. However, the spectrum of their properties can change over longer periods. Salt grit and crushed salt only achieve the required sealing properties after time-dependent compaction has taken place, which is why their functional or intended effect only sets in after a lead-time.

For the construction of abutments (elements with a static function), the following materials could be used:

- Cohesive construction materials, e. g. regular concrete, salt brine concrete, salt concrete, sorel concrete,
- Brickwork (e. g. burnt clinker) as dry masonry walls or with mortar joints

as well as

- Non-cohesive construction materials, e.g. gravels, sands (with or without the addition of Bentonites), clays (mineral aggregates), salt grit / crushed salt (after sufficient compaction) or brickwork compounds made of natural stones.

Abutments made of cohesive construction materials as well as natural stone brickwork are immediately effective, stable against convergence and distribute the load into the surrounding solid rock in order to keep the sealing elements in position. All cement based construction materials like normal concrete, concrete mixed with saturated NaCl brine (salt brine concrete), salt concrete are more or less subject to corrosive processes, so that their stability in the long-term has to be proven in each individual case of use. As Sorel concrete is stable only against $MgCl_2$ saturated brines it is not considered for this situation with only traces/lower amounts of $MgCl_2$ in the intruding brine.

Taking into account the composition of the intruding brines a recipe for the concrete to be used for the StocaMine sealing has to be developed in order to minimize and delay the corrosion effects until the abutments are firmly held in place by the convergence/compression effects.

In order to guarantee the effectiveness of the abutments made of crushed rock salt or salt grit, the construction materials have to be incorporated up to the roof level of the drift and with high density. Due to subsequently accumulating rock convergences, the abutments are fixed in place.

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5.2.2 Technical Requirements provided by INERIS

The following criteria for the conceptual design of the drift sealing dams have been confirmed by INERIS (2011, /9/ & /14/).

I. Mine technical requirements:
   - At a depth of 550 m,
     - The rock temperature is about 37°C,
     - The maximum hydrostatic pressure is about 6 MPa,
     - The maximum lithostatic pressure is about 12 MPa,
   - The total initial opening cross section of all access drifts is about 290 m²,

II. Flooding process:
   - The estimated time that the liquid level reaches the level of the waste disposal is about 240 years,
   - The estimated time that the liquid level reaches the groundwater level is about 300 years,

III. Closure rates of drifts (see also chapter 4.1):
   - Prior to flooding 0.9% per year,
   - After end of flooding 0.1% per year and decreasing as a function of barrier stiffness (in the area of the constructed dams),

IV. Requirements in terms of the sealing element:
   - Each sealing element has to fulfil the following design criteria: $K / L^2 \leq 10^{-21}$, in which L is the length of the sealing element in meters and K is the intrinsic permeability of the sealing element in square meters. This requirement was stated by INERIS but StocaMine no longer pursues this target because subsequent investigations have led to the conclusion that it is not feasible to built dams according to this requirement.
   - Preferably, Bentonite should be used as the material for the sealing element as it possesses not only the required sealing properties, but also an absorbing effect on heavy metals.
   - The permeability of each dam has to be ensured during a period of 1,000 years, after full saturation of each dam until the end of flooding of the waste disposal. The saturation time will depend upon the dam properties and design.
   - Full performance of the dams is ensured after their full saturation and development of few MPa of swelling pressure.

5.2.3 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 inflow and on the other hand all other constraints from which demands on the construction design can be derived.

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5.2.3.1 Basic Data

For the technical conception of the dam construction the following basic data apply,

a) Regarding the dam locations:

   In order to isolate the storage area from the rest of the Amelie mine, drift sealing constructions will be constructed at 12 locations. These proposed locations are required to be confirmed by detailed site investigations.

   An overview of these locations can be found in Figure 3 and ENCLOSURE A.

b) Regarding the dimensions of the access drifts:

   The widths of the drifts and pillars at the dam locations have been obtained from the mine plan. A height between 2.7 m and 3.0 m was considered for the drifts. For double drifts it was assumed that the dam sites should be placed where there is a cut through between the drifts. At the location of this cut through the Bentonite sealing element should be placed to avoid impact on the sealing capability from the intermediate pillar. When this cut through is not available and if absolutely necessary only a minor cut of the intermediate pillar could be done for the construction of the Bentonite sealing element. For other parts of the dam construction the intermediate pillar should be kept intact. An overview of the dimensions of the drifts is contained in Table 1.

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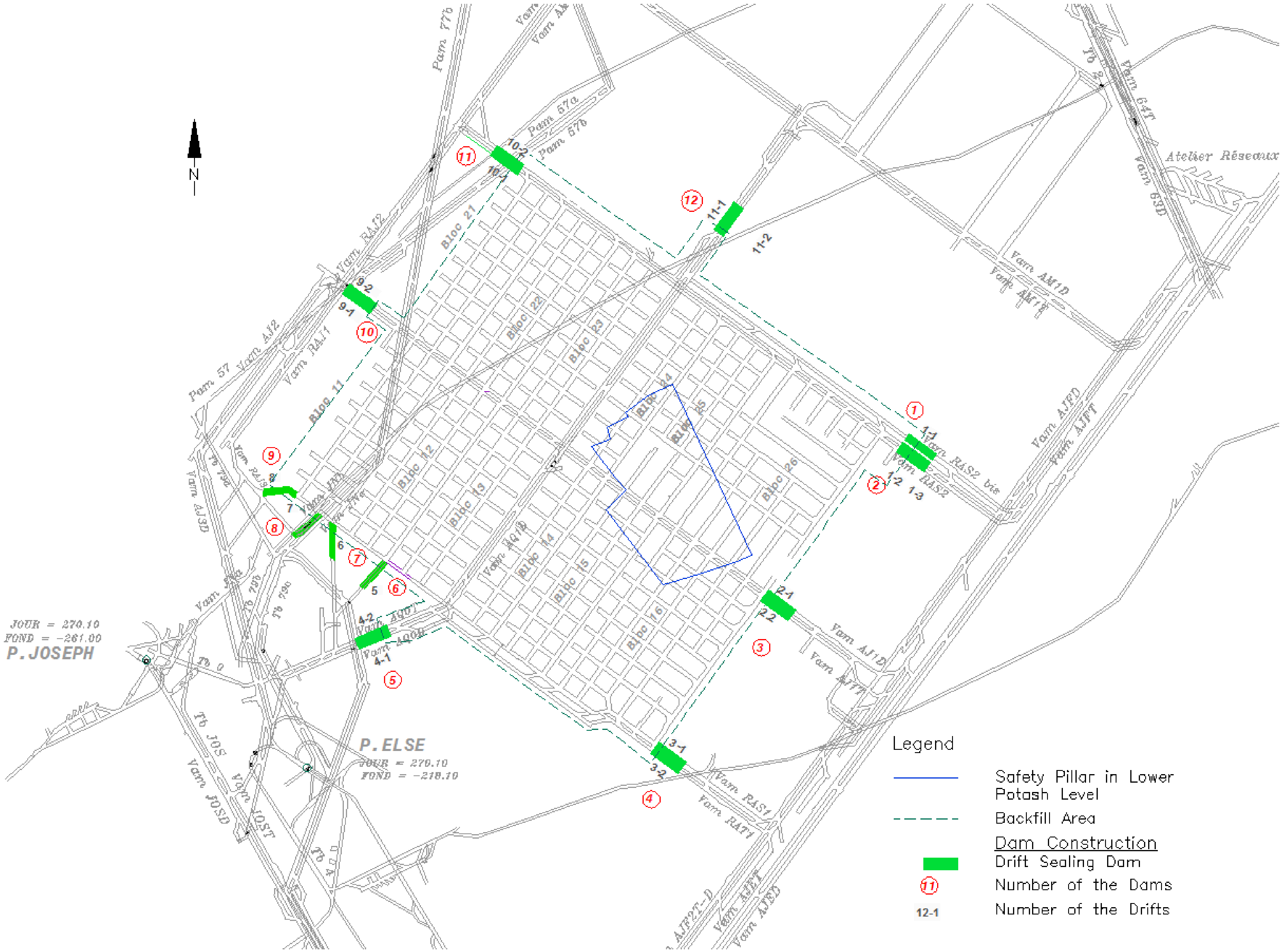

Figure 3 Overview of the Locations of the Planned Dams sites

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

Drift ID	Dam site No.	Height in m	Width in m	Drift Type
1-1	1	3.0	5.6	Parallel Drift
1-2	2	3.0	3.8	Double Drift
1-3	2	3.0	3.9	Double Drift
2-1	3	3.0	3.8	Double Drift
2-2	3	3.0	3.8	Double Drift
3-1	4	2.7	5.5	Double Drift
3-2	4	2.7	5.0	Double Drift
4-1	5	3.0	4.8	Double Drift
4-2	5	3.0	3.8	Double Drift
5	6	3.0	3.8	Single Drift
6	7	3.0	3.8	Single Drift
7	8	3.0	4.2	Single Drift
8	9	3.0	3.8	Single Drift
9-1	10	3.0	3.9	Double Drift
9-2	10	3.0	3.8	Double Drift
10-1	11	3.0	3.8	Double Drift
10-2	11	3.0	3.9	Double Drift
11-1	12	3.0	3.8	Double Drift
11-2	12	3.0	3.8	Double Drift

c) Regarding the geological settings of the dam locations:

On 9th of May 2012, there was an inspection of the dam locations no. 3, 4, 5, 6 and 10. In general the geological barriers of the inner barrier complex are assumed to be intact. The sealing locations are exceptionless situated in the lower part of the Upper Saliferous Zone, which consists of rock salt interbedded with a few thin layers of marl with a thickness of usually less than 10 cm.

It was agreed between StocaMine and ERCOSPLAN to use the assumption to cut 1 m of the excavation disturbed zone (EDZ) for each sealing element, but because the conditions regarding the individual dam locations vary widely this has to be confirmed with further investigation for each location.

For this planning the cutting of the EDZ is estimated at 1.00 m for the area surrounding the sealing element. For the permeability of the trimmed rock salt, a value of $\leq 10^{-19}$ m² is estimated. All further considerations are based on a rock temperature of 37°C, as this represents a conservative case with regard to the viscosities.

It is necessary to prove all these assumptions before the next planning stages by a detailed investigation and description of the individual dam locations (e. g. mine face-

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mapping, measurements of the lateral pillar strain, convergence measurements, rock stress measurements and permeability measurements).

d) Regarding the potential brine inflow and expected fluid pressure:

In the post-closure phase of the StocaMine waste disposal, brine inflows are predicted. The time of such an inflow at the level of the waste disposal is expected, according to ETUDE HYDROGÉOLOGIQUE DE L'ENNOYAGE DU SITE (INERIS, 2011, /10/), after 240 years at the earliest. The estimated time that the brine level reaches the groundwater level is about 300 years.

Both a saturated NaCl-solution and a solution that is in equilibrium with the host rock, NaCl and KCl saturated brine with marginal amounts of $MgCl_2$ (see chapter 4.2), are potential inflowing brines.

The amounts of solved $MgCl_2$ will be so small that is expected to have only an insignificant corrosive effect in the StocaMine waste disposal area. Due to their higher density, these brines will settle in the deepest site location of the mine which greatly diminishes the influence on the sealing dam constructions and possibly in the waste deposit sections.

An overview of the basic parameters of the inflowing brines at 37°C rock temperature is contained in Table 2.

Table 2 Basic Parameters of the Inflowing Brines at 37°C

Inflowing Brine	**Density in g/cm³**	**Dynamic Viscosity in mPa s**
NaCl saturated brine	1.197	1.380
NaCl and KCl saturated brine with marginal amounts of $MgCl_2$[8]	1.236	1.377

The maximum expected fluid pressure amounts is up to 6 MPa (see chapter 5.2.2).

e) Regarding the potential brine extrusion:

The composition of the extruded brines is unknown. It is estimated by INERIS that there will be amounts of the chemical elements As, Ba, Cd, Cr, Cu, Hg, Mo, Ni, Pb, Sb, Se, Zn and Cyanide according to the EVALUATION DU TERME SOURCE DANS LE SCÉNARIO DU STOCKAGE ILLIMITÉ (INERIS, 2011, /8/). Corrosive effects of these chemical elements on the dam construction materials or on backfill material are not known in detail and would have to be investigated further. It is assumed that for the corrosion process the NaCl and KCl present in the brines will be more decisive than the chemical elements mentioned in the source term study for unlimited storage time.

[8] ERCOSPLAN assumes ~ 20 g/l $MgCl_2$

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5.2.3.2 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 rock salt extraction, a reserve area near the storage is ready to produce the 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. Before these or any other existing equipments are considered for cutting and mining works they should be technically tested and mechanically maintained to ensure their operability and availability for the required duties. For this study the operability of the existing equipment and the permission of the respective authority for rock salt extraction are assumed.

c) Working space

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

5.2.4 Design of the Drift Sealing Dams

In comparison to conventional civil engineering structures, drift sealing dams must ensure higher than average safety standards, which requires a structured approach for the development of the construction designs. For this reason, all possible risks and influences will be recorded and later combined such that risk and influence scenarios can be developed for the construction. Based on these scenarios, a basic concept for the drift sealing dam will be subsequently derived.

5.2.4.1 Risk and Influence Analysis

The permanent isolation from the biosphere of the waste deposited in StocaMine is the principal protection objective. The requirements for the drift sealing dams were already listed in Section 5.2.2. As the next step, all theoretically possible influences on the construction must be recorded and their development over time and final state must be described.

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Possible influences on the sealing constructions could,

a) Result from the use of the construction, e. g.:
   - Fluid pressures, which are the result of the flooding process of the connected Amelie mine and which were estimated with 6 MPa in section 5.2.2,
   - Corrosion of the construction materials as a result of mechanical, thermal, physical, chemical and biological influences;
b) Result from the natural surroundings of the construction, e. g.:
   - From mechanical and hydraulic rock properties,
   - Result from dissolution processes and temperature changes;
c) Be affected by the construction, e. g. through:
   - The dead weight of the drift-sealing construction,
   - The magnitude of the swelling pressures and crystallization pressures,
   - Installation or construction dependent temperature changes,
   - Transport processes and disintegration,
   - The construction geometry;
d) Be caused by human error, e. g. through:
   - Inadequacies in the construction work,
   - Human intrusion during the post-closure phase;

as well as

e) Result from unforeseeable circumstances e. g.:
   - Dynamic excitation caused by earthquakes,
   - Tectonic influences,
   - Climatic changes.

From these theoretically possible influences, risk and influence scenarios are derived. A risk and influence scenario is defined by a major risk and accompanying risks. Based on the risk and influence scenarios, the drift sealing dam can be designed and assessed.

The relevant influences on the drift sealing dams for the StocaMine underground waste disposal are summarized in Table 3.

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Table 3 Overview of Possible Risks and Influences Resulting from Each Item

			Risk and influence scenarios			
	Source	Possible influences	Inflow of fluids / brines	Extrusion of fluids / brines	Reduction of the sealing functionality[9]	Translation of the Abutment
Possible risks and influences, resulting from source...	a) Fluids	Fluid pressure outside of the storage area	Major risk	X	X	X
		Fluid pressure inside of the storage area	Zero (conservative)	Major risk	X	-
		Corrosion / structural deterioration of the construction materials due to changes in chemical composition of fluids / brines	X	X	Major risk	X
	b) Natural local scale	Rock pressure	X	X	X	X
		Dissolution processes	X	X	X	X
	c) Technical construction	Dead weight of the construction	X	X	X	X
		Swelling pressure	X	X	X	Major risk
		Temperature changes	Significant during the construction phase			
		Shrinkage	Significant during the construction phase			
		Separation of the materials	Risk limitation by using an adequate quality management			
	d) Human	Construction deficiencies	Risk limitation by using an adequate quality management			
		Human intrusion	Acceptable risk			
	e) Natural large scale	Earthquakes	Acceptable risk			
		Climatic changes	Acceptable risk			
		Tectonic influences	Acceptable risk			

5.2.4.2 Construction Materials that are Stable in Long-term

The dam constructions in the access drifts to the underground waste disposal must be designed for an operating life of 1,000 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:

9 The sealing functionality of the Bentonite elements may be reduced due to corrosion / structural deterioration if the chemical composition of the intruding / extruding fluids / brines changes between unsaturated and saturated conditions.

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- Bitumen / asphalt,
- Clay / Bentonite / mineral mixtures,
- Salt grit / salt debris
- Cement based construction materials (salt concrete and concrete mixed with brine)

and

- 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 group of cement based construction materials like salt concrete, salt brine concrete and slurry backfill can be considered for use under the basic conditions applicable here. Normal concretes, salt concrete and salt brine concrete are subject to corrosive processes in different degrees due to the use of cement as a binding agent and will change during the reference period depending on each composition. Therefore this composition must be adapted according to the StocaMine conditions to guarantee functionality of the dam elements in a convergence and compaction scenario. Abutments made of seam-less 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 tech-nical 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 con-vergence, i.e. after the so called “prologue phase”.

5.2.4.3 Utilisation Plan for the Drift Sealing Construction

The compiled risk and influence scenarios are considered in their development over the time and in its final condition. For this, an utilisation plan for the drift sealing construction is drawn up, so that requirements can be defined for all relevant phases of use (see Table 4).

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Table 4 Development of the Influences for the Storage Area Over the Time

Time Frame		**Development in accordance with the INERIS prognosis (see chapter 4.4)**	**Influences as listed in Table 3**	**Requirements**
Now	2013	15 years since storage excavation	-	Waste removal or total waste inclusion
1. Phase	next 5 to 10 years	Construction of the dams	...of item b), c), d) and e)	Rigorous quality assurance programs and supervising of the construction execution
2. Phase	next 90 years	The storage area (including drifts) is expected to be completely closed	...of item b), d) and e)	Sufficient stability of the construction components
3. Phase	next 240 years	The first brine reaches the peripheral storage area (outside the dams)	...of item a), b), d) and e)	Sealing requirements provided by INERIS
4. Phase	next 350 years	Saturation of the dam constructions is finished, Possible start of flooding the storage area	...of item a), b), d) and e)	Sealing requirements provided by INERIS
5. Phase	next 1,000 years	Possible end of flooding the storage area	...of item a), b), d) and e)	Sealing requirements provided by INERIS
6. Phase	after 1,000 years	Discharge of polluted brine into the aquifer is possible	...of item a), b), d) and e)	Sealing requirements provided by INERIS
7. Phase	after 10,000 years	Diffusive and convective transportation processes	...of item a), b), d) and e)	-

5.2.4.4 Conceptual Design of the Drift Sealing Dam

The proposed drift sealing design basically consists of a long-term sealing element made of a Bentonite-sand-mixture, which requires abutments that are stable in the long-term. The long-term sealing properties shall be guaranteed via compacted Bentonite blocks with a high proportion of sand. The mixing ratio of sand and clay minerals within the Bentonite blocks has to be adjusted in such a way that a permeability of at least $1 \cdot 10^{-18}$ m² is reached. This value results in high demands on a Bentonite-sand mixture and can only be structurally guaranteed by an extensive quality assurance program. The Bentonite sealing element, swelling when in contact with fluids, is immediately effective as well as stable in the long-term.

In order to guarantee the short-term abutment function, abutments made of concrete mixed with saturated NaCl brine will be arranged. In order to satisfy the principles of redundancy and diversity from a technical engineering point of view with regards to at least a short-term functioning (<500 years), injections of the contact zone between host rock and abutment will seal the abutment and provide redundant sealing functionality.

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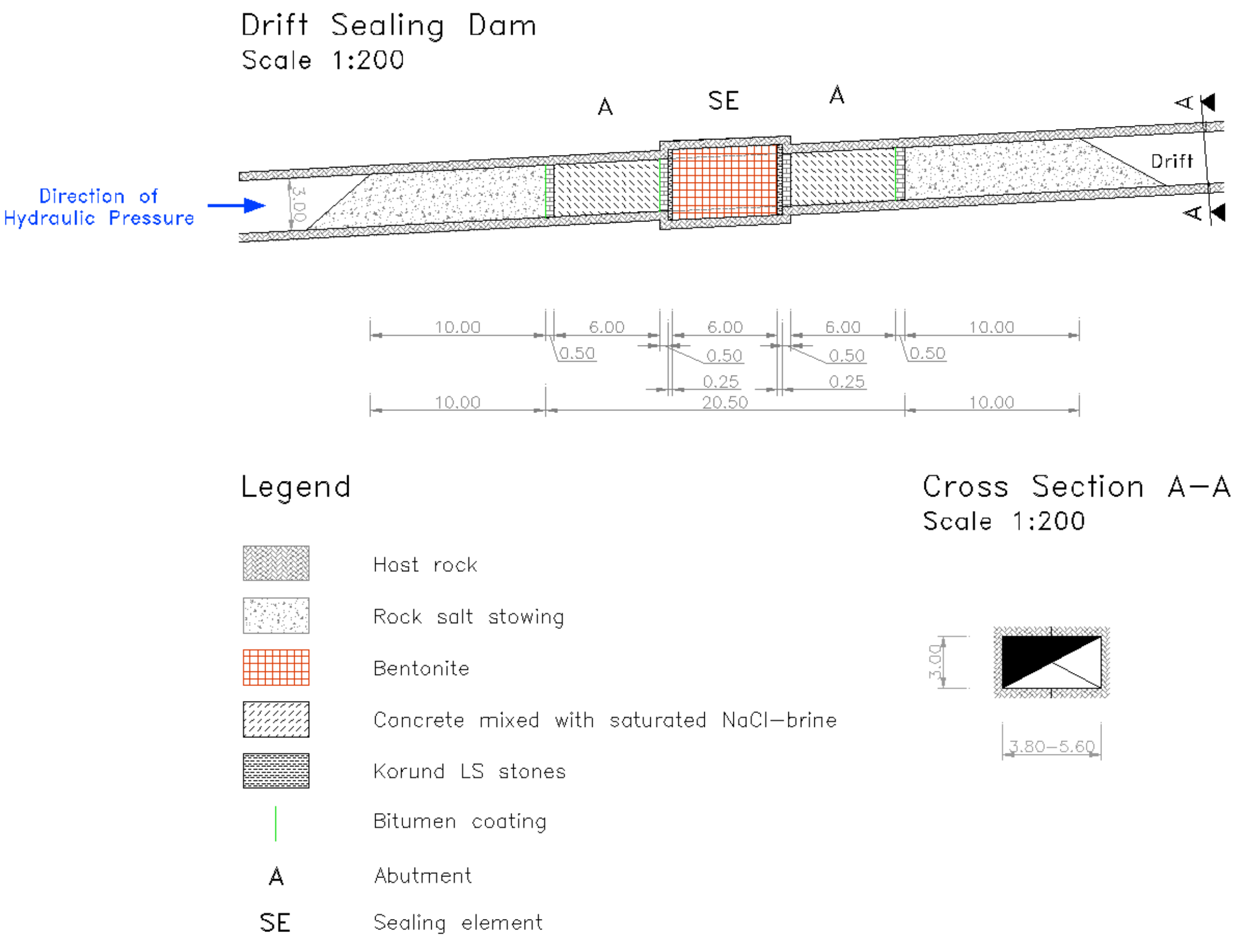

Figure 4 Conceptual Design of the Drift Sealing Dam

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 abutments and the drift cross section that is to be left open, an approx. 10 m long drift stowing made of rock salt grit will be placed in front of every dam construction. The drifts should be stowed with the grit from floor to roof.

- **Abutment (A)**

  The Abutment has a short-term function and will act as a block dam. It will absorb the swelling pressure from the sealing element. The drift contour will not be extended in this area but only trimmed. For this temporary abutment, the use of concrete mixed with saturated NaCl-brine is planned. The duration of the functioning of the concrete constructions can be specified as up to max. 500 years. The construction of comparable structures represents a technology that has been tried and tested for many years in the German potash industry. For additional sealing functionality of the dam construction, the contact zone between host rock and abutment will be closed by injection of grouting material.

- **Sealing Element (SE)**

  The sealing element is made out of compacted Bentonite-sand-bricks, has a long-term sealing function and insulates against the inflowing brines over a long period of time. In order to increase the initial permeability in the central section as opposed to that in the outer section (contact between sealing element and host rock) as well as to achieve an optimal building up of swelling pressure from the core to the contours, filter stones (Korund-LS-stones) will be fitted in the centre of the first formwork wall on the pressure side. In the drift section of the sealing element, the removal of the excavation disturbed zone (EDZ) in the walls as well as in the roof and the floor should be carried out carefully. The depth of EDZ where removal is to be carried out is estimated at 1.0 m and should be determined in the course of construction by means of permeability measurements. The removal will not be necessary, if the permeability of the host rock is lower than $1 \cdot 10^{-18}$ m².

5.2.5 Pre-Dimensioning of the Individual Components

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

5.2.5.1 Pre-Dimensioning of the Abutments

According to QUERSCHNITTSABDICHTUNGEN UNTERTÄGIGER HOHLRÄUME DURCH DÄMME UND PFROPFEN (SITZ, 1982, /13/) for the pre-dimensioning of parallel, interlocked or truncated cone shaped dams verifications based on the equations (5.1) and (5.2) are necessary.

- Shear Stress Analysis:

$$L_1 = \frac{p \cdot A}{Pe \cdot \tau \cdot 0{,}7} \qquad (5.1)$$

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]
	P_e	Perimeter of the drift [m]
	τ	Permissible shear stress of the construction material [N/cm²]

- Flexural Tension Analysis:

$$L_2 = \sqrt{\frac{p \cdot d^2}{6 \cdot \sigma_z}} \qquad (5.2)$$

with:

	L_2	Required length of the abutment [m]
	p	Hydrostatic pressure of the fluid [N/cm²]
	d	Shorter drift dimension [m]

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σ_z Permissible flexural tension of the construction material [N/cm²]

The maximum hydrostatic pressure is given to be 6 MPa. The drift dimensions, which form the basis of the pre-dimensioning, can be found in Table 1. Concrete mixed with saturated NaCl-brine should be used as construction material for the abutments with short-term function. For this construction material, the following values apply to the C 25/30 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 were calculated and can be found in Table 5. The chosen length of the abutment must be equal or higher than the largest required length calculated.

Table 5 Pre-Dimensioning of the Abutments

Abutment	Required Length L_1 in m	Required Length L_2 in m	Chosen Length of the Abutment in m
A	5.1 m to 6.0 m	3.1 m	**6.0 m**

The permeability of the concrete mixed with saturated NaCl-brine as proposed material for the abutment is assumed to be 10^{-18} m² to keep the integrity against corrosive processes and thus fulfil the long-term stability-convergence and compaction relationship.

5.2.5.2 Pre-Dimensioning of the Sealing Element (SE)

After discussion with StocaMine regarding the permeability requirements of the sealing elements, it is no longer required to follow the proposed permeability-length relationship given by INERIS (2011, /9/ and 2012, /14/):

- $\frac{K}{L^2} < 10^{-21}$ (5.3)

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

For the intrinsic permeability, the following values were assumed, based on the permeability-length relationship (cf. equation (5.3)):

- for the bentonite-sand-bricks: 10^{-18} m².

However, instead and due to the available space for sealing elements construction the placing of these elements in the cut through between double drifts was agreed between StocaMine and ERCOSPLAN. This is to ensure the effective sealing of the drifts by placing one sealing

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element over the total width of both drifts and the space of the cut through, thus preventing leakage through deteriorated intermediate pillars. After inspection and measurement of the mine plan, showing that the average length of the cut through is between 5 m and 7 m, the length of the Bentonite sealing element was planned at an average of 6.0 m.

5.2.5.3 Resulting Dam Length

Based on the pre-dimensioned lengths for the abutments and sealing elements, the lengths for the whole drift sealing constructions[10] were calculated and the results are presented in Table 6.

Each sealing structure consists of dam constructions in single drifts (each drift as part of double drifts is assumed as single drift).

Table 6 Resulting Dam Lengths according to the Pre-Dimensioning

Construction components	Dam Length in m
Abutment (A1)	6.00
Abutment (A2)	6.00
Sealing Element (SE)	6.00
Formwork walls (4 units á 0.50 m)	2.00
Korund LS stones (2 units á 0.25 m)	0.50
Dam length[10]	**20.50**

A schematic illustration of the dam construction is shown in Figure 4 and ENCLOSURE B.

[10] For the lengths contained in Table 6, the approximated 10 m long rock salt stowing placed on both sides of the construction was not considered.

5.2.5.4 Estimation of the annual Volume Flow (Rate)

The annual volume flow rate through all drift sealing dams can be estimated with the following equation (5.4):

- $Q = \frac{\Sigma A_i \cdot k_i \cdot \Delta p}{\eta \cdot \Delta l}$ (5.4)

with:

Q		Volume flow (rate) [m³/year]
k_1	$= 10^{-18}$ m²	Permeability of the sealing elements
A_1	= 440 m²	Cross section area of all sealing elements[11]
k_2	$= 10^{-19}$ m²	Permeability of the new EDZ
A_2	= 73 m²	Cross section area of all new EDZ[12]
Δl	= 6 m	Length of one sealing element
η	= 0.001377 Pa s	Dynamic viscosity
Δp	= 6,000,000 Pa	Fluid pressure

- $Q = \frac{((440 \cdot 1 \cdot 10^{-18}) + (73 \cdot 1 \cdot 10^{-19})) \cdot 6{,}000{,}000}{0.001377 \cdot 6} = 3.24 \cdot 10^{-7}\, m^3/s = 10.24\, m^3/year$

In the next 1,000 years an inflow of about 10,240 m³ into the storage area could occur (worst case scenario, because the saturation time of the barrier was neglected). This is a theoretical value as the residual open volume after closure and compaction is estimated by INERIS to be about 7,000 m³ (see chapter 4.2). The abutment and the backfill materials combination, though it is not defined as a sealing element itself, will have a supporting effect on the sealing functionality and the calculated inflow quantity will be additionally reduced.

5.2.6 Description of the Construction Method and Technology

For the construction of each specific dam a site inspection must be made to analyze all available geomechanic and geological information of each drift that is required for the correct selection of the most suitable place for these sealing structures, assuming that they should be placed as close as possible to the waste disposal blocks and to the backfilled drifts, to ensure both technical and economical sealing optimisation.

A site safety investigation must be done considering that the host rock strength should maintain excellent structural safety and stability conditions for the construction works (according to the geological and geomechanical descriptions). This assessment is of relevant importance for the determination of the contour excavation and localisation of the sealing elements.

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[11] Assumption: Cross section of the drift after removal of the EDZ.
[12] Assumption: The depth of the new EDZ is estimated to 0.15 m.

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When there is available updated information from each site investigation a breakdown planning and drawing of each dam site should be made, considering different geological and geomechanic conditions, drift configuration, size, etc.

In the planning of each site should be specified the access roads to transport personal, equipment and materials, using existing drifts or the construction of any alternative access roads, if necessary. These access roads must be studied to optimize the construction techniques, transport time and costs.

All access roads must be in good condition to allow the installation of pipelines for the transport of slurry backfill material to fill the selected blocks 15, 16, 25 and 26, and the safe transport of materials, personal, equipment, energy, ventilation and water to each dam construction site.

Where required rock bolting should be used to provide safe conditions in all places where the works will take place.

In the vicinity of each dam construction site a space or chamber to work as storage for equipment and installations, crew space and possibly escape chamber should be selected.

Because each dam construction will be work intensive, all sites must have enough energy, ventilation and water available to develop all needed construction and excavation works.

The construction and sealing materials (Bentonite bricks, concrete, sand, rock salt, etc.) should be transported by trucks to each site. A list of needed site equipment and materials must be itemised for each dam.

The contour cutting for the dam construction should be done in the drifts that have been selected previously to accommodate the dam elements. The rock salt obtained from the contour cutting could be used for the rock salt stowing of the dam construction.

For the contour cutting the existing underground equipment like the continuous miner “PAURAT E 195” could be used. Before this equipment is considered for cutting and mining works it should be technically tested and mechanically maintained to ensure its operability and availability for the required duties.

The first element of the dam to be built will be the rock salt stowing. As described before and due to technical and economic reasons, the rock salt from the contour cutting should be used for this element. The remaining rock salt to complete the dam construction could be excavated in previously selected areas of the mine using specific existing underground equipment. The rock salt stowing is estimated to have 10.0 m to be adapted to each site conditions. It will be accomplished simultaneously with the erection of the first wall formwork to ensure contact between the wall and the rock salt stowing over the entire drift height.

The contour area for the construction of the first abutment will be inspected and cleaned to provide the ideal contact of the concrete to the host rock. A cutting of 0.15 m of loosening material (EDZ) is estimated. This cutting depth could change depending on the host rock strength and conditions found in each specific site. The abutment construction is estimated to have 6.0 m length but is to be adapted to each site conditions.

After cutting and cleaning the contour for the first abutment, the construction of the first wall formwork can start. With the construction of this wall the rock salt stowing can continue and be finished before the wall is closed. The wall formwork is estimated to have 50 cm of thickness and be made of concrete bricks.

After the first wall formwork is erected there will be a bitumen coating. It is estimated a coating of 1 cm to 2 cm to cover one face of the wall formwork. The wall face to be coated with Bitumen will be the face before the next construction sequence.

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If required and for better adherence, the installation of small pipes in the abutment ring wall area should be considered. Once the abutment dries, there will be injection of concrete to seal any possible gap in between and fit any possible existing ring space.

When the first wall formwork is completed, and sealed with bitumen coating the second wall can start to be built. With the construction of the second wall the concreting of first abutment can proceed simultaneously until it reaches the roof. The wall formwork is estimated to have 50 cm of thickness and be made of concrete bricks.

For completely filling the first abutment chamber with concrete a dome will be cut in the roof and pipes will be inserted. When the second wall of this chamber is finished the pipes will be used for the injection of the remaining concrete to fill the chamber completely.

When the first abutment is completely filled and the second wall formwork is erected a bitumen coating will be done. It is estimated a coating of 1 cm to 2 cm to cover one face of the wall formwork. The wall face to be coated with Bitumen will be the face before the next construction element.

After this sequence the contour cuttings of 1 m for the Bentonite sealing element will be done. The salt extracted from this excavation will be stored to be used in the next rock salt stowing.

When the contact face with the abutment is finished a saturation wall made of permeable material (corundum stone chamber, e.g. Korund-LS-stones) with 0.20 m to 0.25 m of estimated thickness will be assembled.

After finishing the contour cutting for the sealing element the area is ready for filling and application of the Bentonite.

The next construction works will continue mirrored from here until the dam is completed as shown in Figure 4.

Depending on the scale and size of each dam, specialised engineering supervision may be required at critical stages of construction. The level of specialised engineering supervision required is generally proportional to the technical characteristics of each dam. Engineering expertise must be used during the planning and construction, as well as monitoring afterwards.

The general concept of the dam construction using this construction method and technology is technically possible as it was discussed in the previous chapters.

5.3 Conceptual Design of the Geotechnical Barrier “Backfilling”

With the backfilling a sealing concept is pursued in which, apart from the construction of long-term stable drift sealing dams in the access main drifts to the waste disposal area an additional filling of the main drifts in the disposal site is planned. This conceptual design presents an additional filling of the remaining cavities in the disposal blocks not filled with waste material for stabilisation of the area as well as minimisation of remaining voids.

With this additional inner barrier that is placed in addition to the geotechnical barrier (drift sealing), the reactive voids in the main drifts will be reduced so that the long-term deformation processes are decreased and the 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.

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5.3.1 Design Basics

For the technical conception of the Backfilling, apart from those mentioned in Section 5.2, the following basic data and basic conditions also apply:

a) Regarding the location of the main drifts and storage blocks

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

b) Regarding the dimensions of the main drifts

   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.

Figure 5 Overview of the Location of the Planned Dams Sites as well as the Main Drifts and Voids to be Backfilled in the Storage Blocks

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Table 7 Cavity Volume of the Main Drifts

Name of the Drift	**Drift System Cavity Volume in m³**
Vam RAS2 bis & Vam RAS2	14,765.7
Vam AJ1D & Vam AJ1T	11,844.9
Vam RAS1 & Vam RAT1	13,076.1
Vam AQ0T & Vam AQ0D	14,988.0
Total	**54,674.7**
Rounded total	**54,700 m³**

c) 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. As the volume of the remains of the waste material in block 15 is not known and remaining void has to be estimated, and as blocks 16, 25 and 26 were not used for waste deposition, the remaining cavity volume can be calculated directly from the taken dimensions regarding the estimation for the void in block 15. 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**
15	18,639.3	3,639.3	15,000.0
16	34,834.5	-	34,834.5
25	16,797.9	-	16,797.9
26	27,579.9	-	27,579.9
Total	**97,851.6**	**3,639.3**	**94,212.3**
Rounded total			**94,300 m³**

d) Regarding the geological settings of the main drifts and blocks

These drifts and blocks are all found in the Lower Rock Salt Layer (Upper Salt Zone of Sannoisien) and show layers of marl in the level of the excavation.

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5.3.2 Backfill Material

a) 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 area 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).

The salt concrete is obtained from a mix of cement, fly ashes, crushed salt and saturated NaCl brine. The crushed salt replaces sand and gravel as additive and the brine replaces the water. The filling mortar is obtained from a mix of sand, hard rock gravel (granite), cement and NaCl brine. This composition creates a uniform stress distribution, used for corrections of the blocks irregularities.
As these material compositions are used in salt environments, specific consistency levels must be obtained considering distinct brine / cement ratios and their final recipes have to be developed and tested during the project for the StocaMine site conditions.

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 materials, because the task of isolating the waste disposal area is entirely taken over by the geotechnical barriers "drift sealing dams" and the inner barrier mainly serves the purpose of reducing the reactive void, filling mortar (mixed with brine) should be used as backfill material. In terms of cost-effectiveness, this is the best alternative.

b) The backfill material that can be used in the storage blocks under the given conditions:

- Substratum: rock salt,
- Potential intruding brines (cf. Section 5.2.3.1): 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.

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This backfill material is generally self-levelling and very capable of flowing, such that it can thoroughly fill the remaining cavities. When the filling mortar is mixed with saturated NaCl brine, the host rock is not dissolved by this backfill material.

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

- 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 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).

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

Regarding a filling ratio of the cavities of 95%, a total of approx. 52,000 m³ of filling mortar mixed with brine should be brought into the main drifts and a total of approx. 90,000 m³ of filling mortar mixed with brine should be brought into the storage blocks to be backfilled.

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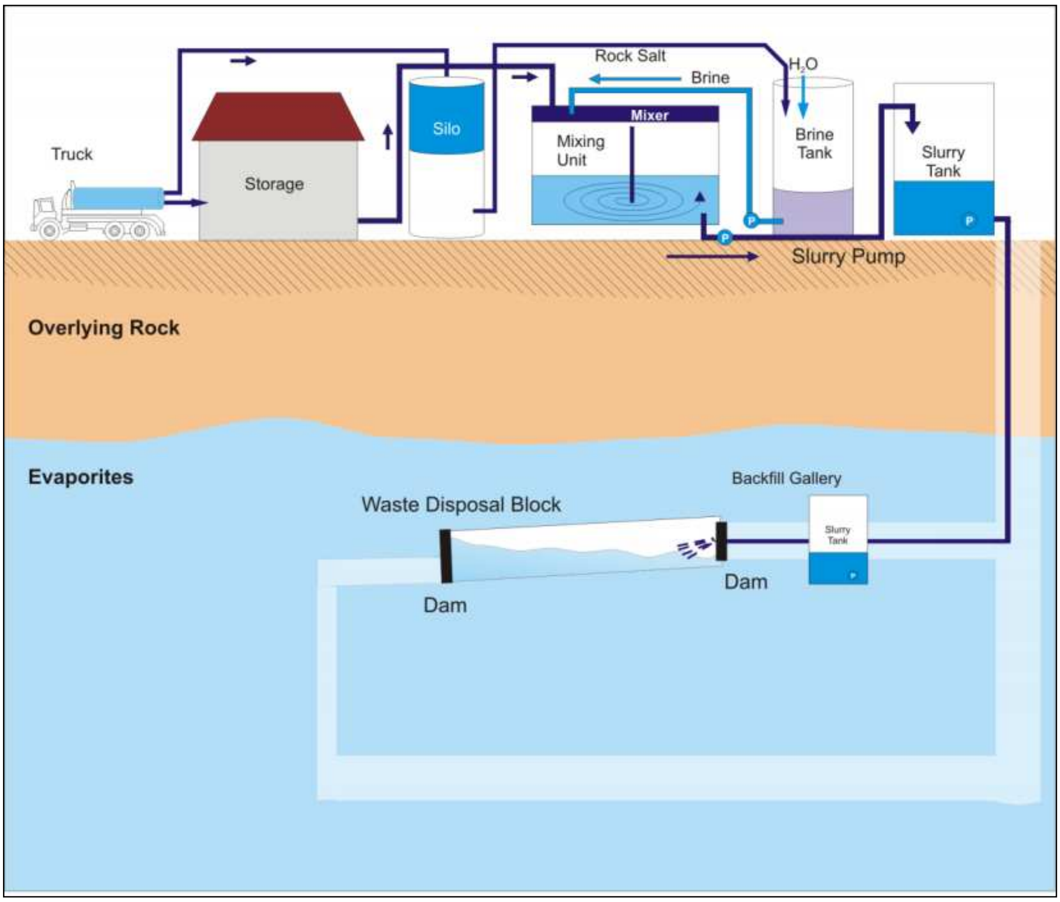

Figure 6 Backfill Technology with the Backfill Plant at the Surface

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6 Time and Costs Estimations

The following chapter gives an overview of the estimated time for dam construction and backfill operation as well as cost estimation for all necessary steps of the sealing of the StocaMine waste disposal. The accuracy is according to the stage of concept design and has to be revised more precisely in future planning stages.

6.1 Time Estimation for the Dam Construction and Backfill Works

The time estimations for the dam construction and backfill work are based on experiences from similar projects, assumed equipment capacities and material availability.

6.1.1 Time Estimation for the Dam Construction

The individual dam construction steps can be realised within the estimated construction periods shown in Table 9. This estimation is based on the assumption that the work will be carried out in 2-shift operations. It shows the average construction time per dam, which may be shorter for dams in single drifts and may be longer for dams in double drifts.

Table 9 Preliminary Estimation of the Construction Period of one Dam Only

Item	**Time in Weeks**
Preparation of the construction site, provision of the construction site equipment and vacating the construction site after finishing all works	4.0
Rock salt stowing	2.0
Cutting of the EDZ	3.0
Construction of abutment, A1	2.0
Abutment hardening, A1	4.0
Construction of the sealing element, SE	2.0
Abutment hardening, A2	4.0
Construction of abutment, A2	2.0
Rock salt stowing	2.0
Total	**25.0**

Considering the work being carried out at one construction site at a time, a construction period of 300 weeks for all 12 dam sites is required. With 50 working weeks throughout the year the sealing of the underground waste disposal will take approximately 6 years. This time might be

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reduced by simultaneous construction work on more than one site as long as sufficient hoisting and transporting capacity are provided. Simultaneous construction work is also dependent on the construction order and provision of accessibility at the individual construction sites. To optimize the project the construction work will be scheduled simultaneously in the next planning stages when more site information is available.

6.1.2 Time Estimation for the Partial Backfill

The backfilling of the main drifts and storage blocks 15, 16, 25 and 26 can be realised within the estimated construction periods shown in Table 10.

Table 10 Preliminary Estimation of the Duration of the Backfill Works

Item	Time in Weeks
Installation/De-installation of the Backfill Mixing Plant	
Installation	22
De-installation	5
Filling of the Main Drifts and of the Blocks 15, 16, 25 and 26 in the waste disposal site	
Backfill Material	
Backfilling	134
Total	**161**

6.1.3 Total Time Estimation

The total construction time for the construction of the drift sealing dams and the partial backfill can be followed in the next Table 11. This is a conservative estimation. The total time might be reduced by simultaneous backfilling and dam construction, but such scheduling cannot be estimated at this stage of planning.

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Table 11 Preliminary Time Estimation for the Dam construction and Backfill Works

Item	Time in Weeks
Installation/De-installation of the Backfill Mixing Plant, Filling of the Main Drifts and of the Blocks 15, 16, 25 and 26	161
Construction of all dams	300
Total	**461**

The sealing of the StocaMine waste disposal site will be done following the sequence:

- Filling the Blocks 15, 16, 25 and 26,
- Construction of most of the drift sealing dams,
- Filling the Main Drifts

and

- Construction of the last drift sealing dams.

If the drift sealing dam works will be done simultaneously at 2 to 3 construction sites at a time, a construction period between 150 and 100 weeks for all 12 dam sites could be reached after tasks coordination is defined considering accesses, transport time and compatible/suitable construction conditions and materials for each site. With 50 working weeks throughout the year the sealing of the underground waste disposal will take approximately 3 to 4 years. The backfill works could be done at the same time of the dam works but will depend on the project development, construction works, site conditions, etc.

This sequence will be done according to detail planning and its accuracy has to be revised in future planning stages.

6.2 Cost Estimations

The cost estimations for the implementation of the drift sealing dams and backfill concerning the separation of hazardous waste from remaining parts of Amelie mine are based on:

- The schematic construction draft for the drift sealing dams as shown in ENCLOSURE B and the backfilling concept as shown in ENCLOSURE C,
- Corresponding estimated quantity determinations

as well as

- Reference prices, which were determined from comparable projects, budgetary quotations and price databases.

The accuracy of the cost estimations is about ±35%. All construction costs are estimated and given in net prices before tax.

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6.2.1 Cost Estimation of the Dam Constructions

The net prices for the construction of the drift sealing dams in the access drifts to the underground waste disposal are shown in Table 12 and include the following items of work in the complete construction of all dam:

- Preparation of the construction site, provision of the construction site equipment, auxiliary ventilation and vacating the construction site,
- Preliminary and extra works under / above ground, e. g. smaller developments for infrastructural facilities, etc.,
- Bricklaying works, including the delivery and fitting in of lime sand bricks in order to install the formwork walls, including plastering of these walls and coating with sealing compound

as well as

- The delivery / transfer of:
  - Rock salt grit with required grain sizes,
  - Concrete mixed with saturated NaCl-brine

  and

  - Bentonite blocks,

up to the individual dam construction sites and fitting into the particular construction components.

In these cost estimations the following details have not been considered, e. g.:

- Supply of electricity: 230V resp. 380V.
- Supply of pressurized air for drilling.
- Supply of water.
- Equipment used in the underground material transport, access / transport of personal to the sites, cutting of the excavation disturbed zone (EDZ), stowing of rock salt, etc.
- Warranty of the operational Health, Safety and Environment conditions and evacuation plan for the personal involved in the construction works.

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Table 12 Cost Estimation of the Dam Constructions in the Access Drifts

Item	Short description	Construction costs
1	Site installation	3,780,000 EUR
2	Preliminary and extra works	1,260,000 EUR
3	Cutting of the EDZ	2,020,000 EUR
4	Rock salt stowing	1,400,000 EUR
5	Bricklaying and plastering works	620,000 EUR
6	Concrete and sealing works	7,210,000 EUR
7	Technical engineering: planning, tender documentation, supervision, preservation of evidence, documentation, building materials testing	1,280,000 EUR
Subtotal		17,570,000 EUR
	5.00% Contingencies	880,000 EUR
Total		**18,450,000 EUR**

According to these calculations, the construction of the drift sealing dams in the access drifts to the underground waste disposal will cost about **19,000,000 EURO**.

On average each drift sealing dam site is estimated to cost 1,600,000 EURO approximately.

6.2.2 Cost Estimation of the Backfill

The net prices for the backfilling of the main drifts in the storage area and part of the blocks in the waste disposal area with applicable material are shown in Table 13 and include the following items:

- 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 section area in between the particular plugging sections with corresponding formwork panels,
- The best possible plugging of the remaining cavities in the 15, 16, 25 and 26 disposal blocks with filling mortar (mixed with brine),
- The sealing of the particular plugging sections with corresponding formwork panels,

and

- The complete filling of the main drifts with filling mortar.

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Table 13 Cost Estimation of Filling of the Main Drifts and of the Blocks 15, 16, 25 and 26

Item	Short Description	Construction Costs
1	Installation/De-installation of the Backfill Mixing Plant	
1.1	Backfill Mixing Plant	4,250,000 EUR
1.2	Installation	1,180,000 EUR
1.3	De-installation	410,000 EUR
2	Filling of the Main Drifts and of the Blocks 15, 16, 25 and 26	
2.1	Backfill Material	10,020,000 EUR
2.2	Backfilling	4,300,000 EUR
3	Technical engineering: planning, tender documentation, supervision, preservation of evidence, documentation, building materials testing	1,470,000 EUR
Subtotal		21,630,000 EUR
	5.00% Contingencies	1,090,000 EUR
Total		**22,720,000 EUR**

According to these calculations, the filling of the main drifts and of the blocks 15, 16, 25 and 26 will cost about **23,000,000 EURO**.

6.2.3 Total Cost Estimation

The net prices for the construction of drift sealing dams in the access drifts to the underground waste disposal and the filling of the main drifts and blocks 15, 16, 25 and 26 in the storage area with applicable material are shown in Table 14.

Table 14 Cost Estimation of the Drift Sealing Dams in the Access Drifts and Backfilling of the Main Drifts and of the Blocks 15, 16, 25 and 26 with Filling Mortar

Item	Short Description	Construction Costs
1	Implementation of Dam Constructions	19,000,000 EUR
2	Installation/De-installation of the Backfill Mixing Plant Filling of the Main Drifts and of the Blocks 15, 16, 25 and 26	23,000,000 EUR
Total		**42,000,000 EUR**

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According to this estimation, the construction of drift sealing dams in the access drifts to the underground waste disposal with the additional backfill of drifts and parts of the blocks in the waste disposal area will cost about **42,000,000 EURO**.

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7 Recommendations and Conclusions

The StocaMine waste disposal site is located directly below the potash mine Amelie and connected to the mined potash levels as well as the biosphere via numerous drifts and shafts. As the potash mines will be flooded in the long-term through already plugged shafts, the waste disposal site has to be isolated from the surrounding mine and the biosphere. A feasible concept for this isolation has been developed and is presented in this report.

The geological-geomechanical as well as the mining situation in the waste disposal level is very complex and demanding for an effective isolation. Unfavourable factors (e.g. highly deteriorated pillars and roofs, etc.) as well as favourable factors (e.g. high closure rates, etc.) have to be considered upon choosing components for a sealing system. Basis for this conceptual design are experience from similar isolation scenarios, information derived from mine maps provided by StocaMine or gained in various discussions with StocaMine representatives and during an inspection of several proposed dam sites, findings of INERIS regarding geomechanical, hydrogeological aspects of the StocaMine site and chemical aspects of the deposited waste material.

However, the geological-geomechanical situation and the state of the mining rooms and drifts requires further investigation before this conceptual design can be developed in following planning stages.

This conceptual design describes the isolation of the waste disposal site by dams sealing the connecting drifts between the waste storage blocks and the surrounding mine workings and by backfilling of the drifts in the storage area as well as the storage blocks 15, 16, 25 and 26. The sealing by dams and, supplementary, by backfilling the drifts will effectively keep fluids from entering the waste disposal site before closure of the voids. The backfilling of several blocks will effectively reduce existing voids to minimise the remaining void after closure that may be filled by fluids migrating into the waste disposal site in the long-term.

The conceptual design comprises backfill operation work which is estimated to require 161 weeks of construction time and to cost about 23,000,000 EURO, and dam construction work which is estimated to require 300 weeks of construction time and to cost about 19,000,000 EURO. Each drift sealing dam site has an estimated average cost of 1,600,000 EURO, approximately.

In these cost estimations for the construction works of the drift sealing dams the following details are not considered, e. g.:

- Supply of electricity: 230V resp. 380V,
- Supply of pressurized air for drilling,
- Supply of water,
- Equipment used in the underground material transport, access / transport of personal to the sites, cutting of the excavation disturbed zone (EDZ), stowing of rock salt, etc.
- Warranty of the operational Health, Safety and Environment conditions and evacuation plan for the personal involved in the construction works.

According to the stage of conceptual design the cost estimation is in the accuracy range of ±35%. Costs are quoted as net prices.

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The time and cost estimation is based on the assumptions described in this report and will have to be revised after further investigations and with more detailed steps of planning.

The presented dam design, consisting of a Bentonite sealing element placed between two abutments and restricted in length by the site conditions at the agreed dam construction sites, is a generic design generally capable of effectively sealing the waste disposal site. This generic design has to be adapted to each site according to the findings of the site inspections and investigations regarding specific geological, geomechanical and mining related properties of the site.

Therefore it is recommended to conduct:

- A geological survey of each proposed dam site,
- A geotechnical survey of each proposed dam site,
- Core drilling and sampling (especially the marl sections) for each proposed dam site,
- permeability measurements (preferably using the core drill holes) at each proposed dam site

and

- Convergency measurements especially in the areas with difficult conditions.

Further it is recommended to investigate the possibilities of constructing an in-situ test dam in the disposal level.

The presented backfill operation design is a generic design generally capable of effectively filling the voids of the cavities to be backfilled. This design has to be adapted in terms of choosing or developing an adequate backfill material to meet the required properties.

It is recommended to find and contact producers of Bentonite, concrete and materials applicable for backfilling and, if there no appropriate recipe exists, to discuss the development of a Bentonite, concrete mixture and backfill material composition or recipe that meets the requirements for this specific application.

It is further advisable to investigate the potential impact of the brine migrating into the storage area as well as the possibly polluted brine extruding from the storage area on concrete and Bentonite of the dams elements.

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