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# Délais de déstockage total des déchets (hors bloc incendié) Stocamine : analyse du délai de 15 ans et de scénarios alternatifs

Rapport final

**BRGM/RP-68334-FR**
Octobre 2018

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***Le BRGM a mis en place un dispositif de déontologie visant à développer une culture de l'intégrité et de la responsabilité dans le quotidien de tous ses salariés.***

***Après examen, il est ressorti qu'il existait un lien d'intérêt entre le BRGM et l'objet ou l'une des parties prenantes de la présente expertise (cf. déclaration en Annexe, sur IM 362 INST).***

***Cependant, le BRGM atteste grâce à la mise en place de son SMQE et de son dispositif de déontologie, que la réalisation de la présente expertise n'a en rien été influencée par le lien d'intérêt identifié.***

***Le BRGM a confié la réalisation de cette expertise à des salariés qui n'ont à titre individuel aucun lien d'intérêt avec l'objet ou l'une des parties prenantes de la présente expertise, de façon à préserver l'indépendance et l'impartialité de la réalisation de cette expertise.***

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# Synthèse

Le projet Stocamine, autorisé en février 1997, prévoyait de stocker des déchets dangereux pendant une durée de trente ans et dans des conditions réversibles « en exploitation », dans des galeries creusées à cet effet dans les couches de sel gemme sous les anciennes couches du gisement de potasse exploité par les Mines de potasse d'Alsace (MDPA). L'incendie survenu dans le bloc 15 le 22 septembre 2002 a empêché la poursuite de l'exploitation et remis en cause les hypothèses de travail, alors qu'environ 44 000 tonnes de déchets avaient été stockées.

Le Préfet du Haut-Rhin a signé le 23 mars 2017 l'arrêté préfectoral autorisant un confinement de durée illimitée après déstockage de l'essentiel des déchets contenant du mercure, contaminant le plus sensible vis-à-vis de la nappe phréatique en cas d'infiltration d'eau et de sa mise en pression dans l'hypothèse d'une défaillance des barrières de confinement prévues. Ce déstockage partiel a été réalisé de 2015 à 2017. Parallèlement, les études et expertises ont permis d'améliorer et de compléter la conception de barrières de confinement diversifiées et au meilleur état de l'art. Les MDPA ont réalisé en 2018 un barrage pilote de confinement.

À la demande du Ministre de la Transition Écologique et Solidaire, et compte tenu des interrogations locales qui demeurent, le Préfet du Haut-Rhin a organisé une réunion avec les principaux élus et parlementaires locaux le 23 mars 2018. La question reste posée de la possibilité ou non de procéder à un déstockage des déchets hors bloc 15, dans des conditions acceptables de sécurité tant minière qu'environnementale, dans un délai substantiellement plus rapide que le délai de 12 à 15 ans indiqué jusqu'à présent par les MDPA pour un tel scénario. En effet, sur une durée aussi longue, le risque de ne pouvoir procéder *in fine* au confinement dans de bonnes conditions est bien réel, mais le problème se poserait différemment si une méthode permettant un déstockage en 3 à 5 ans était praticable.

Le ministère de la Transition Écologique et Solidaire a donc demandé au BRGM le 19 avril 2018 de réaliser une expertise du délai mis en avant par les MDPA de l'ordre de 15 ans nécessaire à un déstockage total hors bloc incendié. Cette expertise devait porter sur l'ensemble de la chaîne de déstockage, des galeries - compte tenu de leur état actuel et de leur dégradation prévisible - jusqu'au reconditionnement des colis et identifier l'(es) étape(s) critique(s) du déstockage. Elle devait également étudier des scénarios de déstockage sur plusieurs fronts, prenant en compte la nécessaire maîtrise des risques pour les opérateurs au fond, et la possibilité qu'un confinement du bloc incendié reste réalisable à l'issue de celui-ci. Le ministère a souhaité que le BRGM fasse appel à une équipe pluridisciplinaire associant des experts internationaux. Le rapport de cette expertise devait être remis au ministère fin octobre 2018.

La mission du BRGM a été menée en s'appuyant sur le groupe d'experts internationaux suivant afin de couvrir tous les aspects opérationnels :

- deux entités expertes sur les aspects opérationnels et particulièrement des travaux miniers dans le sel : DMT GmbH & Co. KG (Allemagne) et PLEJADES GmbH (Allemagne) ;
- une entité experte en sécurité minière : Laboratorio Oficial José María de Madariaga (Espagne) ;
- un expert en mécanique des roches appliquée aux travaux miniers : Prof. Pedro Ramírez Oyanguren (Espagne) ;
- une entité experte en conditionnement des déchets : Sat. Kerntechnik GmbH (Allemagne).

La préparation de l’expertise a débuté aux mois d’avril et mai par la prise de connaissance de la centaine de documents de la bibliographie mise à disposition du BRGM par le ministère. Deux visites *in situ* ont été effectuées en mai par le BRGM afin d’élaborer la méthodologie d’étude à mettre en œuvre pour la réalisation de l’expertise demandée.

L’expertise a débuté par une réunion de lancement le 8 juin à Paris en présence des experts mandatés et la mise à disposition des documents disponibles. Le groupe d’experts a effectué deux visites du site de Stocamine (20 juin et 18 juillet) qui ont également permis d’échanger sur des points techniques avec les responsables des MDPA. Des échanges hebdomadaires ont permis d’harmoniser l’avancement des travaux au sein du groupe jusqu’à la réunion plénière le 22 août à Paris où les experts ont présenté et discuté les résultats de l’étude (les rapports techniques individuels des experts internationaux sont présentés en annexes).

Le BRGM a ensuite rédigé le présent rapport de synthèse.

En s’appuyant sur une méthodologie scientifique décrite dans le présent rapport et en examinant plusieurs scénarios et options pour la réalisation des travaux, le groupe d’experts a estimé la durée optimale nécessaire pour réaliser le déstockage du site et sa mise en confinement à 7,8 années pour une opération réalisée sur trois fronts.

Il est impératif de noter que les résultats de la présente expertise sont obtenus dans un schéma contraint par un ensemble de limites décrites ci-après :

- les solutions techniques proposées par l’expertise ont été jugées réalistes et réalisables, étant donné qu’elles ont été utilisées et éprouvées dans des situations similaires. Cependant, ces solutions sont basées sur des équipements qui ne sont pas actuellement déployés à Stocamine (ou partiellement), et qu’il convient d’acquérir dans la phase de préparation du site ;
- la durée estimée de 7,8 années ne comprend pas les délais relatifs aux éléments suivants :
  - les processus décisionnels aboutissant à la solution opérationnelle qui serait à mettre en œuvre,
  - les démarches administratives préalables qui seraient nécessaires à réaliser avant la mise en œuvre du déstockage (obtention des différentes autorisations de travaux, autorisations de transports de déchets vers un nouveau site à définir, …),
  - les procédures de marchés publics pour la détermination des entreprises qui mettront en œuvre le déstockage (marchés de maitrise d’œuvre, de travaux, de transports, …) ;
- l’expertise se limite à quantifier la durée nécessaire pour récupérer l’ensemble des colis et confiner les blocs concernés. Elle ne propose pas la quantification des coûts potentiels et ne préjuge pas de la pertinence de la solution de déstockage ;
- les résultats présentés font l’hypothèse que la convergence géomécanique se poursuivra à un rythme régulier dans les prochaines années. Ces considérations vont avoir un fort impact sur le délai restant pour extraire les déchets dans des conditions acceptables, en utilisant les options techniques détaillées dans le présent rapport. Les conclusions suivantes peuvent être tirées de cette analyse de l’évolution du site :
  - une probabilité raisonnable de succès des opérations de déstockage est possible jusqu’au milieu des années 2020 environ,
  - au-delà du milieu des années 2020, le déstockage resterait tout de même possible, mais avec une efficacité réduite et des délais probablement allongés.
  - à partir de 2029 environ (avec l’hypothèse de convergence réaliste - 30 mm/an), tous les colis devraient être enclavés c’est-à-dire enserrés dans le sel suite à la convergence des galeries,
  - après la fin des années 2020, la poursuite des opérations de déstockage dans certains fronts risque d’être infaisable avec les moyens techniques décrits dans ce rapport.

# 1. Contexte de la mission d'expertise

Le projet Stocamine, débuté en 1997, concerne le stockage de déchets ultimes solides dans des galeries de sel creusées sous les anciennes couches de potasse exploitées par les Mines de Potasse d'Alsace (MDPA). Un incendie déclaré dans le Bloc 15 en septembre 2002 a stoppé les opérations de stockage alors que 44 000 tonnes de déchets avaient déjà été entreposées.

En 2012, la décision a été prise d'initier la fermeture du site de stockage. Le confinement du site pour une durée illimitée a été acté à condition de récupérer tous les déchets contenant du mercure (l'élément considéré comme le plus polluant parmi les déchets présents). L'opération de récupération des déchets mercuriels a été menée par les MDPA et achevée en 2017, avec plus de 93 % du mercure récupéré. Il reste à ce jour 63 429 colis répartis sur le site (en excluant les colis du Bloc 15). Ces colis se présentent majoritairement sous la forme de Big Bags (85,8 %) ou de palettes de 4 fûts (12,0 %).

La mission confiée au BRGM est d'estimer le temps nécessaire à la récupération de l'ensemble des déchets sauf ceux contenus dans le bloc 15, dans des conditions acceptables de sécurité. En se basant sur son expérience de récupération des colis contenant du mercure, les MDPA ont estimé, par extrapolation du temps moyen effectif d'extraction des colis mercuriels, cette durée à 12 à 15 ans en faisant l'hypothèse de deux fronts d'extraction. Or, les situations très diverses des conditions géomécaniques, l'état différent de conservation des colis ou l'accessibilité différenciée aux déchets doivent être pris en compte pour confirmer ou infirmer cette estimation. De plus, les MDPA basent leur calcul sur les moyens techniques présents sur le site et un mode de gestion qui pourraient être remplacés par des équipements et une logistique plus adaptés au contexte actuel.

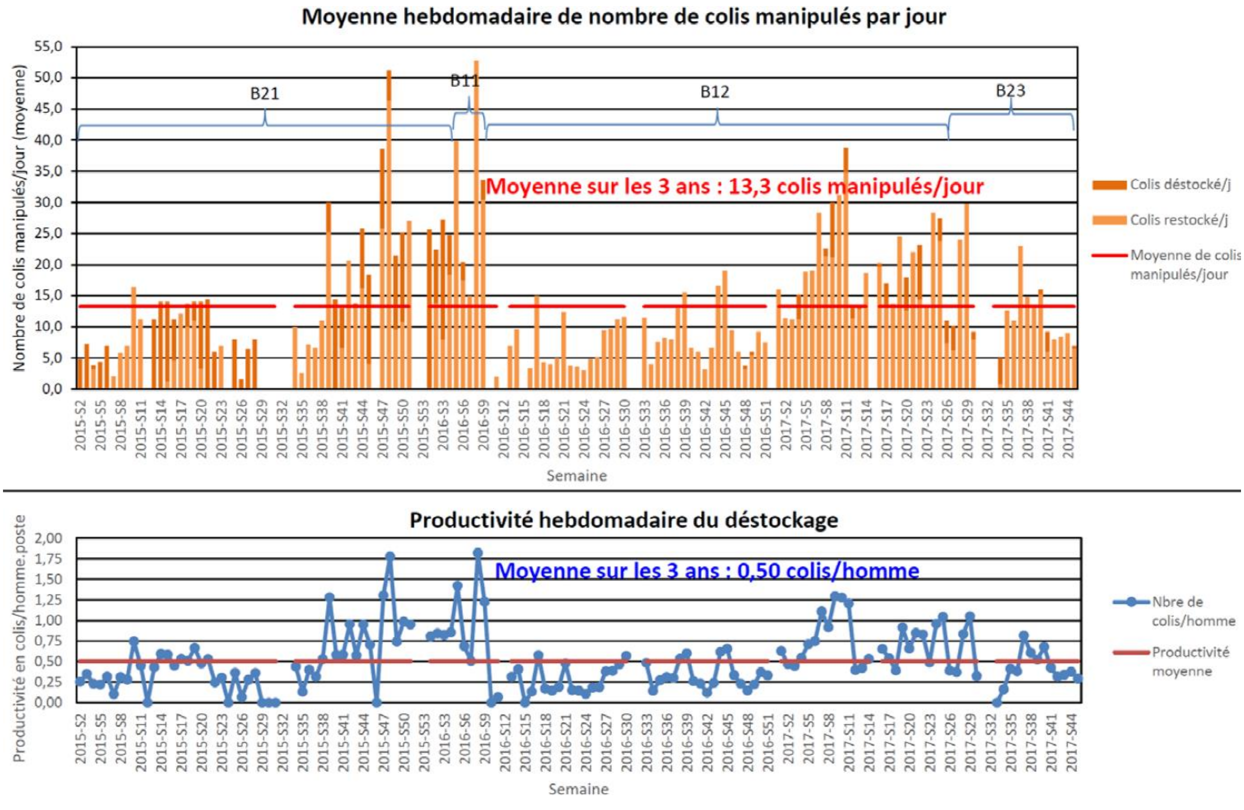


*Figure 1 : Avancement et productivité hebdomadaire lors de la récupération des déchets mercuriels [Présentation MDPA, 2017].*

La mission du BRGM a été menée en s'appuyant sur un groupe d'experts internationaux afin de couvrir tous les aspects opérationnels. À cet effet, les organismes suivants ont été mobilisés.

- *Deux entités expertes sur les aspects opérationnels et particulièrement sur les travaux miniers dans le sel :*

  **DMT GmbH & Co. KG (Allemagne) :** DMT fournit des services multidisciplinaires professionnels sur tous les aspects du développement minier. Il est présent dans toutes les régions minières du monde. Il possède une expertise unique dans le sel et a été mandaté par le BFS (bureau fédéral de la radioprotection) pour piloter l'étude de la faisabilité d'extraction des déchets radioactifs stockés dans la mine de sel d'Asse.

  **PLEJADES GmbH (Allemagne) :** PLEJADES est une société de conseils stratégique, technique et de management. Elle intervient depuis 20 ans au niveau national et international auprès des administrations, services publics et industries sur des questions liées à l'environnement notamment dans le secteur minier et le stockage des déchets.

- *Une entité experte en sécurité minière :*

  **Laboratorio Oficial José María de Madariaga (Espagne) :** LOM est le centre de référence dans le domaine de la sécurité minière en Espagne. Il a été créé par décret présidentiel en 1979. En plus de ses activités de certification et de test, LOM est l'organe expert scientifique et technique de l'administration générale de l'État et assiste la Direction générale de la politique énergétique et des mines de l'Espagne dans ses domaines de compétence.

- *Un expert en mécanique des roches appliquée aux travaux miniers :*

  **Prof. Pedro Ramírez Oyanguren (Espagne) :** Prof. Ramirez est professeur émérite à l'Université Polytechnique de Madrid (UPM) et un spécialiste de la mécanique des roches appliquée à l'exploitation minière mondialement connu. Il est l'auteur de plusieurs ouvrages en génie civil et minier. Il a notamment travaillé en tant qu'ingénieur géotechnicien dans les mines de potasse du nord de l'Espagne. Il possède une vaste expérience en tant que consultant dans l'exploitation des mines métalliques et sédimentaires.

- *Une entité experte en conditionnement des déchets :*

  **Sat. Kerntechnik GmbH (Allemagne)** : Sat. est une entreprise spécialisée dans la sécurité technique des déchets dangereux, basée en Allemagne avec des représentations en Italie et en Suisse. Elle possède des références à l'international et a notamment travaillé pour EDF. L'entreprise intervient dans les domaines de conditionnement, planification et transport des déchets. Elle a reçu le prix de l'innovation en 2008.

## 1.1. MÉTHODE DE RÉALISATION DE L'ÉTUDE

L'expertise a débuté par une réunion de lancement le 8 juin 2018, en présence des experts mandatés. Une première visite de Stocamine a eu lieu le 20 juin, où les experts ont pu échanger avec les responsables des MDPA et demander des documents complémentaires. Après une première étude détaillée des documents mis à disposition, une deuxième visite s'est tenue le 18 juillet 2018 afin d'affiner les premières informations. Des échanges hebdomadaires ont permis d'harmoniser l'avancement des travaux. Enfin, lors d'une réunion plénière le 22 août, les experts ont établi et discuté les résultats de l'étude (rapports techniques individuels en annexes).

L'expertise s'est largement appuyée sur les documents techniques disponibles (cf. annexes), dont certaines conclusions ont constitué le point de départ des travaux. Il est à noter que nous n'avons pas pu vérifier ou contrôler l'exactitude des travaux antérieurs. La pertinence des éléments retenus est donc basée sur « l'opinion d'experts ». Une communication continue et multilatérale entre les experts, avec un partage régulier des conclusions préliminaires, a permis de cerner les contours de ce problème complexe, où le choix de telle ou telle solution technique sur une activité donnée implique des modifications de paramètres sur d'autres tâches.

Pour réaliser la mission, nous avons développé une approche scientifique basée sur la modélisation du processus de déstockage. À cet effet, nous avons utilisé des outils de calcul apparentés à la Recherche Opérationnelle qui permettent une décomposition en tâches élémentaires du problème et une identification des chemins critiques pour aboutir à la solution optimale.

## 1.2. PÉRIMÈTRE DE L'ÉTUDE

L'objectif de l'étude est d'évaluer le temps nécessaire pour le déstockage total des déchets (hors bloc 15) en optimisant les conditions de sécurité du personnel et du site. De plus, la mission a été étendue à l'estimation du délai de fermeture définitive du site. Plus précisément, le plan du confinement du site prescrit l'installation de bouchons ou barrages en béton dans les galeries autour du site. Il a été demandé au BRGM d'inclure dans ses études la possibilité de mener la mise en place de ce confinement en parallèle avec le déstockage. Dans ce but, une analyse des plans de confinement a permis d'identifier 5 bouchons pouvant être installés pendant les opérations de déstockage sans perturber les conditions d'accès et de sécurité. Par ailleurs, l'occlusion de certaines de ces galeries pourrait avoir un effet bénéfique sur l'efficacité du système de ventilation. Dès lors, nous avons intégré les contraintes de cette opération dans la procédure d'estimation du temps total.

Il est impératif de noter que les résultats de la présente expertise sont obtenus dans un schéma contraint par un ensemble de limites, dont voici une liste non-exhaustive :

- les travaux préliminaires pour la préparation du site sont supposés démarrer en janvier 2021 et la récupération des déchets un an plus tard ;
- l'impact de la variation dans le temps des conditions géomécaniques sur l'ensemble de la durée des opérations n'est considérée que pour l'étude de la limite d'opérabilité ;
- les solutions techniques proposées par l'expertise ont été jugées réalistes et réalisables, étant donné qu'elles ont été utilisées et éprouvées dans des situations similaires. Cependant, ces solutions sont basées sur des équipements qui ne sont pas actuellement déployés à Stocamine (ou partiellement), et qu'il conviendrait d'acquérir dans la phase de préparation du site ;
- la durée estimée ne tient pas compte des durées relatives aux procédures administratives à réaliser avant le début de opérations (autorisations de travaux, …). Cependant, on peut faire l'hypothèse que plusieurs travaux préliminaires miniers pourraient être effectués durant cette période administrative ;
- l'expertise se limite à quantifier la durée nécessaire pour récupérer l'ensemble des colis et confiner les blocs concernés. Elle ne propose pas la quantification des coûts potentiels et ne préjuge pas de la pertinence de la solution de déstockage, même si des appréciations qualitatives sont fournies par les experts internationaux dans leurs rapports respectifs et sous leur seule responsabilité.

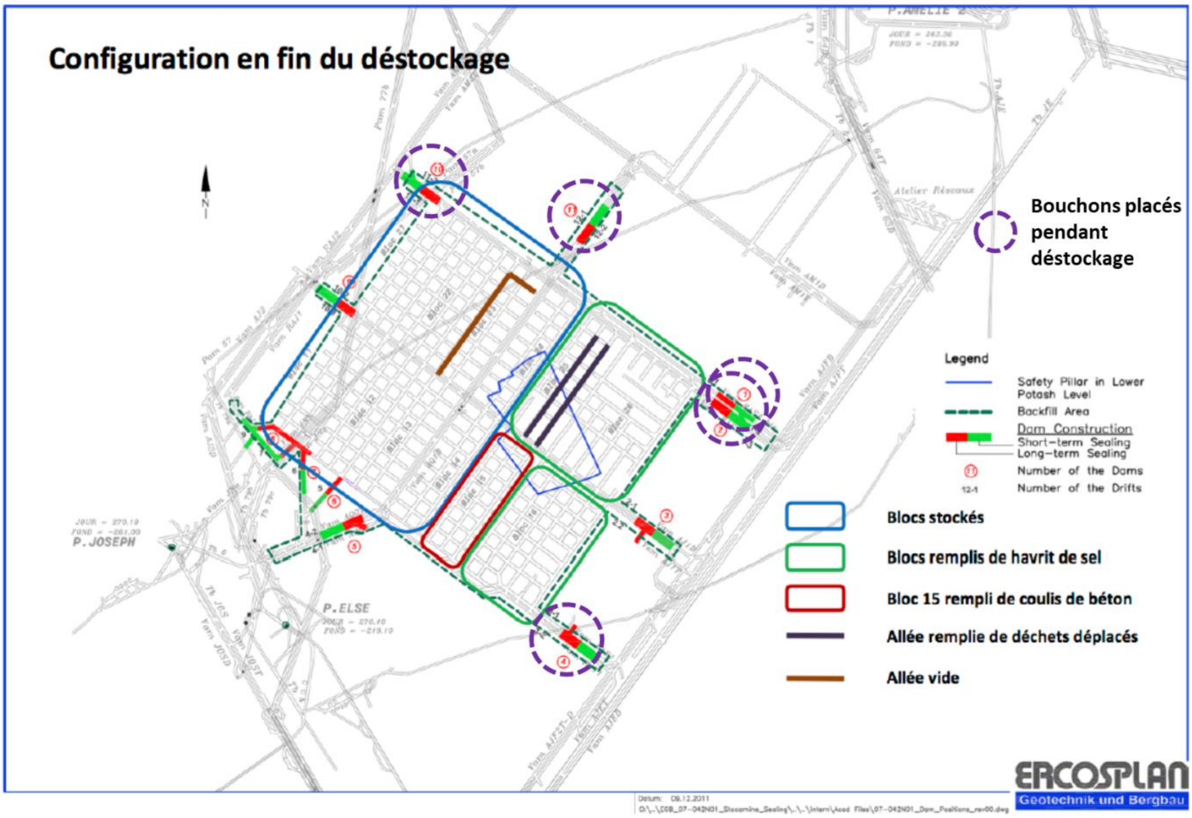


*Figure 2 : Emplacements des 5 bouchons mis en place en parallèle avec le déstockage (cerclés en mauve).*

# 2. Paramètres de modélisation des scénarios de récupération

En préliminaire à la simulation de différents scénarios de récupération des déchets, l'expertise s'est concentrée sur l'identification des différents contraintes ou conditions-limites qui vont conditionner l'approche technique à privilégier. Ces contraintes vont servir de paramètres d'entrée pour la modélisation des scénarios de récupération.

## 2.1. CONTRAINTES EXISTANTES

Les experts ont constaté la présence d'un nombre important de contraintes, qui peuvent être regroupées en six grandes catégories, et qui vont imposer la mise en œuvre de solutions techniques spécifiques, tant au niveau de la sécurité des travailleurs que de la logistique des opérations (voir tableau 1).

| Type | Description | Conséquences immédiates | Conséquences sur les options techniques lors de l'analyse de scénarios de récupérations des déchets |
|---|---|---|---|
| Infrastructure existante | La zone de stockage est connectée à deux puits de l'ancienne mine de potasse. | Les puits et galeries d'accès existants ont une géométrie fixée, qui limite la capacité de transport, de ventilation, etc. | Hypothèses pour assurer la sécurité :<br>- Le nombre d'équipes, de colis et de matériels est limité à environ 3 cycles de transport par heure, pour une capacité du puits d'environ 5 tonnes par voyage.<br><br>- La ventilation disponible par le puits Else est limitée actuellement à un débit de 50 $m^3/s$, et la ventilation secondaire nécessaire est estimée à environ 10 $m^3/s$ par front de travail.<br>- Limitation du nombre de travailleurs sur chaque front d'extraction : équipes d'environ 9 ou 10 travailleurs par front.<br>- Limitation de la taille des équipements mécaniques.<br>- Le taux d'utilisation de l'infrastructure est fixé à 12 heures par jour, pour 250 jours travaillés par an.<br>Ces hypothèses sont considérées comme des facteurs limitants dans la construction de scénarios avec plusieurs fronts d'extraction en parallèle. |
| Conditions géomécaniques | La géologie spécifique du site et le tracé des galeries d'accès au site de stockage conduisent à la fragilisation des roches et à la déstabilisation de la mine, avec une dégradation progressive avec le temps. | Phénomène de convergence: déformation croissante du toit, du plancher et des murs.<br>Chute de blocs: rupture et chute des strates de roches du toit, cisaillement des piliers de murs et effondrement.<br>Planchers endommagés pour l'accès aux zones de stockage: rupture des strates de roches du plancher.<br>Enclavement des colis de déchets.<br>Destruction des colis de déchets. | Classification de catégories spécifiques du site de stockage en plusieurs niveaux d'endommagement :<br>- Faibles déformations et dommages ;<br>- Déformations et dommages modérés ;<br>- Déformations et dommages importants ;. |
| Conditions de travail | Travail d'extraction de déchets impliquant une intervention humaine physique, dans un environnement dangereux. | Fréquence élevée et sévérité importante d'accidents, mises en évidence par les statistiques lors des opérations de retrait des déchets mercuriels. | Ce risque a aussi un fort impact sur l'estimation des temps de récupération, par exemple:<br>- Fréquence d'accidents: 142,3 occurrences par 1 000 000 heures travaillées.<br>- Sévérité: 1,28 jours d'arrêt par 1 000 heures travaillées.<br>La fréquence et la sévérité des accidents pourraient être réduites avec des mesures spécifiques, mais cette réduction potentielle n'est pas prise en compte dans l'évaluation du temps de déstockage (conditions conservatrices).<br>Les interventions physiques doivent être limitées, au profit de la mécanisation des opérations. |
| Présence de déchets toxiques / | L'intégrité des colis peut être compromise, à cause des déformations géomécaniques et des | Les travailleurs sont potentiellement exposés à des matériaux toxiques.<br>Des mesures préventives sont requises, comme l'utilisation d'équipements de protection. | Le travail en présence de déchets toxiques impliquera le déploiement de configurations spécifiques, influant sur la durée des opérations :<br>- Installation de zones et de sas de confinement ; |

| | | | |
|---|---|---|---|
| Transfert de contaminants | opérations d'extraction et de transport. | Des mesures correctives pourraient être nécessaires, comme le reconditionnement et la décontamination des colis.<br>Un système de reconditionnement des déchets libérés doit être utilisé.<br>La fin des opérations doit intégrer une phase de décontamination des zones de travail. | - Préparation d'équipements de protections spécifiques pour les travailleurs ;<br>- Réduction de la productivité pour les travaux physiques effectués avec des équipements de protection. |
| Présence de méthane | La couche supérieure riche en marnes directement au-dessus du toit peut contenir des poches de méthane.<br>Durant l'extraction des, déchets mercuriels, un seul indicent s'est déclaré, avec la libération de méthane d'une concentration initiale de 1,5% ; décroissant rapidement vers une concentration au-dessous de 0,5% en 5 minutes. | La mine de potasse est considérée comment une mine potentiellement exposée au risque de méthane.<br>Des mesures de prévention sont requises :<br>- Utilisation de matériels et d'outils antidéflagrants ;<br>- Contraintes spécifiques sur le système de ventilation (débit minimum pour assurer la dilution du méthane) ;<br>- Préparation de plans pour l'évacuation des zones de travail en cas d'incident.<br>Autre conséquences:<br>- Éviter des activités favorisant la libération du méthane (par exemple, minimiser les forages dans les couches du toit). | Les configurations suivantes sont à prévoir:<br>- Choix d'équipements de protection appropriés ;<br>- Mise en place d'une mesure in-situ de la concentration en méthane ;<br>- Mise en place d'une ventilation suffisante (minimum 5 $m^3/s$ par front d'extraction) ;<br>- Minimisation du nombre de forages verticaux ascendants (ancrage par boulons).<br>Si ces mesures sont mises en œuvre, l'impact d'accidents éventuels devrait être négligeable sur l'estimation de la durée de récupération.<br>Si ces mesures optimales ne peuvent pas être assurées, le risque encouru peut être estimé à partir de l'expérience passée:<br>- En moyenne, un indicent peut arriver pour tous les 3 blocs où les déchets sont extraits (1/3 incident par Bloc, en terme de modélisation) ;<br>- En cas d'incident, la perte d'une durée d'un poste de travail peut être admise (1/3 jour supplémentaire par bloc, en raison de la présence de méthane). |
| Présence de poussières | Émission importante de poussières durant les travaux (environnement sec, mine de potasse).<br>La plupart des déchets est sous forme pulvérulente, surtout les cendres volantes et l'amiante. | Systèmes de prévention des émissions de poussières (sas, zones de confinement).<br>Sélection d'équipements de protection adéquats (masques de type FFP3 au moins en tout lieu du site ; et protection totale en « zone rouge »). | Les émissions de poussières vont considérablement gêner le téléguidage des équipements. Les opérateurs devront être physiquement présents, même s'ils n'accomplissent pas de tâches physiques. |

*Tableau 1 : Contraintes identifiées par les experts et conséquences sur les solutions techniques.*

***La géomécanique***

L'évaluation des contraintes géomécaniques fournies par le rapport ITASCA Consultants (2017) a permis d'identifier des zones de déformation d'ampleurs variables au sein du site (de faibles vitesses de déformation verticale de l'ordre de 10 mm/an, à des vitesses plus élevées, de l'ordre 30 mm/an). Dans l'optique du travail de modélisation et afin d'affiner les conditions d'extraction des colis entre les blocs, le groupe d'experts, suite aux visites sur site et la constatation des situations de déformation locale, a caractérisé le site en trois catégories définies comme suit (voir Figure 3) :

- faibles déformations et dommages (catégorie « verte ») : pas de contraintes d'accès et d'extraction, mais des mesures préventives de sécurisation du toit sont nécessaires ;
- déformations et dommages modérés (catégorie « jaune ») : pas de contraintes majeures d'accès et d'extraction, mais des mesures de sécurisation et des mesures correctives pour l'extraction sont nécessaires ;
- déformations et dommages importants (catégorie « rouge ») : existence de contraintes majeures d'accès et d'extraction (avec enclavement occasionnel des colis), nécessitant des mesures intensives de sécurisation et de correction.


*Figure 3 : Vue schématique des blocs du site de stockage, les couleurs vert/jaune/rouge-rosé indiquant les catégories de déformation identifiées. La zone en orange foncé correspond au bloc 15 non-accessible.*

Cette différentiation spatialisée permet une paramétrisation fine dans le modèle de calcul des conditions de travail dans chaque front d'extraction, où les durées des opérations peuvent être ajustées en fonction de l'état des colis et des conditions de sécurité.

## 2.2. SOLUTIONS TECHNIQUES ENVISAGÉES

Lors de l'enlèvement des déchets mercuriels, le personnel était régulièrement contraint d'opérer manuellement, en contact direct avec les colis (voir Figure 4). Le groupe d'experts a estimé que ce mode opératoire ne devait plus, pour des raisons de sécurité, être utilisé à l'avenir, d'autant plus que ces manœuvres dangereuses ont été la source de nombreux accidents de personnel (entorses, luxations, etc.). L'intervention manuelle du personnel était cependant nécessaire en raison des engins mécaniques utilisés (faible puissance du tracteur, fourches non conçues pour soulever efficacement les oreilles des Big Bags, etc.).

*Figure 4 : Conditions dangereuses d'extraction manuelle des colis liées aux outils utilisés lors de la récupération des déchets mercuriels [Rapport ROV CONSULT, 2016].*

L'étude statistique des accidents (voir par exemple rapport APAVE, 2017) montre que le taux observé aux MDPA pendant l'extraction des colis mercuriels est supérieur à la fréquence normalement observée pour des activités similaires avec du matériel plus adapté. Cependant, afin de rester dans un cadre conservateur, nous avons retenu la fréquence des accidents aux MDPA pour évaluer les « contingences » liées au scénario de déstockage total. Ces éléments sont quantifiés dans le tableau 1 sous la rubrique « conditions de travail ».

Concernant le travail en zone contaminée, les rapports indiquent une activité très éprouvante physiquement (port d'équipements de protection avec appareil respiratoire et masques de type FFP3 avec une autonomie n'excédant pas 90 minutes). Dès lors, une organisation plus optimale du travail auprès des fronts d'extraction est préconisée, à commencer par une définition précise des zones d'exposition aux contaminants[1] (voir Figure 5) :

- « zone rouge » : front d'extraction exposé aux contaminants ;
- « zone bleue » : aire de conditionnement ou décontamination / sas vers la « zone rouge » ;
- « zone verte » : le reste de la mine.

Différents types d'équipements de protection individuelle sont à considérer selon les zones :

- protection intégrale en « zone rouge » : il est nécessaire de protéger entièrement la surface corporelle et les voies respiratoires, par des combinaisons intégrales et une alimentation en air frais ;
- protection partielle en « zone bleue » : port de masques, gants et chaussures de protection pour limiter les voies d'expositions potentielles.

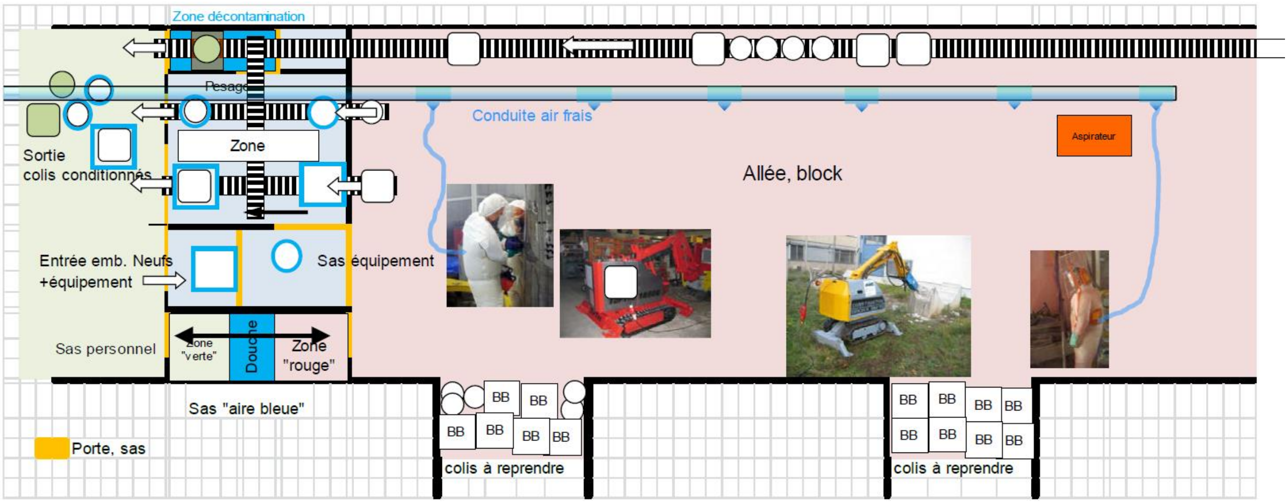


*Figure 5 : Option privilégiée pour l'extraction des colis.*

En particulier, il est recommandé d'organiser une alimentation continue en air frais à l'aide d'un conduit mis en place dans la « zone rouge » : des connecteurs localisés environ tous les 20 mètres permettent alors au personnel de se brancher, à l'aide d'un cordon flexible relié à la combinaison intégrale (voir Figure 6). Cette solution technique permet de dépasser l'autonomie limitée des appareils respiratoires et permet des conditions de travail moins pénibles que l'usage de masques FFP3, évitant ainsi des rotations trop fréquentes du personnel en dehors de la « zone rouge ».

[1] À ne pas confondre avec la caractérisation du site du point de vue géomécanique.

*Figure 6 : Exemple de combinaison intégrale reliée à un cordon d'alimentation en air frais.*

Le travail en « zone rouge » nécessite également une mécanisation accrue de l'extraction des colis, afin de limiter au maximum la survenue d'accidents de personnel. Des engins compacts et puissants, fonctionnant à l'électricité, pourraient être utilisés pour effectuer une multitude de tâches (voir Figure 7) : excavation des parois ou planchers déformés, désenclavement des colis, enlèvement des colis, etc.


*Figure 7 : Exemple d'engin électrique avec bras articulé pouvant effectuer tous types de travaux (source TopTec).*

Ces engins, déjà utilisés avec succès dans des circonstances comparables, possèdent un bras articulé dont la prise standard peut être connectée à une multitude d'outils, permettant ainsi une adaptation optimale à tous types de situation. En fonction du type de colis (Big Bags, palettes, fûts), plusieurs têtes articulées et rotatives sont ainsi disponibles pour manipuler les déchets dans des conditions d'endommagement et d'enclavement très variées (voir Figures 8 et 9). Certains outils peuvent également permettre des travaux d'excavation préalables (havage du plancher) ou de sécurisation du toit (ancrage des boulons).

*Figure 8 : Exemple de tête rotative permettant une préhension des Big Bags par leur côté.*

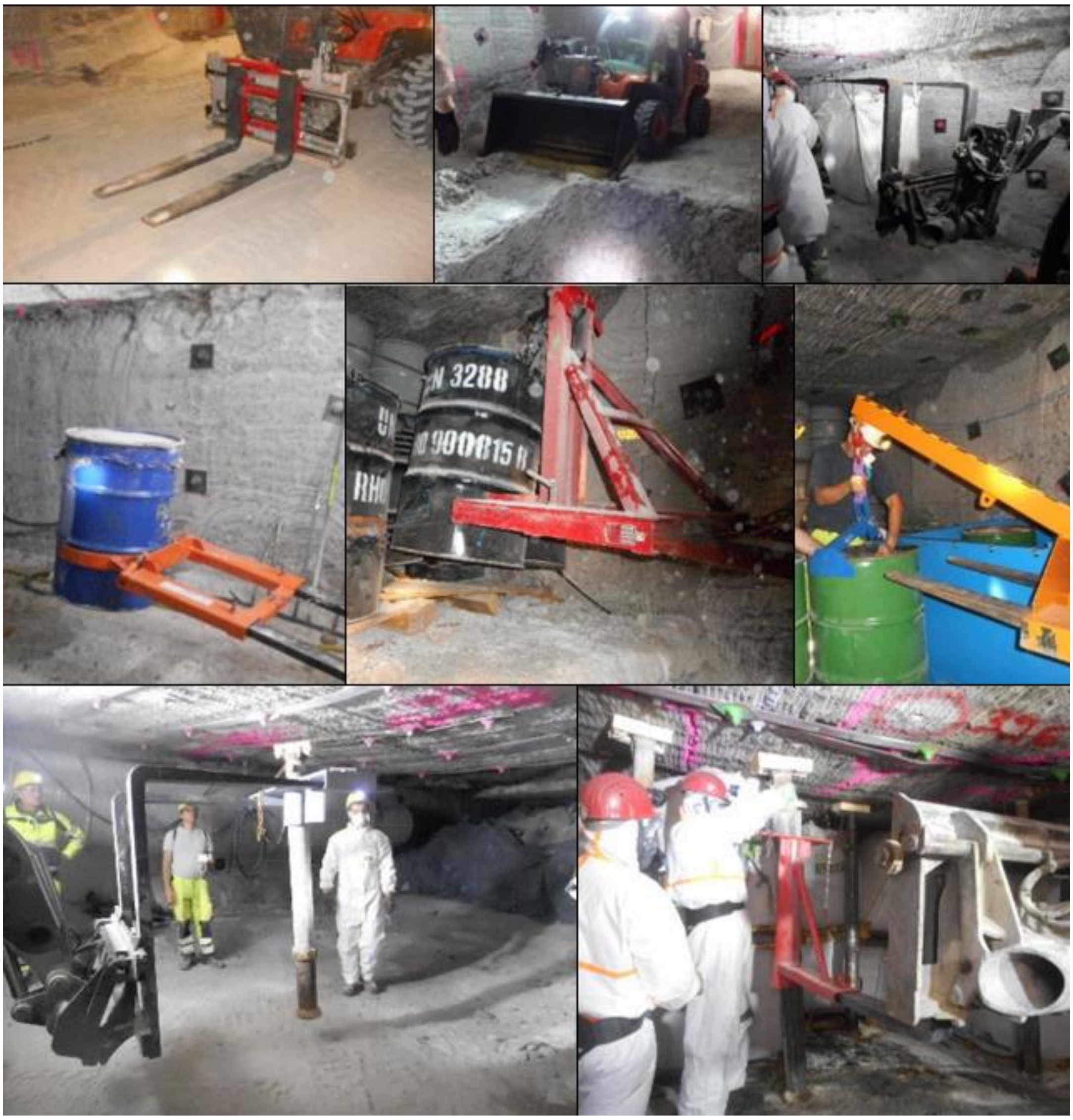


*Figure 9 : Exemples de tâches pouvant être effectuées par un engin mécanique multifonctions.*

Suivant l'état d'endommagement des colis, il est nécessaire de reconditionner certains déchets dans des emballages intacts afin de pouvoir les évacuer vers la surface. Plusieurs cas sont à considérer :

- cas 1 : big bags et fûts intacts, permettant leur manipulation « en l'état », après nettoyage des poussières fixées sur leurs surfaces ;
- cas 2 : colis légèrement endommagés, qui peuvent être corrigés par un suremballage ;
- cas 3 : colis ayant totalement perdu leur intégrité, nécessitant une station de reconditionnement dans la « zone rouge ». Les déchets dispersés peuvent être reconditionnés dans des fûts neufs (voir Figure 10).

Il est à noter qu'un reconditionnement spécifique serait nécessaire en surface pour l'entreposage et/ou le transfert des colis vers d'autres sites.

*Figure 10 : Reconditionnement de déchets dans des fûts, avec un aspirateur manuel (gauche) ou une station de remplissage automatique (droite).*

La phase de décontamination est essentielle pour limiter la propagation des éléments toxiques en dehors de la « zone rouge », notamment les poussières transportées sur l'équipement mécanique et les combinaisons des travailleurs. L'objectif est en effet de réduire au maximum les quantités de matériaux toxiques restant sur le site au moment du confinement. En raison de la forme pulvérulente de la majorité des déchets, des technologies basées sur l'aspiration des poussières sont jugées adaptées au contexte de Stocamine (voir Figure 11).

*Figure 11 : Décapage des surfaces avec aspiration des poussières (gauche) ou utilisation d'un aspirateur industriel (droite).*

Enfin, il est essentiel de noter que les solutions techniques préconisées placent la sécurité des opérations et du personnel au premier plan, ce qui demeure la condition indispensable pour la mise en place d'un plan de déstockage éventuel. Ainsi, il est recommandé d'utiliser des cintres coulissants plutôt que des techniques d'ancrage par boulons, pour la sécurisation du toit des galeries (voir Figure 12). Les cintres coulissants en acier offrent plus de flexibilité, de rapidité d'installation et de démontage. Une réduction du nombre d'ancrages par boulons permet notamment de limiter la libération de poches de méthane lors du perçage du toit.

L'installation de supports hydrauliques peut également faire partie des mesures correctives immédiates pour sécuriser les accès.

À noter que du fait de la présence du méthane, l'ensemble des équipements utilisés au fond devra être certifié « antidéflagrant ».

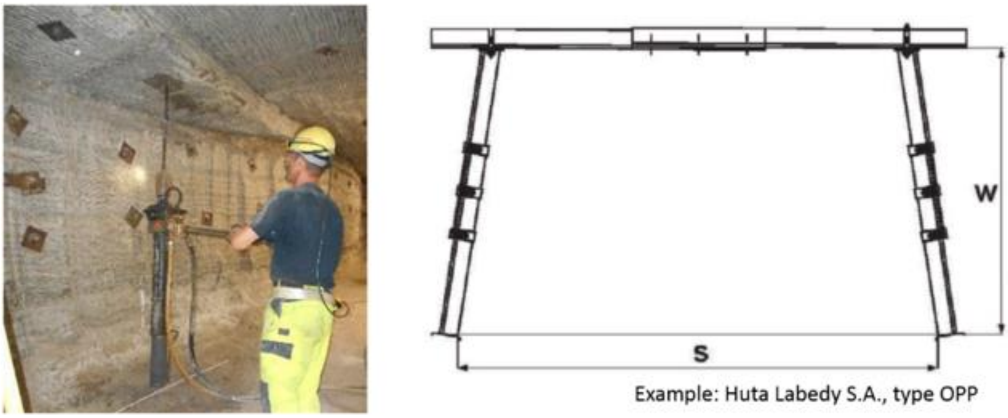


*Figure 12 : Ancrage par boulons habituellement pratiqué (gauche) et schéma de cintre coulissant en acier (droite).*

# 3. Méthodologie de calcul des durées

## 3.1. DÉCOMPOSITION EN PROCESSUS-CLÉS

Le calcul de la durée de récupération des colis et du confinement du stockage s'appuie sur des outils de Recherche Opérationnelle, qui s'attachent d'abord à décomposer le projet en série de processus, afin d'en dégager les tâches essentielles qui forment le « chemin critique » pour une quantification de la durée des opérations. En dehors des processus indispensables relatifs à la gestion des opérations et aux fonctions supports, 8 processus ont été identifiés comme étant au cœur du problème (voir Figure 13) :

- **CP1 :** études techniques / Acquisition de données ;
- **CP2 :** préparation des infrastructures pour la mise en sécurité ;
- **CP3 :** mise en sécurité des zones de travail ;
- **CP4 :** extraction des colis ;
- **CP5 :** décontamination ;
- **CP6 :** conditionnement des colis ;
- **CP7 :** transport des colis vers la surface ;
- **CP8 :** création des bouchons / Confinement.

Ces 8 processus, correspondant à des temps incompressibles pour l'estimation de la durée totale des opérations de récupération des déchets, font l'objet d'une modélisation fine qui est détaillée ci-après. Les autres types de processus, qui figurent aussi dans le schéma ci-dessous, sont tout aussi indispensables pour assurer la faisabilité du projet ; cependant leur mise en œuvre peut en partie se dérouler en parallèle des processus principaux, si bien que l'estimation de leur durée est moins essentielle dans un premier temps.

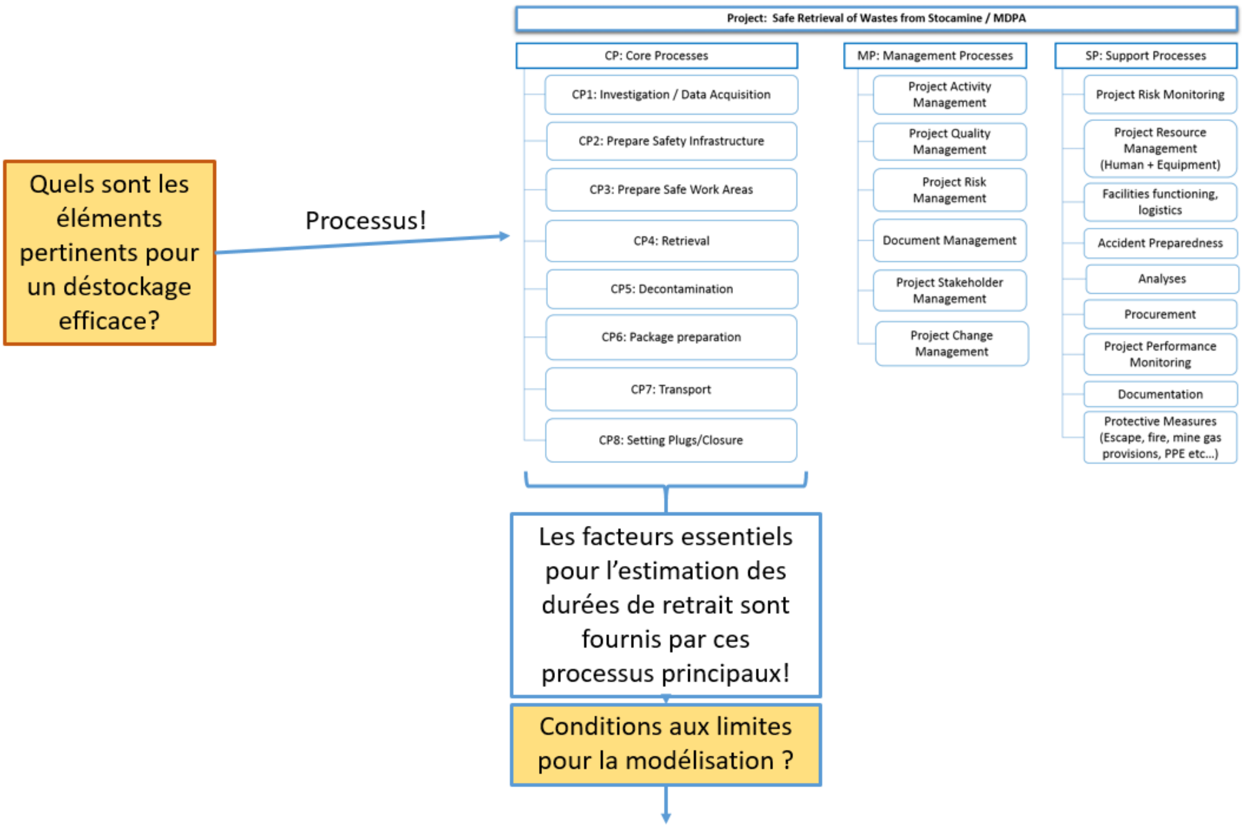


*Figure 13 : Carte des processus considérés dans la modélisation.*

## 3.2. PRISE EN COMPTE DES CONDITIONS-LIMITES DANS LES OPTIONS TECHNIQUES

La modélisation de la durée d'exécution de l'ensemble de ces processus doit ensuite prendre en compte les différentes contraintes et conditions-limites identifiées précédemment. Ces conditions-limites induisent 5 grands types de conséquences sur la sécurité et la logistique des opérations (voir Figure 14) :

- limitation du nombre de postes de travail et de fronts d'extraction, en raison des contraintes liées au système de ventilation et aux capacités du puits d'accès et des galeries de transport ;
- mesures correctives à prévoir pour assurer la sécurité des galeries et fronts affectés par la déformation croissante du site (convergence géomécanique) ;
- mesures de prévention à prévoir en raison du travail dans une mine classée en risque méthane ;
- mesures correctives spécifiques à prévoir pour la réduction de la fréquence et de la sévérité des accidents affectant les travailleurs ;
- mesures de prévention à prévoir pour réduire le risque d'exposition du personnel aux substances toxiques provenant des colis.

L'évolution des conditions géomécaniques du site nécessite une attention toute particulière, avec la possibilité de distinguer plusieurs types de mesures en fonction des trois catégories de déformation précédemment identifiées. Ainsi, des mesures correctives immédiates (utilisation de supports hydrauliques) ou à plus long terme (ancrage du toit, mise en place de portails de support ou de cintres coulissants) peuvent être déployées suivant les cas.

Pour les fronts en catégorie « rouge » (vitesses élevées de déformation), la proportion de colis complétement enclavés par front peut varier en fonction de l'évolution de la convergence : un ratio de 20 % (systématiquement enclavés) / 80 % (partiellement enclavés) a été retenu suite à une étude de sensibilité qui a fait varier ce rapport entre 0 % et 100 % (voir résultats ci-après). Un front avec des colis totalement enclavés implique des opérations d'extraction d'autant plus longues, que les colis peuvent être potentiellement endommagés par la pression de la roche.

Concernant les fronts en catégorie « jaune », il est possible de rencontrer localement des déformations et des endommagements importants, nécessitant d'avoir immédiatement à disposition les moyens techniques adéquats pour appliquer les mesures correctives. Enfin, il est admis que les fronts en catégorie « verte » ne posent pas d'obstacle technique majeur, permettant un retrait des colis dans des conditions normales.

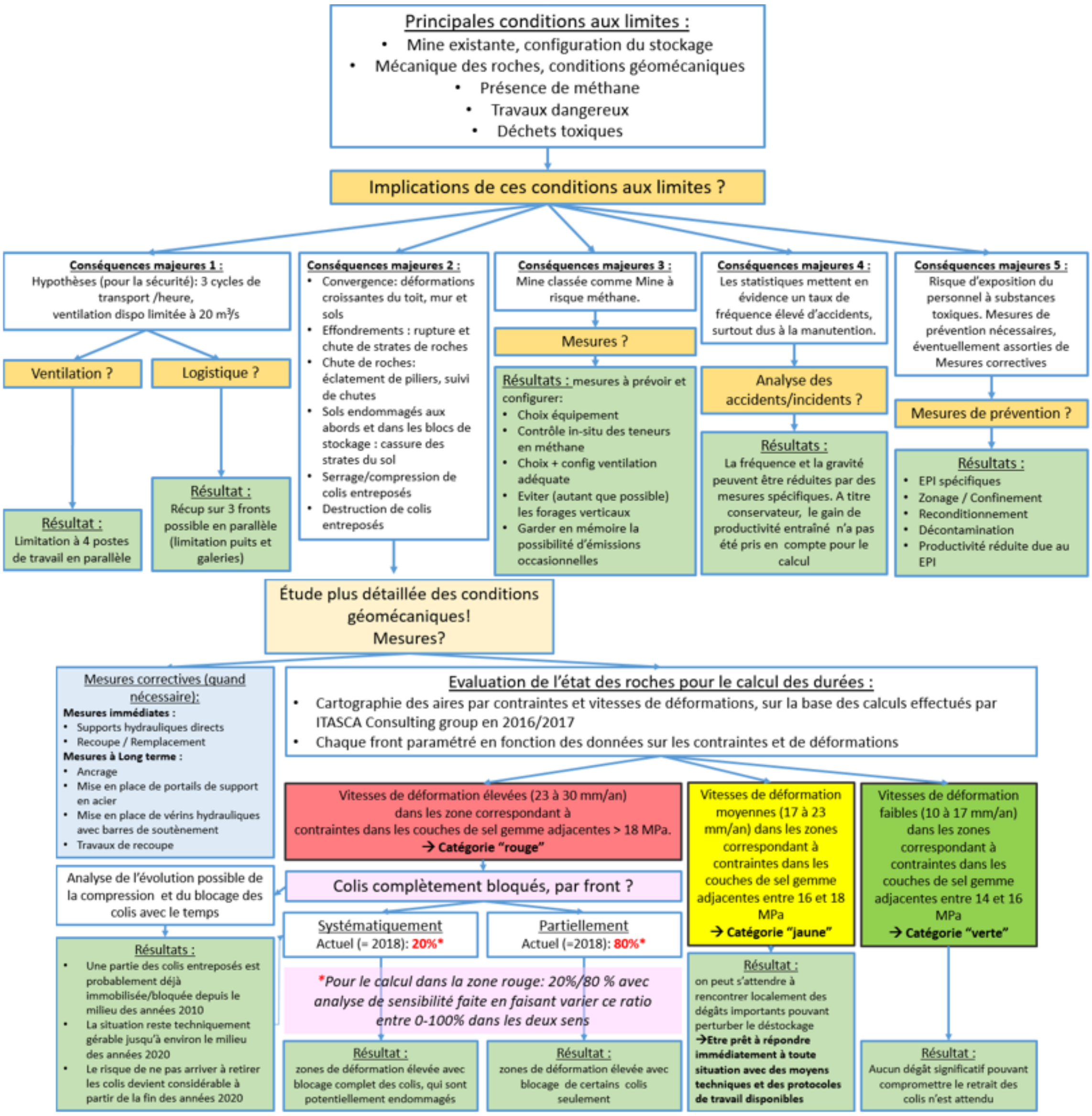


*Figure 14 : Arbre de décision pour la sélection des solutions techniques à partir des conditions aux limites.*

Plusieurs options techniques d'extraction des colis sont considérées, en faisant varier les conditions géomécaniques, la configuration de la « zone rouge » (zone d'exposition aux substances toxiques)[2] et le degré de mécanisation des tâches :

- **option de référence :** il s'agit de la solution technique adoptée par MDPA lors du retrait des colis mercuriels. Les travailleurs, assistés d'un tracteur et équipés d'équipements de protection intégraux, interviennent manuellement dans la « zone rouge » pour faciliter l'extraction des colis enclavés (voir Figure 15) ;
- **option 1 :** il s'agit de l'option « sans contraintes géomécaniques », applicable uniquement dans les fronts à faibles vitesses de déformation. Les colis sont considérés intacts et facilement manipulables sans intervention humaine directe. L'intégrité physique des colis permet d'éviter la mise en place d'une « zone rouge » (voir Figure 16) ;
- **option 2 :** reconditionnement des colis *in situ*, avec confinement local de la « zone rouge ». Le personnel reste en dehors de la « zone rouge » ;
- **option 3 :** extraction par un tracteur contrôlé à distance. Le personnel reste en dehors de la « zone rouge » ;
- **option 4 :** extraction par deux tracteurs contrôlés à distance. Le personnel reste en dehors de la « zone rouge ». L'utilisation de deux tracteurs permet d'éviter de changer constamment d'outils entre chaque opération, mais peut poser des problèmes d'encombrement (espace réduit devant chaque front) ;
- **option 5 :** combinaison des options 2 et 3, où le tracteur peut opérer à l'extérieur de la « zone rouge », à travers un rideau de confinement flexible ;
- **option 6 :** mécanisation adaptée dans une large « zone rouge » entièrement confinée. Cette option propose un confinement à l'échelle d'un bloc, où le personnel et les engins mécaniques interviennent directement. Les travailleurs sont reliés à une conduite d'air frais, permettant des conditions de travail supportables sous les équipements de protections intégrales. La présence humaine à proximité permet une grande flexibilité des situations et des tâches (changements d'outils, tâches en parallèle, etc.) (voir Figure 17).

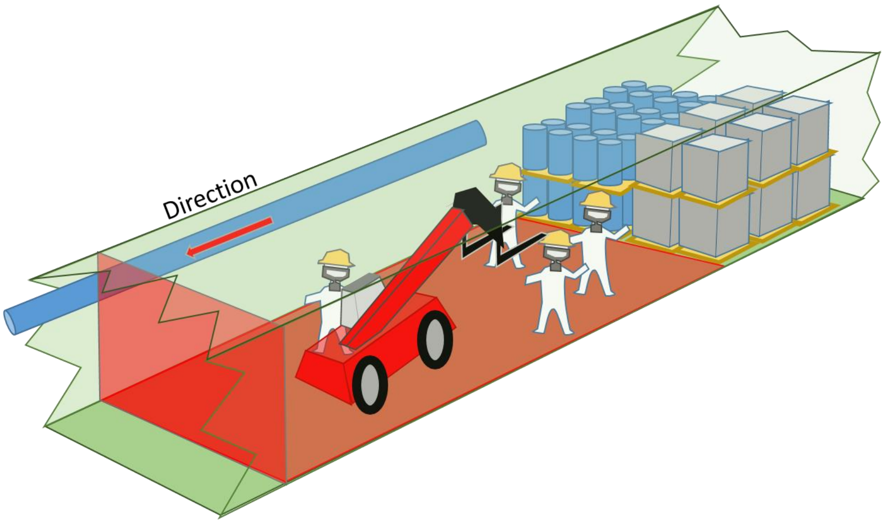


*Figure 15 : Vue schématique de l'Option de référence (approche originelle MDPA).*

[2] À ne pas confondre avec les fronts de catégorie « rouge » pour les raisons géomécaniques

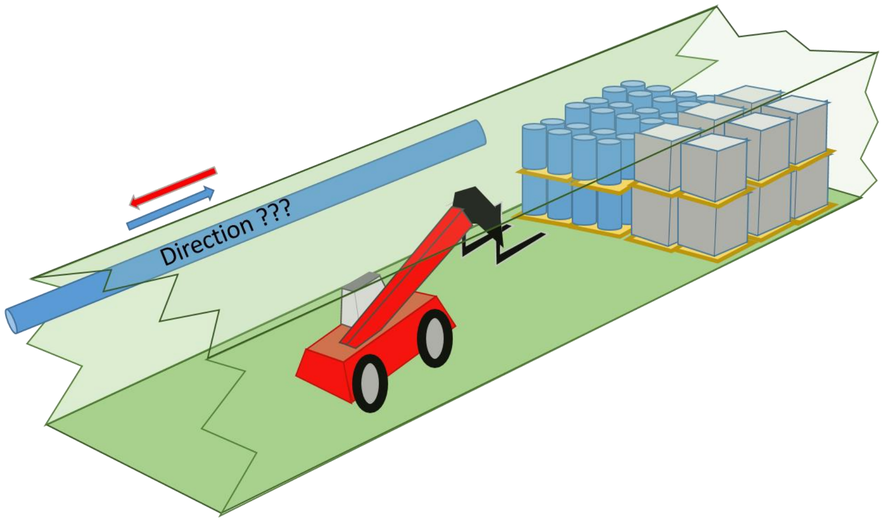


*Figure 16 : Vue schématique de l'Option 1 (absence de « zone rouge »).*

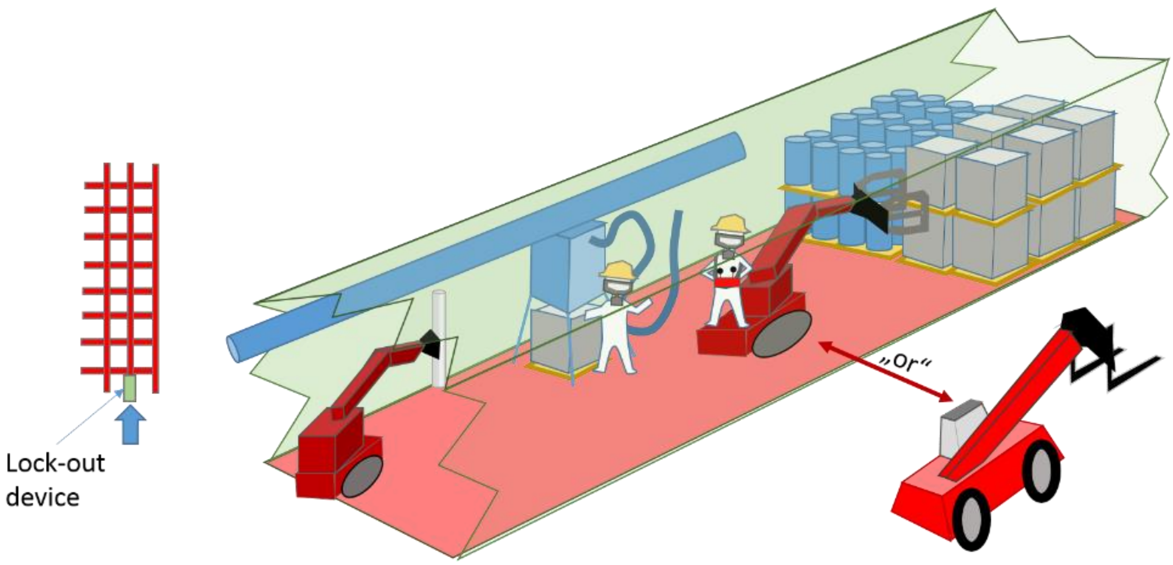


*Figure 17 : Vue schématique de l'Option 6 (approche préconisée).*

Les détails de toutes les options peuvent être consultés dans le rapport DMT - PLEJADES (2018), en annexe du présent rapport.

## 3.3. ESTIMATION DE DURÉES DE DESTOCKAGE PAR FRONTS DE RÉFÉRENCE

Pour chacune des options détaillées précédemment, un calcul de la durée de sécurisation, d'extraction, de reconditionnement et de transport des colis a été effectué (voir exemples dans la Figure 18). Cette évaluation s'appuie sur le principe du « chemin critique » formé par les différents processus identifiés plus haut. Les principaux éléments du chemin critique sont les suivants :

- opérations d'extraction des colis à partir du front (correspondant aux processus **CP4** et **CP6**, et partiellement **CP5**), et transfert en dehors de la « zone rouge » ;

- création et démantèlement des « zones rouges » (correspondant partiellement aux processus **CP1** et **CP2**) : construction et installation des rideaux ou des sas, mesures des concentrations en polluants, décontamination, démantèlement des rideaux ou des sas ;
- sécurisation des toits, parois et planchers (correspondant au processus **CP3**) : installation de supports temporaires vers l'avant, dégagement et installation de supports à usage long-terme à mesure que le front progresse ;
- reconditionnement et gestion des colis extraits (correspondant au processus **CP6**).

Les éléments suivants font partie intégrante du modèle, cependant ils contribuent essentiellement à contraindre les conditions-limites (e.g. capacité de transport par les galeries ou le puits) ; et leur exécution en parallèle des autres processus ne leur confère pas un caractère critique en terme de durée :

- tâches de préparation (correspondant au processus **CP1**, et partiellement **CP2**) ;
- transport intermédiaire (par véhicule) vers le puits d'accès (correspondant au processus **CP7**) ;
- transport intermédiaire vers la surface par le puits d'accès (correspondant au processus **CP7**) ;
- gestion des colis déstockés en surface (source potentielle de fortes contraintes, voir analyse qualitative ci-après).

Les calculs de durée sont effectués sur un « front de référence » et des temps en minutes sont proposés pour chaque tâche élémentaire, par colis ou par front. Les durées sont estimées par les experts, à partir de leurs expériences dans des situations similaires (par ex. retraits de déchets souterrains à partir de zones fortement contaminées, dans l'industrie chimique, nucléaire ou minière). Il est à noter que seules les tâches faisant partie d'un « chemin critique » pour l'estimation de la durée d'enlèvement sont comptabilisées.

Pour prendre en compte les différents conditions géomécaniques, plusieurs coefficients sont affectés aux durées élémentaires en fonction des vitesses de déformations inhérentes à chaque front (i.e., établissement d'un « front de référence » par chaque catégorie de déformation verte, jaune et rouge). En particulier, l'enclavement des colis a une influence importante sur la durée d'extraction, si bien que la catégorie « rouge » est subdivisée en deux sous-catégories : une partie sans enclavement des colis et une partie avec un enclavement systématique des colis. Cette dernière partie, la plus chronophage, est considérée comme constituant 20 % des fronts de la catégorie « rouge », à condition que les travaux de retrait débutent immédiatement. Il faut cependant s'attendre à une augmentation de cette proportion due à la progression de la convergence géomécanique, si les travaux d'extraction sont retardés par rapport au schéma retenu.

**Reference Option (based one existing experience)**

| | Reference Option (based one existing experience) |
|---|---|
| Rock mechanics | flexible (within limits) |
| Package condition | flexible (within limits) |
| Flexibility | Yes, but physical human intervention is high |

| | reference unit | weighting/scaling factor 1=100% | | | | Time [Min.] | summary per 'front' [h] | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | roof, wall, floor ok | localy support required | support required | support required & packages clamped | | Stoß, Firste, Sohle ok | Lokal Sicherung erforderlich | Sicherung erforderlich | Sicherung erforderlich, Gebinde eingespannt |
| **Retrieval from 'Front'** | | | | | | | | | | |
| Journey time outwards-backwards | per package | 1 | 1 | 1,2 | 1,2 | 10 | 1,58 | 1,58 | 1,90 | 1,90 |
| Pick up the package | per package | 0,75 | 1 | 1,25 | 4 | 10 | 1,19 | 1,58 | 1,98 | 6,33 |
| Rangieren / rotate | per package | 1 | 1,25 | 2 | 2 | 3 | 0,48 | 0,59 | 0,95 | 0,95 |
| In Tisch Ablegen | per package | 0 | 0 | 0 | 0 | | | | | |
| waiting for lock-out process (close overpack and prepare next one) | per package | 0 | 0 | 0 | 0 | | | | | |
| Bumper time / (intervention via tunnel / other works) | per package | 0 | 0 | 0 | 0 | | | | | |
| **Creation and removal of zoning** | | | | | | | | | | |
| seperation 'red Area' | per 'front' | 0,1 | 0,25 | 0,25 | 0,25 | 360 | 0,60 | 1,50 | 1,50 | 1,50 |
| Sampling / securing of evidence / free measurement | per 'front' | 0,1 | 0,25 | 0,25 | 0,25 | 60 | 0,10 | 0,25 | 0,25 | 0,25 |
| reworking / Decontamination (suck off, milling off) | per 'front' | 0,1 | 0,25 | 0,25 | 0,25 | 120 | 0,20 | 0,50 | 0,50 | 0,50 |
| deconstruction | per 'front' | 0,1 | 0,25 | 0,25 | 0,25 | 180 | 0,30 | 0,75 | 0,75 | 0,75 |
| **Securing of roof, walls and floor** | | | | | | | | | | |
| temporary support at the 'front' | per 'front' | 0 | 0,2 | 1 | 1 | 75 | | 0,25 | 1,25 | 1,25 |
| endoscopic drillings | per 'front' | 0,5 | 1 | 1,5 | 1,5 | 30 | 0,25 | 0,50 | 0,75 | 0,75 |
| final support | per 'front' | 0 | 0,2 | 1 | 1 | 90 | | 0,30 | 1,50 | 1,50 |
| Berauben/strossen | per 'front' | 0 | 0,1 | 0,8 | 1 | 60 | | 0,10 | 0,80 | 1,00 |
| **Intermediate Transport (per vehicle) to repackaging** | | | | | | | | | | |
| Pick up/place package | per package | 0 | 0 | 0 | 0 | 4 | | | | |
| Journey time outwards-backwards | per package | 0 | 0 | 0 | 0 | 8 | | | | |
| **Subsequent package management/repackaging** | | | | | | | | | | |
| Edit Package | per package | 0 | 0 | 0 | 0 | 20 | | | | |
| **Intermediate transport (per vehicle) to shaft** | | | | | | | | | | |
| Journey time outwards-backwards | 4 packages | 0 | 0 | 0 | 0 | 20 | | | | |
| Pick up/place package | 4 packages | 0 | 0 | 0 | 0 | 20 | | | | |
| **Intermediate transport through shaft** | | | | | | | | | | |
| driving game | 4 packages | 0 | 0 | 0 | 0 | 15 | | | | |
| Pick up/place package | 4 packages | 0 | 0 | 0 | 0 | 5 | | | | |
| | | | | | | **Time per 'Front' [h]:** | **4,70** | **7,91** | **12,13** | **16,68** |
| | | | | | | Number of 'Fronts' per color (all): | 608 | 2280 | 3257,6 | 814,4 |
| | | | | | | **Time for all 'Fronts' [h]** | **2855** | **18036** | **39512** | **13587** |
| | | | | | | | | | | Summary |
| | | | | | | | | | | **73445** |

**Option 6 'Adapted mechanisation in established confinement'**

| | Option 6 'Adapted mechanisation in established confinement' |
|---|---|
| Rock mechanics | highly fleible |
| Package condition | highly flexible |
| Flexibility | high due to human control in confined zone but with reduced physical human intervention |

| | reference unit | weighting/scaling factor 1=100% | | | | Time [Min.] | summary per 'front' [h] | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | roof, wall, floor ok | localy support required | support required | support required & packages clamped | | Stoß, Firste, Sohle ok | Lokal Sicherung erforderlich | Sicherung erforderlich | Sicherung erforderlich, Gebinde eingespannt |
| **Retrieval from 'Front'** | | | | | | | | | | |
| Journey time outwards-backwards | per package | 1 | 1 | 1 | 1 | 10 | 1,58 | 1,58 | 1,58 | 1,58 |
| Pick up the package | per package | 1 | 1 | 1,5 | 4 | 5 | 0,79 | 0,79 | 1,19 | 3,17 |
| Rangieren / rotate | per package | 1 | 1 | 1 | 1 | 5 | 0,79 | 0,79 | 0,79 | 0,79 |
| In Tisch Ablegen | per package | 0 | 0 | 0 | 0 | 3 | | | | |
| waiting for lock-out process (close overpack and prepare next one) | per package | 0 | 0 | 0 | 0 | 2 | | | | |
| Bumper time / (intervention via tunnel / other works) | per package | 1 | 1 | 1 | 1 | 2 | 0,32 | 0,32 | 0,32 | 0,32 |
| **Creation and removal of zoning** | | | | | | | | | | |
| seperation 'red Area' | per 'front' | 0 | 0 | 0 | 0 | 360 | | | | |
| Sampling / securing of evidence / free measurement | per 'front' | 0 | 0 | 0 | 0 | 60 | | | | |
| reworking / Decontamination (suck off, milling off) | per 'front' | 0 | 0 | 0 | 0 | 120 | | | | |
| deconstruction | per 'front' | 0 | 0 | 0 | 0 | 180 | | | | |
| **Securing of roof, walls and floor** | | | | | | | | | | |
| temporary support at the 'front' | per 'front' | 0 | 0,2 | 0,75 | 1 | 75 | | 0,25 | 0,94 | 1,25 |
| endoscopic drillings | per 'front' | 0,2 | 0,5 | 0,7 | 0,7 | 30 | 0,10 | 0,25 | 0,35 | 0,35 |
| final support | per 'front' | 0 | 0,2 | 0,5 | 1 | 90 | | 0,30 | 0,75 | 1,50 |
| Berauben/strossen | per 'front' | 0 | 0,1 | 0,5 | 1 | 60 | | 0,10 | 0,50 | 1,00 |
| **Intermediate Transport (per vehicle) to repackaging** | | | | | | | | | | |
| Pick up/place package | per package | 0 | 0 | 0 | 0 | 4 | | | | |
| Journey time outwards-backwards | per package | 0 | 0 | 0 | 0 | 8 | | | | |
| **Subsequent package management/repackaging** | | | | | | | | | | |
| Edit Package | per package | 0,1 | 0,2 | 0,3 | 0,5 | 20 | 0,32 | 0,63 | 0,95 | 1,58 |
| **Intermediate transport (per vehicle) to shaft** | | | | | | | | | | |
| Journey time outwards-backwards | 4 packages | 0 | 0 | 0 | 0 | 20 | | | | |
| Pick up/place package | 4 packages | 0 | 0 | 0 | 0 | 20 | | | | |
| **Intermediate transport through shaft** | | | | | | | | | | |
| driving game | 4 packages | 0 | 0 | 0 | 0 | 15 | | | | |
| Pick up/place package | 4 packages | 0 | 0 | 0 | 0 | 5 | | | | |
| | | | | | | **Time per 'Front' [h]:** | **3,90** | **5,02** | **7,37** | **11,54** |
| | | | | | | Number of 'Fronts' per color (all): | 608 | 2280 | 3257,6 | 814,4 |
| | | | | | | **Time for all 'Fronts' [h]** | **2371** | **11438** | **23998** | **9400** |
| | | | | | | | | | | Summary |
| | | | | | | | | | | **47206** |

*Figure 18 : Exemple de calcul pour le temps passé (en heures de travail) par front, pour l'option de référence (gauche) et l'option 6.(droite).*

## 3.4. DÉFINITION DES SCÉNARIOS

La décomposition des activités de récupération en tâches élémentaires permet alors d'obtenir une durée cumulée en heures de travail. Cette durée doit être placée dans un contexte plus global, prenant en compte les contraintes logistiques, le nombre effectif de postes et d'heures travaillées par jour, ainsi que les tâches préparatoires et les opérations de confinement après enlèvement des déchets.

Pour ce faire, 4 scénarios (A, B, C et D) sont définis, proposant plusieurs conditions de parallélisation des fronts d'extraction (voir tableau 2). Étant donné les contraintes sur le système de ventilation et sur le puits d'accès, au maximum trois fronts d'extraction peuvent être envisagés en parallèle. L'option 6 est retenue pour le calcul de l'ensemble des scénarios, étant donné que la modélisation des tâches élémentaires a mis en évidence qu'il s'agit de l'option la moins coûteuse en temps. Le scénario D propose également d'appliquer l'option 1 pour les fronts soumis à de faibles vitesses de déformation, permettant ainsi une parallélisation accrue des tâches.

| Scénario | Description | Chemin critique | Options |
|---|---|---|---|
| Scénario A:<br>1 front d'extraction à la fois | La récupération des colis se fait sur un seul front à la fois.<br>Cinq bouchons sont créés en parallèle des opérations de récupération. Les autres travaux de confinement (création des autres bouchons) sont effectués une fois les activités de récupération achevées. | Tâches préparatoires<br>+<br>Récupération<br>+ Confinement | Option 6 |
| Scénario B:<br>2 fronts d'extraction à la fois | La récupération des colis se fait sur deux fronts en parallèle.<br>Cinq bouchons sont créés en parallèle des opérations de récupération. Les autres travaux de confinement (création des autres bouchons) sont effectués une fois les activités de récupération achevées. | Tâches préparatoires<br>+<br>Récupération<br>+ Confinement | Option 6 |
| Scénario C:<br>3 fronts d'extraction | La récupération des colis se fait sur trois fronts en parallèle ; avec une productivité moindre sur le 3ème front, en raison des possibles interférences limitantes entre les activités parallèles.<br>Cinq bouchons sont créés en parallèle des opérations de récupération. Les autres travaux de confinement (création des autres bouchons) sont effectués une fois les activités de récupération achevées. | Tâches préparatoires<br>+<br>Récupération<br>+ Confinement | Option 6 |
| Scénario D:<br>3 fronts d'extraction & optimisation des tâches en parallèle | La récupération des colis se fait sur trois fronts en parallèle.<br>La récupération des colis dans les unités de déformation vertes (voir Figure 3) peut se faire en parallèle des tâches préparatoires.<br>Cinq bouchons sont créés en parallèle des opérations de récupération (voir Figure 2). Les autres travaux de confinement (création des autres bouchons) sont effectués une fois les activités de récupération achevées. | Tâches préparatoires<br>+<br>Récupération<br>+ Confinement | Option 6 & Option 1 pour les zones sans contraintes (unités en 'vert' dans la Figure 3) |

*Tableau 2 : Scénarios identifiés en termes de parallélisation des tâches.*

# 4. Résultats des simulations

## 4.1. ÉVALUATION DES QUATRE SCÉNARIOS

Les résultats des simulations pour les quatre scénarios sont détaillés dans la Figure 19, aboutissant à des durées totales entre 7,8 et 19,4 années (incluant les activités de préparation, d'enlèvement des déchets et de confinement du site). Ces résultats ont été obtenus à partir des hypothèses suivantes :

- **tâches préparatoires :** une durée de 200 jours est estimée pour planifier les travaux préliminaires de préparation du site et pour certifier les modes opératoires (qui sont différents de ceux déjà mis en œuvre lors de l'enlèvement des déchets mercuriels). D'autres travaux sont également nécessaires en amont des opérations (e.g. préparation de l'infrastructure, acheminement des engins, etc.), ceux-ci sont estimés à 100 jours. Il est cependant admis que ces derniers peuvent débuter 50 jours avant la fin des activités de planification ;
- **contraintes logistiques :** il a été estimé que la principale contrainte logistique limitante est due à la capacité de transport du personnel, du matériel et des colis par le puits d'accès. En fixant une utilisation des infrastructures à 12 heures par jour[3] , 3 cycles de transport par heure ont été considérés comme une estimation conservatrice de la capacité du puits (5 tonnes par voyage). En outre, pour un calcul en nombre d'années, il a été fait l'hypothèse de 250 jours travaillés par an ;
- **activités de confinement :** des bouchons ou barrages en béton doivent avoir été installés conformément aux plans validés pour la fermeture définitive du site. Une analyse des plans de confinement a permis d'identifier 5 bouchons pouvant être créés en parallèle de l'enlèvement des déchets, sans perturber le système de ventilation ni les conditions d'accès et de sécurité. Les bouchons restants doivent cependant être installés une fois les activités de retrait des déchets achevées. En utilisant une estimation conservatrice, une durée supplémentaire d'environ 600 jours a été proposée pour clôturer les opérations de confinement.

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[3] L'hypothèse est un travail posté en continu sur 24 h dont la moitié est effectivement consacrée aux tâches correspondant aux processus de déstockage. Le reste du temps est consacré à des tâches annexes comme par exemple la maintenance des installations.

| | Scenario A | | | | | Scenario B | | | | | Scenario C | | | | | Scenario D | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Preperation | | | | | Preperation | | | | | Preperation | | | | | Preperation | | | | |
| | 1 'Front' at once | | | | | 2 'Fronts' at once | | | | | 3 'Fronts' at once | | | | | 3 'Fronts' at once - optimised | | | | |
| | Closure | | | | | Closure | | | | | Closure | | | | | Closure | | | | |
| used option | Option 6 | | | | | Option 6 | | | | | Option 6 | | | | | Option 6 + Option 1 | | | | |
| | Time [d] | Basic team | Retrieval team 1 | Retrieval team 2 | Retrieval team 3 | Time [d] | Basic team | Retrieval team 1 | Retrieval team 2 | Retrieval team 3 | Time [d] | Basic team | Retrieval team 1 | Retrieval team 2 | Retrieval team 3 | Time [d] | Basic team | Retrieval team 1 | Retrieval team 2 | Retrieval team 3 |
| **Preparation Phase** | | | | | | | | | | | | | | | | | | | | |
| **Detailed planning, approval and procurement + installation** | | | | | | | | | | | | | | | | | | | | |
| time [d] | 200 | 200 | *150* | | | 200 | 200 | *150* | | | 200 | 200 | *150* | | | 200 | 200 | *150* | | |
| **Preparation in underground for start of retrieval** | | | | | | | | | | | | | | | | | | | | |
| Advanced removal of 608 'green' fronts with option 1 | | | | | | | | | | | | | | | | 182 | 182 | | | |
| Parallelisation preciding step before [d] | 50 | | | | | 50 | | | | | 50 | | | | | 50 | | | | |
| time [d] | 100 | | 100 | | | 100 | | 100 | | | 100 | | 50 | **50** | | 100 | | 50 | **50** | |
| **Retrieval Phase** | | | | | | | | | | | | | | | | | | | | |
| **first 'front' [d]** | 3934 | | 3934 | | | 1920 | | 1920 | | | 1341 | | 1341 | | | 1045 | | 1045 | | |
| **second 'front' [d]** | 0 | | | | | 2014,1 | | | 2014,1 | | 1341,4 | | | 1341,4 | | 1044,7 | | | 1044,7 | |
| **third 'front' [d]** | 0 | | | | | 0 | | | | | 1251 | | | | 1390 | 983,22 | | | | 1092,5 |
| **Closure Phase** | | | | | | | | | | | | | | | | | | | | |
| **plugs no. 1 to 5 [d]** | 425 | 425 | | | | 425 | 425 | | | | 425 | 531 | | | | 425 | 531 | | | |
| **plugs no. 6 to 12 [d]** | 595 | | *595* | | | 595 | | *595* | | | 595 | | *595* | | | 595 | | *595* | | |
| ***Waste retrieval part of Teams:*** | | | 4034 | 0 | 0 | | | 2020 | 2014 | 0 | | | 1391 | 1391 | 1390 | | | 1095 | 1095 | 1092 |
| ***Retrieval time - net*** *(without planning time, post-closure process, methan and Incident risk)* | | | **16,1** | | | | | **8,1** | | | | | **5,6** | | | | | **4,4** | | |
| **Overall time without 'contingency' [d]** | | *625* | **4779** | *0* | *0* | | *625* | **2765** | *2014* | *0* | | *731* | **2136** | *1391* | *1390* | | *913* | **1840** | *1095* | *1092* |
| **[year]** | | *2,5* | **19,1** | *0,0* | *0,0* | | *2,5* | **11,1** | *8,1* | *0,0* | | *2,9* | **8,5** | *5,6* | *5,6* | | *3,7* | **7,4** | *4,4* | *4,4* |
| **Contingency calculation** | | | | | | | | | | | | | | | | | | | | |
| Number of parallel workplaces | | | 0,0 | | | | | 1,0 | | | | | 2,5 | | | | | 3,0 | | |
| assumed number of workers | | | *10* | *0* | *0* | | | *10* | *10* | *0* | | | *10* | *10* | *8* | | | *12* | *12* | *10* |
| contingency for incidents/accidents | | | 77 | | | | | 85 | | | | | 95 | | | | | 96 | | |
| contingency for methane | | | 3 | | | | | 3 | | | | | 3 | | | | | 3 | | |
| **Overall time including 'contingency' [d]** | | | **4859** | **d** | | | | **2853** | **d** | | | | **2234** | **d** | | | | **1938** | **d** | |
| **[year]** | | | **19,4** | **years** | | | | **11,4** | **years** | | | | **8,9** | **years** | | | | **7,8** | **years** | |

*Figure 19 : Résultats des quatre scénarios étudiés donnant la durée totale de récupération et de confinement en incluant les contingences éventuelles.*

Les durées estimées sont résumées dans le tableau 3, où l’impact de plusieurs types de « contingences » est également mis en évidence. En particulier, le taux d’accidents observé précédemment lors de l’enlèvement des déchets mercuriels a été adopté dans le présent calcul, même si l’implémentation des innovations techniques proposées plus haut devrait permettre d’augmenter sensiblement la sécurité du personnel. Ainsi, sur la durée totale des opérations, 3 incidents dus à la libération de méthane (équivalant à 3 journées de travail perdues) ont été prévus dans chaque scénario. Enfin, entre 77 et 96 journées de travail perdues en raison d’accidents de travail ont été considérées, ce nombre étant variable en fonction du nombre d’équipes intervenant en parallèle (équipes d’une dizaine de travailleurs par front).

Il est à noter que certaines contingences exceptionnelles n’ont pas été intégrées dans les présents calculs bien qu’elles pourraient potentiellement remettre en cause la possibilité d’achever dans de bonnes conditions les opérations de déstockage. Ces contingences exceptionnelles pourraient être par exemple un incendie de grande ampleur ou un accident mortel en début de chantier de récupération des colis dont la cause serait liée au processus et non pas aux conditions locales. Ces contingences exceptionnelles n’ont pas été prises en compte dans les calculs en raison de leur imprévisibilité en termes d’occurrence, d’intensité et d’impact.

| Durée [années] | Scénario A | Scénario B | Scénario C | Scénario D |
|---|---|---|---|---|
| Durée nette d'enlèvement | 16,1 | 8,1 | 5,6 | 4,4 |
| Durée totale sans contingences | 19,1 | 11,1 | 8,5 | 7,4 |
| Durée totale en incluant les contingences | 19,4 | 11,4 | 8,9 | 7,8 |

*Tableau 3 : Synthèse des résultats de simulation. La durée totale inclut les activités de préparation, d'enlèvement des déchets et de confinement du site.*

## 4.2. CAS D'ÉVALUATION DE LA DURÉE DU SCÉNARIO DES MDPA

Pour rappel, les MDPA avaient estimé le temps de déstockage des déchets entre 12 et 15 années en se basant sur l'expérience mercurielle, par extrapolation du temps moyen à l'ensemble des colis restants, en exploitant deux fronts d'extraction en même temps.

Afin d'évaluer cette durée, nous avons effectué une simulation en utilisant l'option de référence dans le scénario B (i.e. deux fronts de déstockage en parallèle), reproduisant ainsi les conditions les plus proches au scénario des MDPA.

Les résultats de ce calcul sont présentés ci-dessous :

- temps net du déstockage : 12,5 années ;
- temps total, y compris le confinement du site : 15,5 années ;
- temps total, y compris les contingences : 16,1 années.

On notera que le résultat des calculs des MDPA est assez proche de celui issu de notre simulation, bien que les hypothèses et les méthodes de calcul soient différentes.

## 4.3. ÉVOLUTION DES CONTRAINTES GÉOMÉCANIQUES

La convergence géomécanique se poursuivra à un rythme régulier dans les prochaines années. Ces considérations vont avoir un fort impact sur le délai restant pour extraire les déchets dans des conditions acceptables, en utilisant les options techniques détaillées dans le présent rapport.

Ainsi, dans le cas des déchets conditionnés dans des big bags (contenu en poudres ou à granularité fine, facilement compressible), il est estimé qu'un taux de compression jusqu'à environ 20 % a peu de chance d'endommager le conditionnement ou d'en altérer sa forme. La faisabilité du déstockage, sous les conditions techniques spécifiées ici, serait remise en cause à partir de taux de compression supérieurs : dans ce cas, la séparation physique des déchets et des roches de sel gemme serait très compromise avec les moyens décrits ci-dessus.

Il est à noter que même dans ce cas, l'extraction des déchets serait réalisable mais en utilisant des techniques minières, ce qui engendrerait une quantité de déchets supplémentaires estimés à 5 à 7 fois le volume actuel à extraire.

Dans le cas des colis contenus dans les zones de déformation élevée (catégorie « rouge »), une analyse temporelle est proposée pour estimer l'évolution du taux de compression des big bags en fonction de la convergence géomécanique (voir Figure 20). Des vitesses de convergence de 30 mm/an (hypothèse réaliste) à 60 mm/an (hypothèse conservatrice, quoique peu probable) sont considérées.

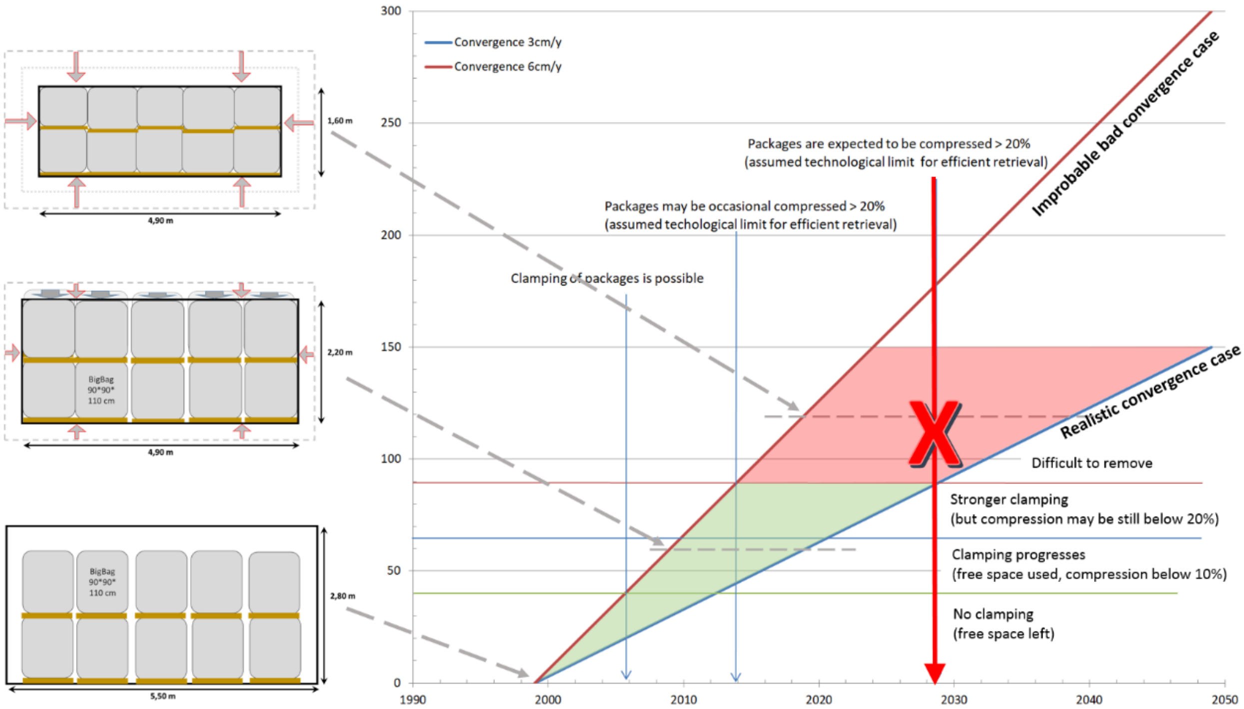


*Figure 20 : Évolution des contraintes de convergence et différentes étapes d'enclavement des colis.*

Les conclusions suivantes peuvent être tirées de cette analyse de l'évolution du site, à partir de sa date d'ouverture en 1999 :

- une partie des colis serait déjà enclavée depuis le milieu des années 2010, en admettant des vitesses de convergence élevées (2 x 30 mm/an) : le déstockage reste cependant possible tant que la réduction de l'espace de la galerie reste en dessous de 100 cm ;
- à partir de 2029 environ (avec l'hypothèse de convergence réaliste - 30 mm/an), tous les colis devraient être enclavés ;
- en prenant 20 % comme le taux maximal de compression des colis au-delà duquel les colis seraient enclavés et/ou endommagés, cette situation correspondrait à une convergence de 150 cm dans l'espace de stockage :
  - ➔ la situation resterait alors acceptable jusqu'au milieu des années 2020 environ, avec une probabilité raisonnable de succès des opérations de déstockage,
  - ➔ au-delà, le déstockage resterait tout de même possible, mais avec une efficacité réduite et des délais probablement allongés,
  - ➔ après la fin des années 2020, la poursuite des opérations de déstockage dans les fronts en catégorie « rouge » risque d'être infaisable avec les moyens techniques décrits dans ce rapport.

Remarque : La réalisation des bouchons n'est pas affectée par le délai imposé par la convergence des terrains sur le site de stockage. En effet, ces bouchons sont placés dans les galeries d'accès situées en périphérie du site. Elles sont accessibles tant que la mine est gardée ouverte et que les opérations de maintenance sont effectuées. De ce fait, la mise en place des bouchons peut aller bien au-delà de la fin des années 2020.

## 4.4. ANALYSE DE SENSIBILITÉ

Le scénario D, qui a été identifié comme le plus efficace, aboutit à une durée nette d'enlèvement des déchets de 4,4 années, en faisant l'hypothèse que 20 % des fronts dans la catégorie « rouge » (déformation élevée) présentent une majorité de colis enclavés, contre 80 % des fronts avec seulement quelques colis enclavés. Cette proportion est modifiée entre 0 % et 100 % (voir Figure 21), et les calculs de durée sont repris pour les différents cas de figures : il en ressort une variation entre - 0,3 années (réduction de la durée si 0 % de fronts systématiquement enclavés) et + 1,3 années (allongement de la durée si 100 % de fronts systématiquement enclavés).

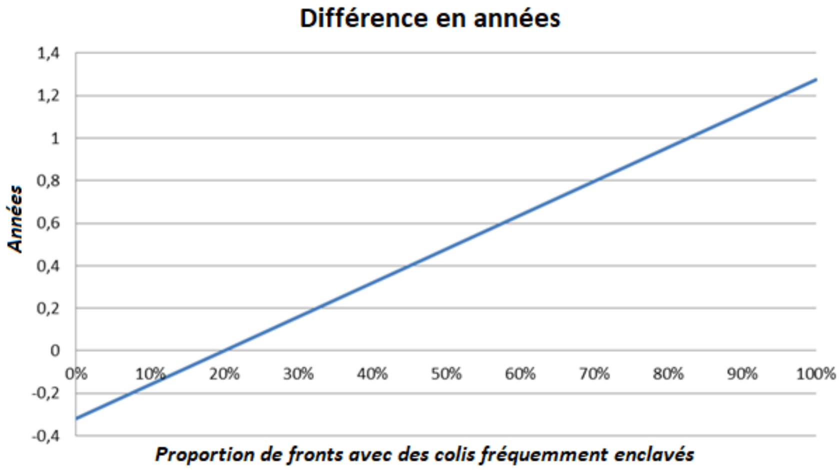


*Figure 21 : Influence de la proportion de fronts en catégorie « rouge » dont les colis seraient fréquemment ou systématiquement enclavés (hypothèse de départ = 20 %), pour le scénario D.*

D'autres paramètres peuvent faire varier la durée de déstockage, à savoir :

- effets de risques divers (e.g. effets de la convergence et progression de l'endommagement des colis), estimés à un délai supplémentaire de 1 +/- 0,25 années ;
- mesures d'optimisation du scénario D (e.g. parallélisation accrue de certaines tâches), permettant de gagner entre 5 % et 20 % du temps requis, soit 1 +/- 0,6 années.

Au final, en prenant respectivement les hypothèses minimum et maximum, la durée totale de 7,8 années peut être raisonnablement encadrée par - 1,9 années et + 2,55 années (intervalle de [5,9 - 10,4] années) ou +/- 1,9 années si l'on exclue l'incertitude sur la réalisation des bouchons. Ces résultats sont reportés dans le chronogramme prévisionnel des tâches de la figure 22, et confrontés aux échéances vraisemblablement imposées par les contraintes géomécaniques.

Il est à noter que l'évolution du taux de convergence dans le temps ne peut pas être déterminée avec précision. Seule une fenêtre de temps à partir de laquelle les risques liés à la convergence deviennent préoccupants peut être avancée. Le seul point de certitude est que ces risques augmentent avec le temps et menacent donc d'avoir un impact sur le délai de la fermeture.

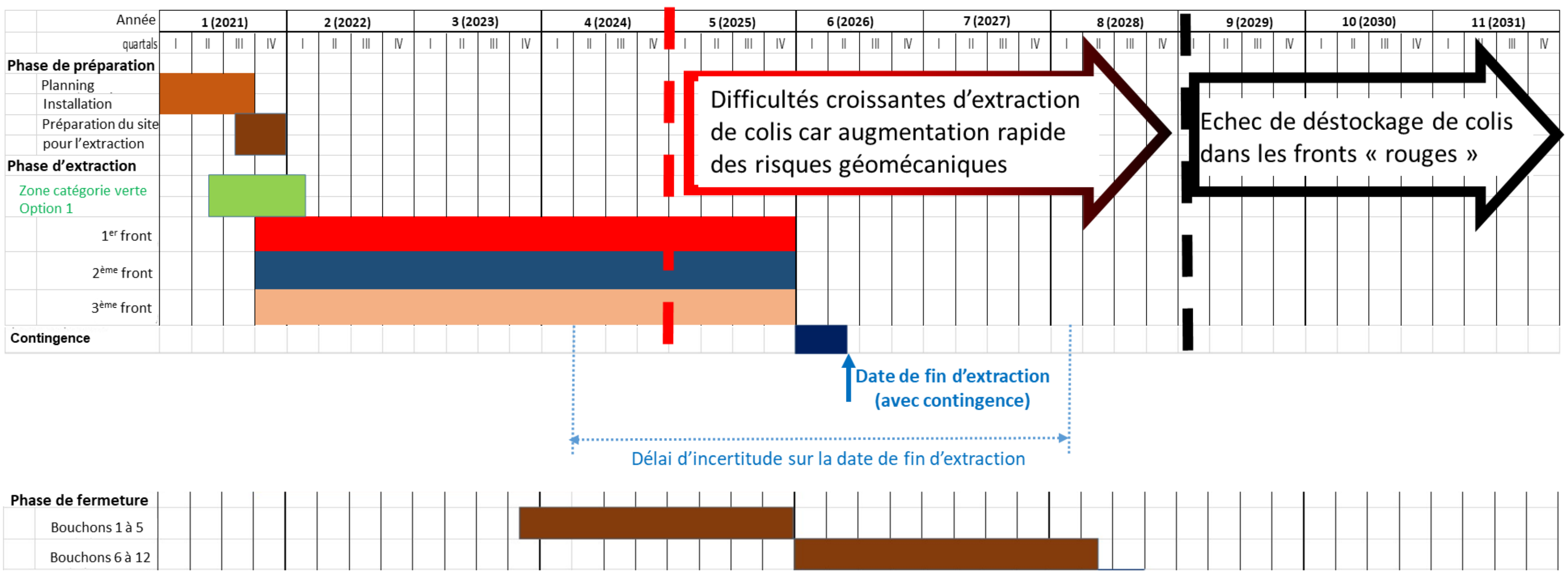


*Figure 22 : Durée totale estimée pour le scénario D en incluant les incertitudes, et les échéances liées aux risques géomécaniques.*

Remarque : La date du début des opérations est fixée au 1er janvier 2021, en supposant un délai de deux ans pour les démarches administratives et décisionnelles à partir du 1er janvier 2019.

## 4.5. BESOIN EN EFFECTIFS

Pour la réalisation des opérations de déstockage une estimation rapide des besoins en main-d'œuvre basée sur l'expérience acquise sur des sites miniers et des activités comparables a été réalisée (tableau 4). En tant que tels, les chiffres présentés peuvent être utilisés comme une indication qu'il faudra affiner lors de la phase de conception des opérations de récupération.

| Opération | Nombre de personnes |
|---|---|
| Opérations de la maintenance de la mine :<br>Minimum: 25 travailleurs avec supervision<br>Maximum: 48 travailleurs (supervision incluse) | 48 |
| Opérations d'extraction des déchets<br>3 équipes par shift | 100 |
| Mise en place des bouchons | 20 |
| Opérations de transport et chargement du puits | 9 |
| Total | 177 |
| Contingence (20 %) | 35 |
| Estimation total | **212** |

*Tableau 4 : Évaluation des effectifs.*

Cette estimation rapide de la main-d'œuvre a été effectuée pour le scénario D. Elle est valable pour la première période de récupération qui durera approximativement 5 ans. Les besoins seront réduits de moitié en phase de fermeture post-déstockage, soit environ 100 personnes.

## 4.6. INSTALLATIONS EN SURFACE

La question des installations en surface n'a pas été intégrée dans le calcul de la durée du déstockage et de la fermeture du site, en raison notamment des inconnues entourant les perspectives de réexpédition et de restockage des déchets vers d'autres sites. À ce titre, la gestion des colis en surface n'est pas incluse dans les processus formant le chemin critique, en faisant l'hypothèse que ces tâches de reconditionnement et d'entreposage pourraient être effectuées en parallèle des activités souterraines.

Il convient cependant de prendre conscience, dès à présent, des contraintes et des choix techniques qui devraient entourer la logistique des colis remontés du fond vers la surface. L'organisation en surface doit impérativement prendre en compte les éléments suivants :

- certains colis ne peuvent pas être entreposés ensemble en raison de la présence de différentes classes et types de déchets ;
- le(s) site(s) de restockage final pourraient varier en fonction de la classe et du type des déchets ;
- un intervalle de temps significatif est à prévoir entre l'arrivée des colis à la surface et leur transport vers le(s) site(s) de restockage final.

En tenant compte de l'incertitude autour des procédures de restockage, les éléments d'infrastructure en surface doivent être pris en compte (voir Figure 23) :

1. zone-tampon près du puits d'accès (dans le Bâtiment d'Exploitation), pour assurer les opérations suivantes :
    - contrôle des colis par pesée (si nécessaire),
    - enregistrement des colis dans une base de données, documentation,
    - fixation d'un code-barres ou d'une étiquette de traçabilité sur chaque colis,
    - marquage de chaque colis suivant la signalétique ADR ;
2. itinéraire dédié de transfert vers le bâtiment d'entreposage temporaire :
    - nécessité d'assurer un transfert sûr et direct des colis ;
3. bâtiment d'entreposage temporaire, à ériger sur le périmètre des MDPA (ou requalification de bâtiments existants avec installation d'un système de ventilation adéquat et amélioration des mesures de sécurité) :
    - une attention toute particulière devra être portée à l'obtention des autorisations administratives, qui diffèrent selon le lieu de dépôt de déchets sous terre ou en surface,
    - un réarrangement des colis doit rester possible à tout moment notamment pour des raisons de sécurité (organisation logistique flexible) : pas de système FIFO (First In First Out) ou LIFO (Last In First Out),
    - prévoir une surface au sol suffisante, par ex. 10 000 ou 15 000 m$^2$ pour environ une année d'activités de déstockage,
    - un espace suffisant doit être prévu pour gérer et séparer plusieurs classes et types de déchets,
    - un reconditionnement spécifique en surface doit être réalisé. Un espace suffisant doit être prévu pour un suremballage nécessaire à l'entreposage des colis et au transport routier (par ex. dans des containers aux normes ISO),
    - des systèmes de ventilation et de purification de l'air (production de déchets secondaires) doivent être installés,
    - prévoir des mesures de sécurité contre les intrusions (effraction) ou les événements extérieurs (incendie, tempête, foudre, collision de véhicules, inondations, séismes, etc.).

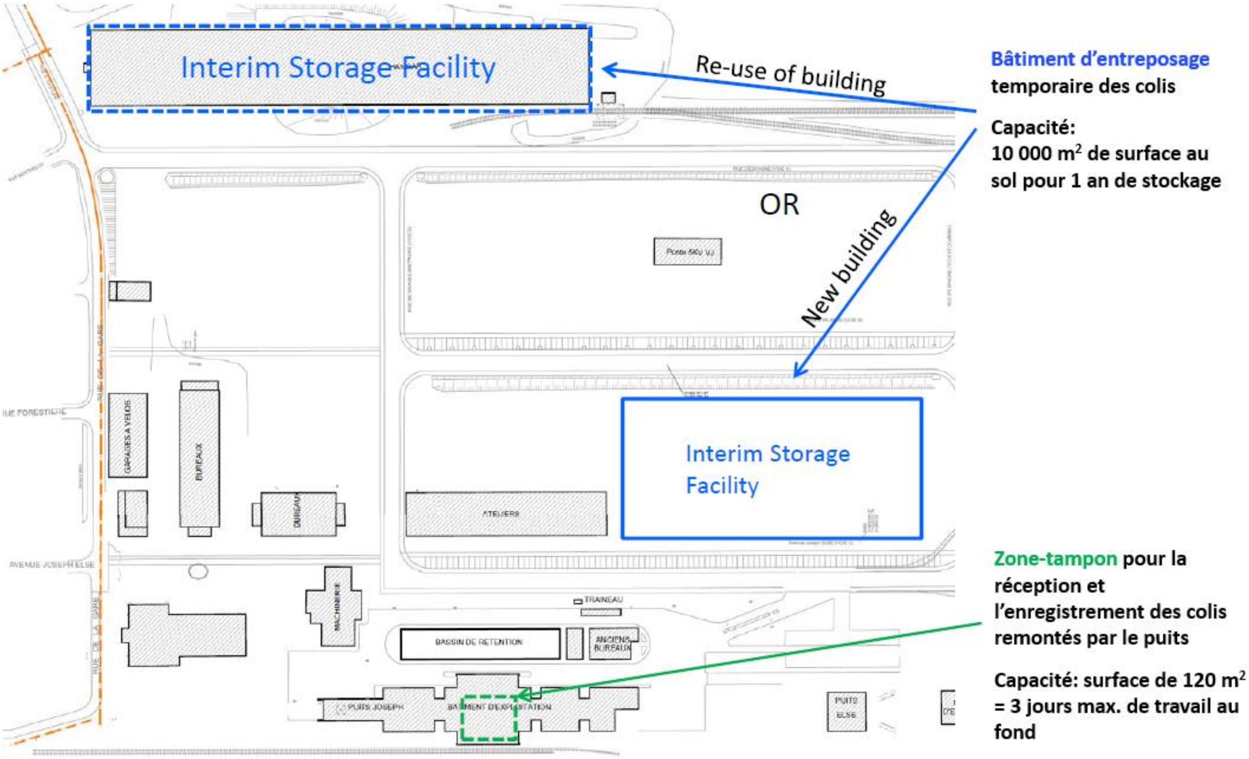


*Figure 23 : Scénarios possibles d'installations en surface pour le stockage temporaire des colis avant réexpédition.*

# 5. Conclusions

Le présent rapport d'expertise, établi par le BRGM notamment à partir de la contribution de plusieurs experts internationaux, a mis en évidence la faisabilité des opérations de déstockage hors bloc incendié et de fermeture du site de Stocamine tout en assurant, dans la mesure du possible la sécurité du personnel, du site et la préservation de l'environnement. La durée de ces opérations a été estimée au mieux à 7,8 années jusqu'à la fermeture définitive du site, suivant un des scénarios évalués (le scénario D, basé sur l'exploitation de 3 fronts d'extraction en parallèle).

Ce résultat a cependant été obtenu sur la base de plusieurs hypothèses qui peuvent rapidement s'avérer très contraignantes. **Si l'option du déstockage hors bloc incendié est retenue, il est impératif, en raison de la convergence géomécanique continue des galeries, de démarrer les démarches préparatoires au plus vite, au risque que les délais annoncés ne puissent plus être respectés.** Ainsi, la phase de préparation des travaux ne devrait pas être repoussée au-delà du début 2021.

La durée estimée de 7,8 années ne comprend pas les délais relatifs aux éléments suivants :

- les processus décisionnels aboutissant à la solution opérationnelle qui sera à mettre en œuvre ;
- les démarches administratives préalables qui seront nécessaires à réaliser avant la mise en œuvre du déstockage (obtention des différentes autorisations de travaux, transports de déchets vers un nouveau site à définir, …) ;
- les procédures de marchés publics pour la détermination des entreprises qui mettront en œuvre le déstockage (marchés de maitrise d'œuvre, de travaux, de transports, …).

Par ailleurs, le scénario D préconisé dans le présent rapport correspond à une solution techniquement ambitieuse qui requiert des (ré)aménagements lourds et couteux :

- nécessité de procéder à un renouvellement quasi intégral des équipements mécaniques ;
- nécessité de mettre en œuvre une préparation technique et une formation adéquate du personnel, qui devra être amené à intervenir dans des conditions difficiles ;
- nécessité de mettre en place, en amont, une organisation du travail et une gestion des postes en accord avec les options techniques préconisées : la mise en place de trois fronts d'extraction en parallèle présente un défi logistique de taille, sensible à des dérives potentielles en termes de gestion du temps.

Le restockage des déchets extraits est une autre contrainte majeure qui n'a pas été étudiée par la présente expertise mais qui constitue une condition nécessaire pour le déstockage. En effet, le niveau de dangerosité de ces déchets est incomparablement plus élevé en surface.

Enfin, dans la perspective d'un déstockage hors bloc incendié, une solution alternative - sur laquelle l'ensemble des experts consultés semblent converger - pourrait consister en un déstockage partiel du site. Les déchets sans capacité de dissolution dans l'eau ou dans la saumure, tels que les cendres volantes (déjà utilisées pour combler les puits aux MDPA) et l'amiante, pourraient ainsi être laissés au fond et confinés par les bouchons en béton. Ce type de déchets représente environ 75 % des colis restants. Bien que la durée de déstockage sera sensiblement identique, eu égard au fait que les déchets solubles sont éparpillés au sein du stockage, cette solution a l'avantage de réduire considérablement les contraintes et les risques en surface listées au chapitre 4.6, par la simple réduction des volumes de déchets à traiter et à restocker.

# Annexe 1

# Déclarations de liens d'intérêts

**brgm** | *Déclaration d'intérêts institutionnels*

Je soussignée : Madame Michèle ROUSSEAU........................................

Agissant en qualité de : Présidente-Directrice générale du BRGM.

Réf. de l'expertise : Stocamine : Avis sur le délai nécessaire à un déstockage total des déchets (hors bloc incendié).

Demandeur : Ministère de la Transition Ecologique et Solidaire / Direction Générale de la Prévention des Risques.

Considère, dans le cadre du devoir de déclaration des liens d'intérêt du BRGM avec une partie prenante ou avec l'objet de l'expertise citée en référence ci-dessus, devoir déclarer les liens ci-après mentionnés.

Je m'engage à actualiser cette déclaration dès qu'une modification interviendra concernant ces liens ou que de nouveaux liens sont noués pendant la durée de l'expertise.

| Lien d'intérêt | Commentaires |
|---|---|
| Un lien d'intérêt institutionnel entre le BRGM et Stocamine (client du BRGM) | Le BRGM a été amené à conduire par le passé une étude pour Stocamine. Cette étude (rapport RP-60256-FR) réalisée en 2011 consistait à modéliser une fuite de saumure à partir du site de stockage souterrain de StocaMine (simulation d'un 5ème scénario). L'objectif était de déterminer, à l'échelle régionale, le devenir de ces saumures dans la nappe alluviale en simulant l'extension du panache de pollution à moyen terme (100 ans), long terme (1000 ans) et très long terme (10 000 ans). L'objet de l'expertise demandée par la DGPR en avril 2018 est sans rapport avec le sujet de l'étude réalisée en 2011 pour Stocamine. |
| Un lien d'intérêt institutionnel entre le BRGM et les MDPA (client du BRGM) | Le BRGM a été amené à assurer la surveillance au titre de l'après-mine d'anciens sites miniers pour le compte de l'Etat mais certains d'entre eux avaient les MDPA comme ancien exploitant par le passé. Cette activité n'a pas engendré de relation contractuelle entre le BRGM et les MDPA. |
| Un lien d'intérêt institutionnel entre le BRGM et Charbonnage de France (Alain Rollet DGD) | Lors de la préfiguration de l'organisation opérationnelle de la mission « après-mine », confiée par l'Etat au BRGM, le BRGM, était en contact étroit avec Alain Rollet DGD de CdF en charge de la liquidation de l'entreprise minière. L'objet de ce contact étroit étant sans lien avec le stockage Stocamine. |
| Un lien d'intérêt personnel pour Pierre Toulhoat, actuel DGD du BRGM | Pierre Toulhoat, a été contributeur d'un rapport scientifique sur l'évaluation du terme source à une période où il était salarié de l'INERIS. Pierre Toulhoat sera tenu à l'écart des circuits de décision et de production du BRGM pour cette expertise. |
| Un lien d'intérêt personnel pour certains agents de l'ANGDM mis à disposition du DPSM | Certains salariés actuellement mis à disposition au BRGM par l'ANGDM étaient placés sous l'autorité hiérarchique d'Alain Rollet (actuel dirigeant de Stocamine) lorsqu'ils étaient salariés de Charbonnages de France. Ces salariés ANGDM seront |

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**brgm** | *Déclaration d'intérêts institutionnels*

| | |
|---|---|
| | tenus à l'écart des circuits de décision et de production du BRGM pour cette expertise. |

| | |
|---|---|
| *Michèle Rousseau* | *11 juin 2018* |
| *Signature* | *date* |

Dans la charte de l'expertise du BRGM, l'établissement s'engage à *« informer les parties prenantes d'une expertise des liens éventuels pouvant exister entre le sujet de l'expertise ou le demandeur d'une part et les intervenants BRGM d'autre part, susceptibles de compromettre leur neutralité. »*

En vertu de l'article 2 de la loi n° 2013-907 du 11 décembre 2013, constitue un lien d'intérêts toute situation d'interférence entre un intérêt public et des intérêts publics ou privés qui est de nature à influencer ou paraître influencer l'exercice indépendant et objectif d'une fonction.

Pour éviter que les liens d'intérêt institutionnels du BRGM ne risquent de conduire à des conflits d'intérêts, le BRGM choisit la transparence avec les parties prenantes concernées. La déclaration d'intérêt a pour but d'assurer cette transparence.

La déclaration est faite sous la responsabilité de Madame Michèle ROUSSEAU, Présidente-Directrice générale du BRGM, avec une copie au chargé de mission expertise et déontologie qui en assure l'archivage.

Exemples de liens d'intérêts :

- Tous types de contrats ou conventions (commercial, partenariat, prestation,…),
- Participation au capital,
- Participation à la gouvernance,
- Détention de brevets ou de licences,
- …

Situations concernées : expertises.

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**brgm** | *Déclaration d'intérêts pour acteurs expertise*

Je soussigné : Philippe Sabourault........affectation : BRGM/DRP/DPSM........ reconnais avoir pris connaissance de l'**obligation de déclarer tout lien d'intérêt** (cf verso) **avec une partie prenante du BRGM** (entreprise, établissement, collectivité, administration, association, ONG, société savante ou organisme dont les activités, les techniques et les produits entrent dans le champ de compétence du BRGM) **ou avec l'objet de l'expertise citée en référence ci-dessous dans le cadre de sa réalisation.**

Je m'engage à actualiser cette déclaration dès qu'une modification intervient concernant ces liens ou que de nouveaux liens sont noués pendant la durée de l'expertise.

Je renseigne cette déclaration en qualité de : Chef de projet BRGM de l'expertise Stocamine.

Réf. de l'expertise : Délai mis en avant par les Mines De Potasse d'Alsace (MDPA) de l'ordre de 15 ans nécessaire à un déstockage total des déchets (hors bloc incendié)........

Demandeur : Ministère de la Transition Ecologique et Solidaire / Direction Générale de la Prévention des Risques........

| Lien d'intérêt | Oui | Description |
|---|---|---|
| Participation à des travaux de conception ou de réalisation du projet/dossier objet de l'expertise. | ☐ | *Nature des travaux, bénéficiaire, date :* |
| Participation à des études ou travaux. | ☐ | *Nature des travaux, bénéficiaire, date :* |
| Participation financière dans le capital d'une société (> 5000€). | ☐ | *Société-Etablissement-Organisme, valeurs mobilières hors SICAV ou FCP :* |
| Participation à la gouvernance. | ☐ | *Société-Etablissement-Organisme, fonction, nature du contrat, dates de début et de fin :* |
| Activité de prestation intellectuelle entrant dans le champ de compétences du BRGM. | ☐ | *Société-Etablissement-Organisme, nature de l'activité, rémunérée ou non, dates de début et de fin :* |
| Mandat électif, participation à des groupes d'intérêt, sociétés prof. ou savantes, médias, ONG, congrès-conférences. | ☐ | *Dénomination, nature de la participation, dates de début et de fin :* |
| Propriété intellectuelle. | ☐ | *Identification du brevet, produit, procédé, rémunération perçue :* |
| Proches possédant des intérêts financiers ou intellectuels dans une entreprise ou organisme. | ☐ | *Société-Etablissement-Organisme, fonction, lien de parenté, dates de début et de fin :* |
| Autre lien d'intérêt. | ☐ | *Préciser la nature.* |
| Si vous n'avez aucun lien d'intérêt (cad aucun item renseigné), cochez la case ci-après : ☒ | | |

[signature] — *2 mai 2018*

*Signature du salarié* — *date*

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**brgm** | *Déclaration d'intérêts pour acteurs expertise*

Dans la charte de l'expertise du BRGM, l'établissement s'engage à *« informer les parties prenantes d'une expertise des liens éventuels pouvant exister entre le sujet de l'expertise ou le demandeur d'une part et les intervenants BRGM d'autre part, susceptibles de compromettre leur neutralité. »*

En vertu de l'article 2 de la loi n° 2013-907 du 11 décembre 2013, constitue un lien d'intérêts toute situation d'interférence entre un intérêt public et des intérêts publics ou privés qui est de nature à influencer ou paraître influencer l'exercice indépendant et objectif d'une fonction.

Article 9.3 du Règlement Intérieur du BRGM sur les liens d'intérêts :

> 9.3.1 Les salariés mandatés par le BRGM pour la réalisation de missions ou de travaux, notamment dans le domaine de l'expertise, sont tenus d'éviter tout conflit d'intérêts qu'ils pourraient avoir avec des engagements ou des activités externes à l'entreprise. Si une telle situation venait à se présenter, ils devraient en informer leur hiérarchie afin de mettre en œuvre une solution adaptée à la situation en cause.
>
> 9.3.2 Quelles que soient ses fonctions, un salarié ne peut posséder dans une entreprise en relation d'affaires avec le BRGM des intérêts de nature à compromettre son indépendance, que ce soit par lui-même, par personne interposée et y compris par le moyen de titre miniers.
>
> 9.3.3 Le salarié qui possède, avant son engagement, des intérêts dans une entreprise telle que visée ci-dessus, doit en faire la déclaration préalable auprès de la direction générale. Sauf interdiction formelle, son engagement par le BRGM vaut alors autorisation de conserver lesdits intérêts.
>
> 9.3.4 De même, le salarié qui vient au cours de la durée de sont contrat de travail, à détenir des intérêts dans une entreprise en relation d'affaires avec le BRGM, doit en faire la déclaration auprès de la direction générale. Celle-ci propose alors des délais et des mesures compatibles avec les intérêts de l'établissement, en vue de régulariser la situation de l'intéressé.

Pour éviter que les liens d'intérêt de salariés participant à certaines activités du BRGM ne conduisent à des conflits d'intérêts pour ces activités, ces liens doivent être transparents pour le BRGM et les parties prenantes concernées.

La déclaration d'intérêt a pour but d'assurer cette transparence. Si un salarié du BRGM est sollicité pour intervenir sur un projet ou une expertise dans lequel il aurait un lien d'intérêt direct ou indirect, il appartient à son responsable hiérarchique de déterminer les conditions qui rendraient sa participation acceptable dans le respect des règles déontologiques, ou si cette situation l'empêche d'accomplir cette mission

Pour remplir les différentes rubriques de la présente déclaration d'intérêt, il convient de préciser toutes les activités exercées au cours des 5 dernières années entrant dans le champ de compétence du BRGM.

La déclaration est faite loyalement sous la responsabilité du salarié déclarant, elle est remise à son responsable hiérarchique, avec une copie au chargé de mission expertise et déontologie qui en assure l'archivage.

Salariés concernés : salariés chargés de la réalisation d'expertises.

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**brgm** | *Déclaration d'intérêts pour acteurs expertise*

Je soussigné : Behrooz Bazargan-Sabet................................affectation : BRGM/DRP..............
reconnais avoir pris connaissance de l'**obligation de déclarer tout lien d'intérêt** (cf verso) **avec une partie prenante du BRGM** (entreprise, établissement, collectivité, administration, association, ONG, société savante ou organisme dont les activités, les techniques et les produits entrent dans le champ de compétence du BRGM) **ou avec l'objet de l'expertise citée en référence ci-dessous dans le cadre de sa réalisation.**

Je m'engage à actualiser cette déclaration dès qu'une modification intervient concernant ces liens ou que de nouveaux liens sont noués pendant la durée de l'expertise.

Je renseigne cette déclaration en qualité de : Chef des experts mobilisés pour le dossier BRGM d'expertise Stocamine.......

Réf. de l'expertise : Délai mis en avant par les Mines De Potasse d'Alsace (MDPA) de l'ordre de 15 ans nécessaire à un déstockage total des déchets (hors bloc incendié)..................

Demandeur : Ministère de la Transition Ecologique et Solidaire / Direction Générale de la Prévention des Risques..........................................................................................

| Lien d'intérêt | Oui | Description |
|---|---|---|
| Participation à des travaux de conception ou de réalisation du projet/dossier objet de l'expertise. | ☐ | *Nature des travaux, bénéficiaire, date :* |
| Participation à des études ou travaux. | ☐ | *Nature des travaux, bénéficiaire, date :* |
| Participation financière dans le capital d'une société (> 5000€). | ☐ | *Société-Etablissement-Organisme, valeurs mobilières hors SICAV ou FCP :* |
| Participation à la gouvernance. | ☐ | *Société-Etablissement-Organisme, fonction, nature du contrat, dates de début et de fin :* |
| Activité de prestation intellectuelle entrant dans le champ de compétences du BRGM. | ☐ | *Société-Etablissement-Organisme, nature de l'activité, rémunérée ou non, dates de début et de fin :* |
| Mandat électif, participation à des groupes d'intérêt, sociétés prof. ou savantes, médias, ONG, congrès-conférences. | ☐ | *Dénomination, nature de la participation, dates de début et de fin :* |
| Propriété intellectuelle. | ☐ | *Identification du brevet, produit, procédé, rémunération perçue :* |
| Proches possédant des intérêts financiers ou intellectuels dans une entreprise ou organisme. | ☐ | *Société-Etablissement-Organisme, fonction, lien de parenté, dates de début et de fin :* |
| Autre lien d'intérêt. | ☐ | *Préciser la nature.* |
| Si vous n'avez aucun lien d'intérêt (cad aucun item renseigné), cochez la case ci-après : ☒ | | |

*Signature du salarié* | *2 mai 2018* *date*

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**brgm** | *Déclaration d'intérêts pour acteurs expertise*

Dans la charte de l'expertise du BRGM, l'établissement s'engage à *« informer les parties prenantes d'une expertise des liens éventuels pouvant exister entre le sujet de l'expertise ou le demandeur d'une part et les intervenants BRGM d'autre part, susceptibles de compromettre leur neutralité. »*

En vertu de l'article 2 de la loi n° 2013-907 du 11 décembre 2013, constitue un lien d'intérêts toute situation d'interférence entre un intérêt public et des intérêts publics ou privés qui est de nature à influencer ou paraître influencer l'exercice indépendant et objectif d'une fonction.

Article 9.3 du Règlement Intérieur du BRGM sur les liens d'intérêts :

> 9.3.1 Les salariés mandatés par le BRGM pour la réalisation de missions ou de travaux, notamment dans le domaine de l'expertise, sont tenus d'éviter tout conflit d'intérêts qu'ils pourraient avoir avec des engagements ou des activités externes à l'entreprise. Si une telle situation venait à se présenter, ils devraient en informer leur hiérarchie afin de mettre en œuvre une solution adaptée à la situation en cause.
>
> 9.3.2 Quelles que soient ses fonctions, un salarié ne peut posséder dans une entreprise en relation d'affaires avec le BRGM des intérêts de nature à compromettre son indépendance, que ce soit par lui-même, par personne interposée et y compris par le moyen de titre miniers.
>
> 9.3.3 Le salarié qui possède, avant son engagement, des intérêts dans une entreprise telle que visée ci-dessus, doit en faire la déclaration préalable auprès de la direction générale. Sauf interdiction formelle, son engagement par le BRGM vaut alors autorisation de conserver lesdits intérêts.
>
> 9.3.4 De même, le salarié qui vient au cours de la durée de sont contrat de travail, à détenir des intérêts dans une entreprise en relation d'affaires avec le BRGM, doit en faire la déclaration auprès de la direction générale. Celle-ci propose alors des délais et des mesures compatibles avec les intérêts de l'établissement, en vue de régulariser la situation de l'intéressé.

Pour éviter que les liens d'intérêt de salariés participant à certaines activités du BRGM ne conduisent à des conflits d'intérêts pour ces activités, ces liens doivent être transparents pour le BRGM et les parties prenantes concernées.

La déclaration d'intérêt a pour but d'assurer cette transparence. Si un salarié du BRGM est sollicité pour intervenir sur un projet ou une expertise dans lequel il aurait un lien d'intérêt direct ou indirect, il appartient à son responsable hiérarchique de déterminer les conditions qui rendraient sa participation acceptable dans le respect des règles déontologiques, ou si cette situation l'empêche d'accomplir cette mission

Pour remplir les différentes rubriques de la présente déclaration d'intérêt, il convient de préciser toutes les activités exercées au cours des 5 dernières années entrant dans le champ de compétence du BRGM.

La déclaration est faite loyalement sous la responsabilité du salarié déclarant, elle est remise à son responsable hiérarchique, avec une copie au chargé de mission expertise et déontologie qui en assure l'archivage.

Salariés concernés : salariés chargés de la réalisation d'expertises.

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**brgm** | *Déclaration d'intérêts pour acteurs expertise*

Je soussigné : Pierre Gehl.......................................affectation : BRGM/DRP/RSV...............
reconnais avoir pris connaissance de l'**obligation de déclarer tout lien d'intérêt** (cf verso) **avec une partie prenante du BRGM** (entreprise, établissement, collectivité, administration, association, ONG, société savante ou organisme dont les activités, les techniques et les produits entrent dans le champ de compétence du BRGM) **ou avec l'objet de l'expertise citée en référence ci-dessous dans le cadre de sa réalisation.**

Je m'engage à actualiser cette déclaration dès qu'une modification intervient concernant ces liens ou que de nouveaux liens sont noués pendant la durée de l'expertise.

Je renseigne cette déclaration en qualité de : ingénieur BRGM de l'expertise Stocamine.

Réf. de l'expertise : Délai mis en avant par les Mines De Potasse d'Alsace (MDPA) de l'ordre de 15 ans nécessaire à un déstockage total des déchets (hors bloc incendié)...................

Demandeur : Ministère de la Transition Ecologique et Solidaire / Direction Générale de la Prévention des Risques.......................................................................................

| Lien d'intérêt | Oui | Description |
|---|---|---|
| Participation à des travaux de conception ou de réalisation du projet/dossier objet de l'expertise. | ☐ | *Nature des travaux, bénéficiaire, date :* |
| Participation à des études ou travaux. | ☐ | *Nature des travaux, bénéficiaire, date :* |
| Participation financière dans le capital d'une société (> 5000€). | ☐ | *Société-Etablissement-Organisme, valeurs mobilières hors SICAV ou FCP :* |
| Participation à la gouvernance. | ☐ | *Société-Etablissement-Organisme, fonction, nature du contrat, dates de début et de fin :* |
| Activité de prestation intellectuelle entrant dans le champ de compétences du BRGM. | ☐ | *Société-Etablissement-Organisme, nature de l'activité, rémunérée ou non, dates de début et de fin :* |
| Mandat électif, participation à des groupes d'intérêt, sociétés prof. ou savantes, médias, ONG, congrès-conférences. | ☐ | *Dénomination, nature de la participation, dates de début et de fin :* |
| Propriété intellectuelle. | ☐ | *Identification du brevet, produit, procédé, rémunération perçue :* |
| Proches possédant des intérêts financiers ou intellectuels dans une entreprise ou organisme. | ☐ | *Société-Etablissement-Organisme, fonction, lien de parenté, dates de début et de fin :* |
| Autre lien d'intérêt. | ☐ | *Préciser la nature.* |
| Si vous n'avez aucun lien d'intérêt (cad aucun item renseigné), cochez la case ci-après : ☒ | | |

*Signature du salarié* — *11 juin 2018* — *date*

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**brgm** | *Déclaration d'intérêts pour acteurs expertise*

Dans la charte de l'expertise du BRGM, l'établissement s'engage à *« informer les parties prenantes d'une expertise des liens éventuels pouvant exister entre le sujet de l'expertise ou le demandeur d'une part et les intervenants BRGM d'autre part, susceptibles de compromettre leur neutralité. »*

En vertu de l'article 2 de la loi n° 2013-907 du 11 décembre 2013, constitue un lien d'intérêts toute situation d'interférence entre un intérêt public et des intérêts publics ou privés qui est de nature à influencer ou paraître influencer l'exercice indépendant et objectif d'une fonction.

Article 9.3 du Règlement Intérieur du BRGM sur les liens d'intérêts :

> 9.3.1 Les salariés mandatés par le BRGM pour la réalisation de missions ou de travaux, notamment dans le domaine de l'expertise, sont tenus d'éviter tout conflit d'intérêts qu'ils pourraient avoir avec des engagements ou des activités externes à l'entreprise. Si une telle situation venait à se présenter, ils devraient en informer leur hiérarchie afin de mettre en œuvre une solution adaptée à la situation en cause.
>
> 9.3.2 Quelles que soient ses fonctions, un salarié ne peut posséder dans une entreprise en relation d'affaires avec le BRGM des intérêts de nature à compromettre son indépendance, que ce soit par lui-même, par personne interposée et y compris par le moyen de titre miniers.
>
> 9.3.3 Le salarié qui possède, avant son engagement, des intérêts dans une entreprise telle que visée ci-dessus, doit en faire la déclaration préalable auprès de la direction générale. Sauf interdiction formelle, son engagement par le BRGM vaut alors autorisation de conserver lesdits intérêts.
>
> 9.3.4 De même, le salarié qui vient au cours de la durée de sont contrat de travail, à détenir des intérêts dans une entreprise en relation d'affaires avec le BRGM, doit en faire la déclaration auprès de la direction générale. Celle-ci propose alors des délais et des mesures compatibles avec les intérêts de l'établissement, en vue de régulariser la situation de l'intéressé.

Pour éviter que les liens d'intérêt de salariés participant à certaines activités du BRGM ne conduisent à des conflits d'intérêts pour ces activités, ces liens doivent être transparents pour le BRGM et les parties prenantes concernées.

La déclaration d'intérêt a pour but d'assurer cette transparence. Si un salarié du BRGM est sollicité pour intervenir sur un projet ou une expertise dans lequel il aurait un lien d'intérêt direct ou indirect, il appartient à son responsable hiérarchique de déterminer les conditions qui rendraient sa participation acceptable dans le respect des règles déontologiques, ou si cette situation l'empêche d'accomplir cette mission

Pour remplir les différentes rubriques de la présente déclaration d'intérêt, il convient de préciser toutes les activités exercées au cours des 5 dernières années entrant dans le champ de compétence du BRGM.

La déclaration est faite loyalement sous la responsabilité du salarié déclarant, elle est remise à son responsable hiérarchique, avec une copie au chargé de mission expertise et déontologie qui en assure l'archivage.

Salariés concernés : salariés chargés de la réalisation d'expertises.

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**brgm** | *Déclaration d'intérêts institutionnels*

Je soussigné-e : Agustín Montes Antón affectation : Directeur Général

Agissant en qualité de : Représentant de Fundación General de la Universidad Politécnica de Madrid- LOM

Réf. de l'expertise : Stocamine

Demandeur : BRGM

Considère, dans le cadre du devoir de déclaration des liens d'intérêt du BRGM avec une partie prenante ou avec l'objet de l'expertise citée en référence ci-dessus, devoir déclarer les liens ci-après mentionnés.

Je m'engage à actualiser cette déclaration dès qu'une modification interviendra concernant ces liens ou que de nouveaux liens sont noués pendant la durée de l'expertise.

| Lien d'intérêt | Commentaires |
|---|---|
| Néant | |

*2018-09-26*

Dans la charte de l'expertise du BRGM, l'établissement s'engage à *« informer les parties prenantes d'une expertise des liens éventuels pouvant exister entre le sujet de l'expertise ou le demandeur d'une part et les intervenants BRGM d'autre part, susceptibles de compromettre leur neutralité. »*

En vertu de l'article 2 de la loi n° 2013-907 du 11 décembre 2013, constitue un lien d'intérêts toute situation d'interférence entre un intérêt public et des intérêts publics ou privés qui est de nature à influencer ou paraître influencer l'exercice indépendant et objectif d'une fonction.

Pour éviter que les liens d'intérêt institutionnels du BRGM ne risquent de conduire à des conflits d'intérêts, le BRGM choisit la transparence avec les parties prenantes concernées. La déclaration d'intérêt a pour but d'assurer cette transparence.

La déclaration est faite sous la responsabilité du manager du chef de projet ou du responsable de l'expertise, avec une copie au chargé de mission expertise et déontologie qui en assure l'archivage.

Exemples de liens d'intérêts :
- Tous types de contrats ou conventions (commercial, partenariat, prestation,…),
- Participation au capital,
- Participation à la gouvernance,
- Détention de brevets ou de licences,
- …

Situations concernées : expertises.

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2018.09.26 12:28:50 +02'00'

*IM 362_INST version 5 avril 2016*

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**brgm** | *Déclaration d'intérêts institutionnels*

Je soussigné-e : Jens-Peter Lux affectation : CEO

Agissant en qualité de : Représentant de DMT GmbH & Co.KG, Essen, Allemange

Réf. de l'expertise : Expertise sur retrait (partiel) de déchets N°HADRP180528 (Stocamine)

Demandeur : BRGM – Prof. Behrooz BAZARGAN SABET

Considère, dans le cadre du devoir de déclaration des liens d'intérêt du BRGM avec une partie prenante ou avec l'objet de l'expertise citée en référence ci-dessus, devoir déclarer les liens ci-après mentionnés.

Je m'engage à actualiser cette déclaration dès qu'une modification interviendra concernant ces liens ou que de nouveaux liens sont noués pendant la durée de l'expertise.

| Lien d'intérêt | Commentaires |
| --- | --- |
| Néant: Notre expertise pour le BRGM est préparée indépendamment, sans aucun conflit d'intérêt concernant StocaMine (opéré par MDPA) et leurs activités | |

| | |
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| [signature] | 27.09.2018 |
| [signature] | 27.09.2018 |
| *Signature and stamp* | *date* |

DMT GmbH & Co. KG
Am Technologiepark 1
45307 Essen

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**brgm** | *Déclaration d'intérêts institutionnels*

Dans la charte de l'expertise du BRGM, l'établissement s'engage à *« informer les parties prenantes d'une expertise des liens éventuels pouvant exister entre le sujet de l'expertise ou le demandeur d'une part et les intervenants BRGM d'autre part, susceptibles de compromettre leur neutralité. »*

En vertu de l'article 2 de la loi n° 2013-907 du 11 décembre 2013, constitue un lien d'intérêts toute situation d'interférence entre un intérêt public et des intérêts publics ou privés qui est de nature à influencer ou paraître influencer l'exercice indépendant et objectif d'une fonction.

Pour éviter que les liens d'intérêt institutionnels du BRGM ne risquent de conduire à des conflits d'intérêts, le BRGM choisit la transparence avec les parties prenantes concernées. La déclaration d'intérêt a pour but d'assurer cette transparence.

La déclaration est faite sous la responsabilité du manager du chef de projet ou du responsable de l'expertise, avec une copie au chargé de mission expertise et déontologie qui en assure l'archivage.

Exemples de liens d'intérêts :

- Tous types de contrats ou conventions (commercial, partenariat, prestation,…),
- Participation au capital,
- Participation à la gouvernance,
- Détention de brevets ou de licences,
- …

Situations concernées : expertises.

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**brgm** | *Déclaration d'intérêts institutionnels*

Je soussigné : **Frank AMBOS** affectation : **CEO**

Agissant en qualité de : Représentant de **SAT Kerntechnik GmbH, Worms, Allemagne**

Réf. de l'expertise : **Expertise sur retrait (partiel) de déchets N°HADRP180525 (Stocamine)**

Demandeur : **BRGM – Prof. Behrooz BAZARGAN SABET**

Considère, dans le cadre du devoir de déclaration des liens d'intérêt du BRGM avec une partie prenante ou avec l'objet de l'expertise citée en référence ci-dessus, devoir déclarer les liens ci-après mentionnés.

Je m'engage à actualiser cette déclaration dès qu'une modification interviendra concernant ces liens ou que de nouveaux liens sont noués pendant la durée de l'expertise.

| Lien d'intérêt | Commentaires |
|---|---|
| **Néant**: Notre expertise pour le BRGM est préparée indépendamment, sans aucun conflit d'intérêt concernant StocaMine (opéré par MDPA) et leurs activités. | |

sat. Kerntechnik GmbH
Vangionenstraße 15
67547 Worms
Tel.: 06241 / 8603-16 · Fax: 06241 / 8603-40

*26 septembe 2018*

*Timbre* *Signature* *Date*

***IM 362_INST** version 5 avril 2016*

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**brgm** | *Déclaration d'intérêts institutionnels*

Dans la charte de l'expertise du BRGM, l'établissement s'engage à *« informer les parties prenantes d'une expertise des liens éventuels pouvant exister entre le sujet de l'expertise ou le demandeur d'une part et les intervenants BRGM d'autre part, susceptibles de compromettre leur neutralité. »*

En vertu de l'article 2 de la loi n° 2013-907 du 11 décembre 2013, constitue un lien d'intérêts toute situation d'interférence entre un intérêt public et des intérêts publics ou privés qui est de nature à influencer ou paraître influencer l'exercice indépendant et objectif d'une fonction.

Pour éviter que les liens d'intérêt institutionnels du BRGM ne risquent de conduire à des conflits d'intérêts, le BRGM choisit la transparence avec les parties prenantes concernées. La déclaration d'intérêt a pour but d'assurer cette transparence.

La déclaration est faite sous la responsabilité du manager du chef de projet ou du responsable de l'expertise, avec une copie au chargé de mission expertise et déontologie qui en assure l'archivage.

Exemples de liens d'intérêts :

- Tous types de contrats ou conventions (commercial, partenariat, prestation,…),
- Participation au capital,
- Participation à la gouvernance,
- Détention de brevets ou de licences,
- …

Situations concernées : expertises.

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**brgm** | *Déclaration d'intérêts institutionnels*

Je soussigné-e : ...Norbert Molitor..................................................affectation : Management..........................

Agissant en qualité de : ..Représentant de PLEJADES GmbH – Independent Experts
..............................................

Réf. de l'expertise : Stocamine.................................................................................................................................

Demandeur :.BRGM

Considère, dans le cadre du devoir de déclaration des liens d'intérêt du BRGM avec une partie prenante ou avec l'objet de l'expertise citée en référence ci-dessus, devoir déclarer les liens ci-après mentionnés.

Je m'engage à actualiser cette déclaration dès qu'une modification interviendra concernant ces liens ou que de nouveaux liens sont noués pendant la durée de l'expertise.

| Lien d'intérêt | Commentaires |
| --- | --- |
| Néant: Notre expertise pour le BRGM est préparée indépendamment, sans aucun conflit d'intérêt concernant StocaMine (opéré par MDPA) et leurs activités. | |

Dr. Norbert Molitor — 26.09.2018

*Signature and stamp* — *date*

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# Annexe 2

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*[84] Arrêté préfectoral n°2014 303-0004 du 30 octobre 2014 portant prescriptions complémentaires à la société des Mines de Potasse d'Alsace MDPA suite à la déclaration du changement d'exploitant et de la dissolution de la société STOCAMINE au 1er janvier 2014 et suite à la demande de modification de certaines dispositions de l'arrêté préfectoral du 3 février 1997 sur son site situé avenue Joseph Else à Wittelsheim (68310) – Octobre 2014.*

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*[86] CAMUSSO M. – Stockage de Wittelsheim, étude de comparaison entre les barrages en bentonite et les barrages en béton Sorel – ITASCA – Janvier 2015.*

**Liste des références et documents mis à disposition du BRGM le 16 mai 2018 par les MDPA pour la réalisation de l'étude**

[1] Prises de vues entre le 28 mai 2014 au 21 décembre 2017 : 62 fichiers vidéos et 5891 photos.

[2] « État du stockage en fin de chantier de déstockage partiel du site StocaMine », préparé par Curium/BG pour les MDPA, daté du 04/01/2018

[3] « Rapport de fin de chantier : Déstockage de déchets mercuriels du site StocaMine », préparé par Curium/BG pour les MDPA, daté du 14/02/2018

[4] « Stockage de Wittelsheim, Estimation de l'état d'endommagement actuel des galeries du stockage », Rapport 17R-001A1, préparé par ITASCA Consultants, S.A.A, daté du 17/02/2017

[5] « Rapport final : Mission d'assistance en matière de prévention des risques liés aux opérations de déstockage partiel de déchets ultimes », préparé par APAVE ALSACIENNE SAS, daté du 14/12/2017

[6] « Expertise des opérations de déstockage partiel de déchets », N/Réf. 09.16.ROV.195, préparé par ROV CONSULT INGENIEURS EXPERTS pour les MDPA, daté du 18/11/2016

[7] « Rapport d'étude DRS-15-152897-05557A : Recherche des mécanismes des fractures observées dans le stockage de StocaMine à partir de modélisations 3D », préparé par l'INERIS pour les MDPA, daté du 15/06/2015

[8] « Constat d'experts concernant StocaMine - MDPA Wittelsheim. Évaluation géomécanique de la tenue des toits et des parements dans le contexte du déstockage des déchets dans le Bloc 21 », préparé par K-UTEC AG Salt Technologies daté du 15/09/2015

[9] « Évaluation logistique et technique de variantes de réversibilité du stockage », préparé par BMG Engineering AG pour les MDPA, daté du 28/10/2013

[10] « Constat d'experts concernant StocaMine - MDPA Wittelsheim. Évaluation d'expert d'une nouvelle méthode de déstockage de colis de déchets dans le bloc 21 (septembre 2015), préparé par K-UTEC AG Salt Technologies daté du 25/09/2015

[11] « Fermeture du Stockage StocaMine, Situation fin des travaux de déstockage », présentation préparée par les MDPA, datée de 2017

[12] Base de données post-déstockage partiel, « Curium_data_post_destock.xlsx », préparée par les MDPA, datée de 2018

# Annexe 3

# Document produit par DMT/Plejades pour l’étude

# Report:
# Evaluation of Time Required for Inventory Recovery

Final Version: 4.0

Date: 23/10/2018

Authors:

Dr Norbert Molitor, Cécile Javelle, Plejades GmbH – Independent Experts

Carsten Scior, DMT GmbH & Co.KG

**Table of contents**

# 1. Introduction

StocaMine is an underground storage facility for ultimate wastes which was operated in a former potash mine since the end of the 1990's. After a fire incident in 2002 in 'block 15', decision was taken to terminate waste storage activities and to close the mine.

It was also decided to retrieve waste material containing mercury prior to the mine closure. The retrieval was already completed, and amounts to 97% of the initially stored mercury inventory.

StocaMine has obtained regulatory approval on a closure plan substantiated by a safety analysis confirming ecologically safe conditions after the mine closure.

On request of the local authorities before implementation of the approved closure plan, BRGM was commissioned to check feasibility of safe retrieval of remaining waste inventory before the natural convergence phenomena in the ageing mine render a safe closure technically impossible.

A series of supporting studies was commissioned by BRGM to complementary expert organisations in order to support an independent and unbiased analysis of possible retrieval schemes for remaining waste inventory prior to mine closure. DMT GmbH & Co.KG and Plejades GmbH were assigned the task of evaluating the time required for safe removal of remaining waste inventory, with focus on an expedited removal under the deteriorating mine conditions.

The present report documents and summarises the results of this evaluation.

Section 1 (present section) gives a short introduction on the background and the scope of the present study and the structure of the present report. The methodology and approach for the present study as well as a list of the key reference documents are provided in Section 2. Section 3 analyses the processes of retrieval under the relevant boundary conditions and technical elements, with the aim to identify a preferred retrieval approach allowing for accelerated retrieval. Section 4 describes the parameters used for modelling the preferred retrieval approach. In section 5, analyses of critical path are performed on the basis of simulation for different scenario to identify a reasonably feasible expedited removal scenario. The results of the simulations are analysed in a broader context in section 6. This analysis also considers sensitivity to possible changes and other decision elements for a safe retrieval. Recommendations based on the elements and results described in the previous sections are developed in section 7. A summary of the main results is provided in section 8.

The present report has been prepared in consideration of existing key documents, in close interaction with other expert groups involved in analysis of safe retrieval.

## 2. Methodology and Approach

The overall approach consists in analysing the necessary processes to be implemented, the possible waste retrieval technologies applicable under the StocaMine underground conditions and time required, based on a combination of elements of process analysis, operational research and critical path analysis.
The analysis was carried out in a series of logical steps, leading to recommendations on the best approach:

- Developing an integrated process map
- Process description
- Process modelling
- Identification of streamlined safe recovery process chain
- Simulation of scenarios
- Analysing simulation results (time, sensitivity analysis: input parameters for processes, scenario configuration)
- Summary analysis of results and findings
- Recommendations

The following key documents were used for the analysis:

[1] « Etat du stockage en fin de chantier de déstockage partiel du site StocaMine », prepared by Curium/BG for MDPA, dated 04/01/2018
[2] « Rapport de fin de chantier : Déstockage de déchets mercuriels du site StocaMine », prepared by Curium/BG for MDPA, dated 14/02/2018
[3] « Stockage de Wittelsheim, Estimation de l'état d'endommagement actuel des galeries du stockage », Rapport 17R-001A1, prepared by ITASCA Consultants, S.A.A, dated 17/02/2017
[4] « Rapport final : Mission d'assistance en matière de prévention des risques liés aux opérations de déstockage partiel de déchets ultimes », prepared by APAVE ALSACIENNE SAS, dated 14/12/2017
[5] « Expertise des opérations de déstockage partiel de déchets. », N/Réf. :09.16.ROV.195, prepared by ROV CONSULT INGENIEURS EXPERTS for MDPA dated 18/11/2016
[6] « Rapport d'étude DRS-15-152897-05557A : Recherche des mécanismes des fractures observées dans le stockage de StocaMine à partir de modélisations 3D », prepared by INERIS for MDPA, dated 15/06/2015
[7] « Evaluation logistique et technique de variantes de réversibilité du stockage », prepared by BMG Engineering AG pour MDPA, dated 28/10/2013
[8] « Fermeture du Stockage StocaMine, Situation fin des travaux de déstockage », presentation prepared by MDPA, 2017
[9] « Mémoire complémentaire répondant aux demandes du Préfet et à l'avis de l'Autorité Environnementale, MDPA, Juin 2016
[10] Curium_data_post_destock.xlsx ; MDPA, 2018

All these documents have been used for specific aspects. To avoid multiple cross-referencing they are not systematically individually quoted further in the remainder of this document.

Further input was obtained through close coordination by BRGM and interaction (almost weekly to bi-weekly) within the expert groups comprising:

- BRGM experts (overall coordination and site specific information, closure concept)
- Experts from LOM, Spain (mine safety)
- Experts from UPM , Spain (rock mechanics)

Further meetings with site visits were organised at StocaMine site with experts from MDPA who provided first-hand information regarding the site and the history of storage and retrieval.

# 3. Process Map and Description of Processes

## 3.1 Process Map

**Background**

The overall objective is to ensure long term safety with regard to the StocaMine site which has been created in geological salt structures underlying a former salt and potash mine and had been operated by MDPA.
MDPA ceased the underground waste disposal operations at this site in 2002 after a major incident and has developed a plan for safe closure of the site. This plan is divided into three major phases:

- safe retrieval of mercury-bearing wastes,
- safe closure of the storage area with plugs to ensure long term confinement and
- safe closure of the remaining mining comprising closure of all mine openings/ shafts to mitigate any negative interaction of the former mine with the environment.

The first phase of retrieval of mercury-bearing wastes was implemented successfully, with retrieval of 97% of the mercury bearing wastes by the year 2017.

The logical next step is to proceed with the safe closure of the disposal area, a process for which MDPA has recently completed successfully a pilot plug to demonstrate the feasibility and the performance of the proposed technologies for these operations.
However, prior to starting with the systematic closure, the question of feasibility of further partial or complete waste retrieval has been raised. In other words, removal options for all or part of the waste shall be studied to assess whether/what is possible within the limited remaining lifetime of the aged mine infrastructures.

The analysis of the feasibility and duration of complete or extended removal of waste inventory was made through an analysis of critical paths for different retrieval and closure scenarios which have been developed on the basis of necessary processes.

Rationale:

- Overall Objective: Safe retrieval of waste inventory from StocaMine site.
- Main criteria: Safety for general public, workers and environment.
- Main concern (=key parameter) and need for optimisation: Time for retrieval and closure which due to the progressing of degradation of conditions needs to be minimized.
- Expression of the result: output/ quantity of wastes produced comprising wastes retrieved and secondary wastes produced during retrieval operation.
- Optimization criteria: time for all works underground related to waste retrieval and closure of the mine.
- The further management of wastes after the successfully retrieval is out of scope of the present study (e.g. diversion of produced wastes by identification and authorisation of suitable waste management facilities and transport from the site to them). It is assumed that these boundary conditions will be ensured by the operator.

The identified process steps required to retrieve toxic waste from the StocaMine have been organized into an integrated process map (Figure 1). The processes are divided into Core processes (=CP), Management processes and Support processes according to modern safety management practices.

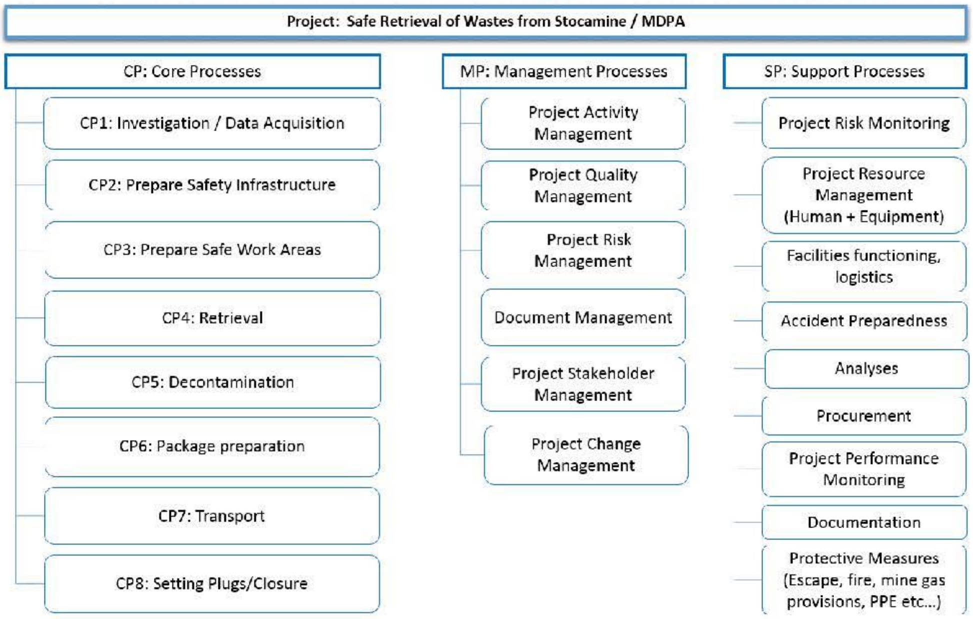


*Figure 1: Overall Process Map (core, management and support processes)*

For an efficient and safe waste retrieval, all processes shown in the above diagram must be well designed, licensed/authorised, financed and implemented. For time optimisation, the core processes provide the essential elements for required time estimations.
Of course, a set of both management and supporting processes need to be implemented in order to create the suitable framework for effective and efficient implementation of the core processes. It can be assumed that StocaMine already has in place all necessary provisions for adequate management and supporting processes. Hence, the analysis of time requirements in the present study is focussed on (optimisation of) the core processes.

Beside the organisational settings, there are imperative technical boundary conditions for modelling the retrieval. These are summarized in the following section.

## 3.2 Boundary Conditions for Modelling

The retrieval and closure of StocaMine is subject of several specific boundary conditions which needs to be taken into account for a correct evaluation of the time needs. They have an impact on process development, selection of technical options for retrieval, modelling of scenarios for safe retrieval of wastes from StocaMine and safe closure of the StocaMine site.

The following Table 1 summarizes the main relevant boundary conditions and described further below.

*Table 1: Main relevant boundary conditions for safe retrieval*

| Type | Short description | Immediate consequences | Consequences for technical option for retrieval and scenario analysis |
|---|---|---|---|
| Existing mine and storage design | The storage area is connected to 2 shafts of the former potash mine. | Existing shaft, corridors have given geometry, offering limited capacity for transport, ventilation etc. ... | Assumptions (for safety): Amount of staff, wastes and materials is limited to some 3 transport cycles per hour, available ventilation is limited to 20 $m^3/s$, and current secondary ventilation with capacity of some 10 $m^3/h$ allows suction ventilation of 2 workplaces. These assumptions are used as limiting factors for scenario with multiple simultaneous workplaces. |
| Rock mechanics, geo-mechanical conditions | The specific site geology and the layout of the underground storage accesses and premises lead to weakening of the rock and mine stability which worsen degradations over time | - Convergence: increasing deformations of roof, walls and floor<br>- Collapse: break and falling down of roof strata<br>- Rock fall: splitting and fall of wall pillars<br>- Damaged floor in access and storage premises: breakage of floor strata<br>- Clamping of stored waste packages (WP)<br>- Destruction of stored WP | Make retrieval design for different damage levels:<br>- Low deformation and damages: no constraints for access and retrieval, but preventive roof support measures necessary<br>- Medium deformation and damages: no major constraints for access and retrieval, but some safety and corrective measures necessary for retrieval<br>- Strong deformation and damages: major constraints for access and retrieval, with waste packages occasionally clamped, requiring intense safety and corrective measures<br>- Very strong deformation and damages: major constraints for access and retrieval, with most waste packages clamped, requiring unclamping of waste packages, massive safety and corrective measures |
| Methane presence | Overlying silty strata above roof may contain methane. Only a single incidence recorded over the last years in StocaMine with release of methane in concentration of some 1,5% decreasing down below 0,5% CH4 within some 5 minutes and further decreasing (average 0,12% CH4 in the first 30 minutes) | Mine is categorised as mine with potential CH4 hazard.<br>Preventive measures required:<br>- Specific requirements for equipment used (methane/explosion-proof)<br>- Specific requirements for ventilation (minimum volumes for dilution)<br>- Be prepared for emergency evacuation of work area in case of incident / release<br>Other considerations:<br>- Avoid release inducing activities (e.g. minimize drilling into roof strata) | Foresee corresponding configuration elements:<br>- Select/configure appropriate equipment<br>- Consider in-situ control measurement of methane<br>- Chose/configure sufficient ventilation (e.g. ca. 4-5 $m^3$ per working front)<br>- Avoid (frequent) vertical drillings (e.g. for anchoring)<br>With these configuration measures no further impact due to eventual incidences may be assumed on the period of intervention. If such optimal configuration cannot be ensured, the risk evaluation based on past experience (available statistics) is:<br>- In average, 1 release incident for each 3 blocks removal (or for modelling 1/3 incidence per block)<br>- Time damage in case of CH4 release incident: assume 1 lost shift or working day (1/3 additional day required per block due to eventual presence of methane) |
| Dangerous work | Retrieval work involving human physical work in underground mine environment is dangerous. | Records and statistics show obvious high frequency of accidents / incidents. | This risk has also relevant impact on the time estimates for retrieval, e.g.:<br>- Frequency: 142,3 incidences per 1 000 000 hours worked<br>- Consequences: 1,28 lost days per 1000 hours worked<br>Impact can be reduced with specific safety measures. As conservative assumption, the known values on frequency and consequences have been kept in the model. |
| Toxic wastes | Packages may be compromised (due to rock deformation, retrieval or transport operations) | Workers may be exposed to toxic materials.<br>Preventive measures will be required for Workers protection<br>Corrective measures may be required: Repackaging, Decontamination | Work with toxic wastes has multiple incidence on time:<br>- Installation of zoning and confinement<br>- Use of appropriate workers protection in specific exposure configurations<br>- Reduced productivity for physical works performed under protection |
| Logistics after successful retrieval | Produced (retrieved) wastes must be managed (evacuated )according appropriate diversion routes | Licensed waste receiving facilities and accordingly permitted waste transports are to be made available in a timely manner | Any delay or failure of availability of permitted waste management routes puts the underground waste retrieval at risk. Such roadblock may be eliminated with implementing a surface interim storage facility for the produced wastes, but also this may take substantial licensing time. Any administrative delay for such authorisation would also be very detrimental to the retrieval. |

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**Existing mine and storage design**

The physical and geometrical settings of the storage area from which the wastes shall be retrieved are major boundary conditions.

Figure 2 displays a layout of the storage area at StocaMine. The storage area is constructed below a former potash mine and can be accesses by slope galleries attached to the mine shafts 'Puits Joseph' and 'Puits Else' ensuring transport of staff and material as well as ventilation. The storage area has been designed and constructed in a grid pattern, regrouping two series with 6 storage blocks, each distributed on both sides of a central access double corridor ('Voie centrale') and limited by the adjacent storage block or boundary corridors. The storage blocks located south of the central corridor are numbered from 11 to 16 (West to East) while the blocks located north of the central corridor are numbered from 21 to 26. Block n° 15 is the block damaged heavily by the fire of 2002.

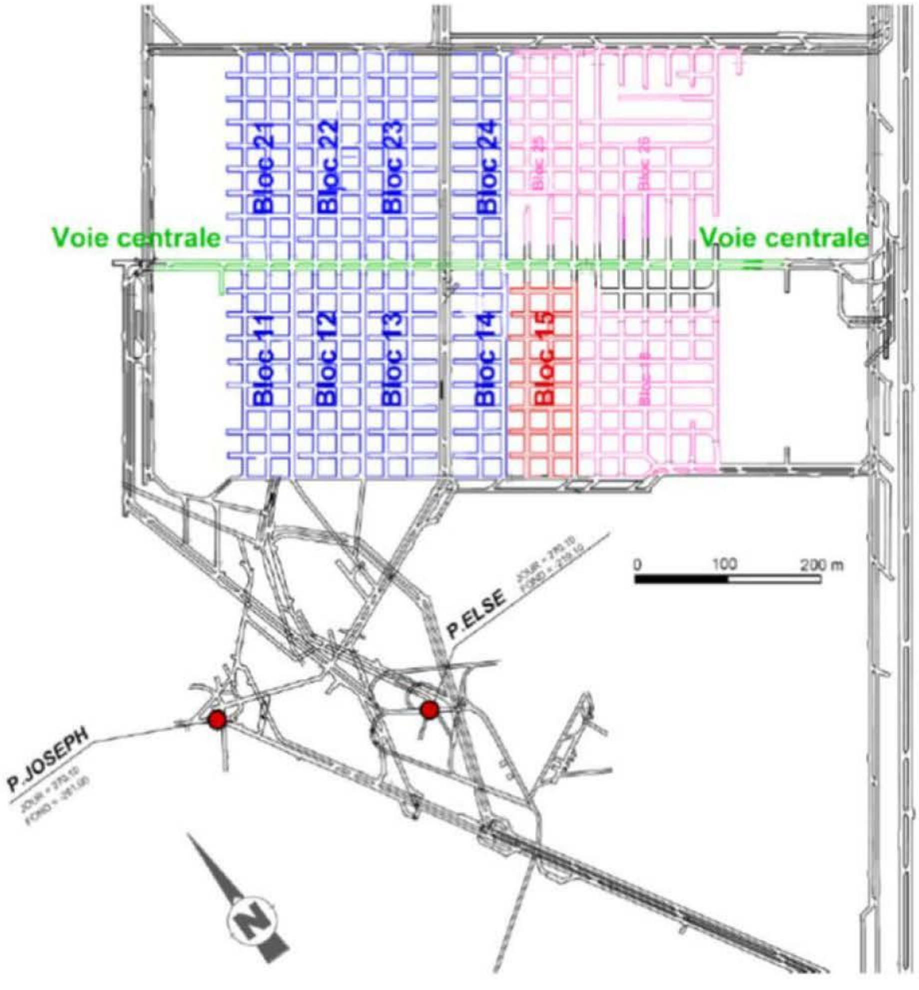


*Figure 2: Map of StocaMine*

The layout of each block consists of access corridors ('Allée') attaching the block to the central corridor and perpendicular crosscutting corridors ('Recoupe'). These access and cross cutting corridors were constructed horizontally by cutting technology with an original rectangular section of 5,5 m width x 2,8 m height. The axis distance between the access corridors and cross-cutting corridors were 25 m, leaving more or less quadratic pillars of salt rock ('sel gemme') with edges of originally some 20 m length (Reference [R9]). All access and crosscutting corridors were designed for waste storage typically performed in standard waste packages (big bags, drums, but other packages are also encountered) put on transport pallets which were placed in subsequent waste rows (up to 4 rows per 'unité') numbered and diligently documented. For retrieval purposes, these rows are called 'fronts' with up to 10 pallets placed per 'front'. From statistical analysis it has been deducted that one average 'front' is statistically occupied by 8,5 pallets with big bags and 1,5 pallets with drums. The following Figure 3 illustrates the terms used and typical dimensions for a typical block (example block n° 11).

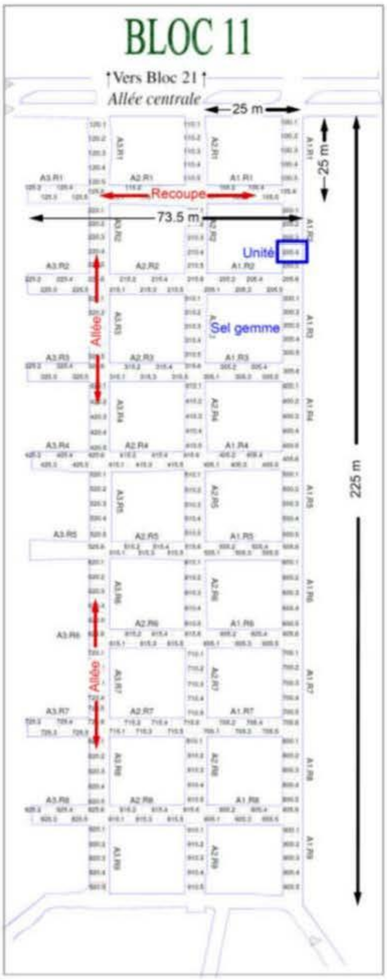


*Figure 3: Terms used and dimensions to describe a block (example B11)*

**Geo-mechanical conditions**

Beside the geometry of storage area, the other most important boundary conditions relevant for safety and retrieval are the deteriorating geo-mechanical conditions. Due to the geology (salt formation with inclination not congruent with the horizontal layout of the storage facility, intersecting silt seams, occasional presence of methane) and the mechanical salt rock properties (e.g. rheo-plasticity of salt rock, disassociation of strata), the load applied on salt rock around the disposal structures induces significant deformation (convergence, bending, faulting, shear fractures, breakage and rock fall). The deformation processes have started with the creation of the voids. They are already partially in an advanced stage as illustrated in Figure 4 and Figure 5 and will continue further until the voids eventually close.


*Figure 4: damaged roof and inclination of strata layer*


*Figure 5: Floor heave and damaged side wall*

These damages have been studied in detail (e.g. Itasca report, reference No [3]) and require appropriate corrective actions for ensuring safety. Corrective actions can be sorted into immediate measures at the front (e.g. by hydraulic props visible in above figures) or by mid to longer term focussed measures (e.g. anchoring) as practiced at StocaMine intensively in the past, or placement of steel support gates (see Figure 6).

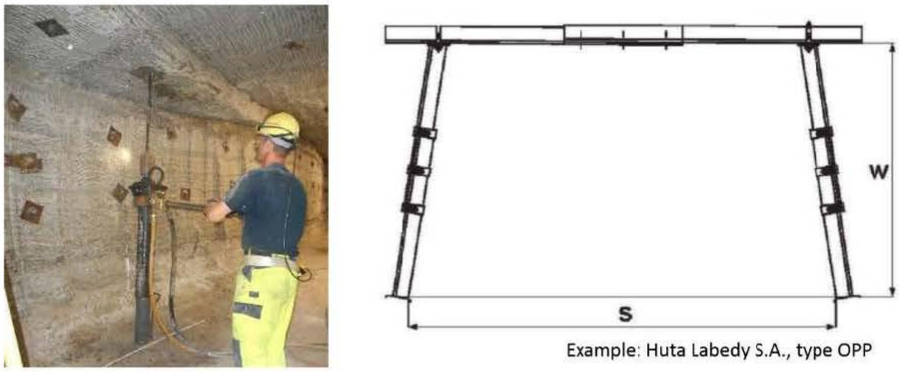


*Figure 6: Anchoring as practiced (left), example of deformable steel support as portal frame (right)*

Note: Three of the most used storage package types are visible in Figure 5 (picture down left):

- big bags (standard size of 90 cm x 90 cm x 110 cm). Big bags are typically placed on a wooden transport pallet.
- drums (standard size of 200 l, solid containers (steel containers). Drums are typically placed by set of 4 on a wooden transport pallet.
- other ('autre') packages.

Up to 4 'fronts' were placed in one 'storage unit'.

**Evaluation of the rock condition for time estimate**

As described above, deformation is an ongoing dynamic process, which has been evaluated by former studies, from which the following has been retained.

- High deformation speeds (23 to 30 mm / year) in the area of the figure corresponding to stresses in the adjacent rock salt greater than 18 MPa.
- Medium deformation speeds (17 to 23 mm / year) in the area of the figure corresponding to stresses in the adjacent rock salt between 16 and 18 MPa.
- Low deformation speeds (10 to 17 mm / year) in the area of the figure corresponding to stresses in the adjacent rock salt between 14 and 16 MPa.

The areas with different stress situation and deformation speeds can be mapped by referring to the stress calculation provided by ITASCA Consulting group in 2016/2017 (used reference n° [3]) shown in following Figure 7.

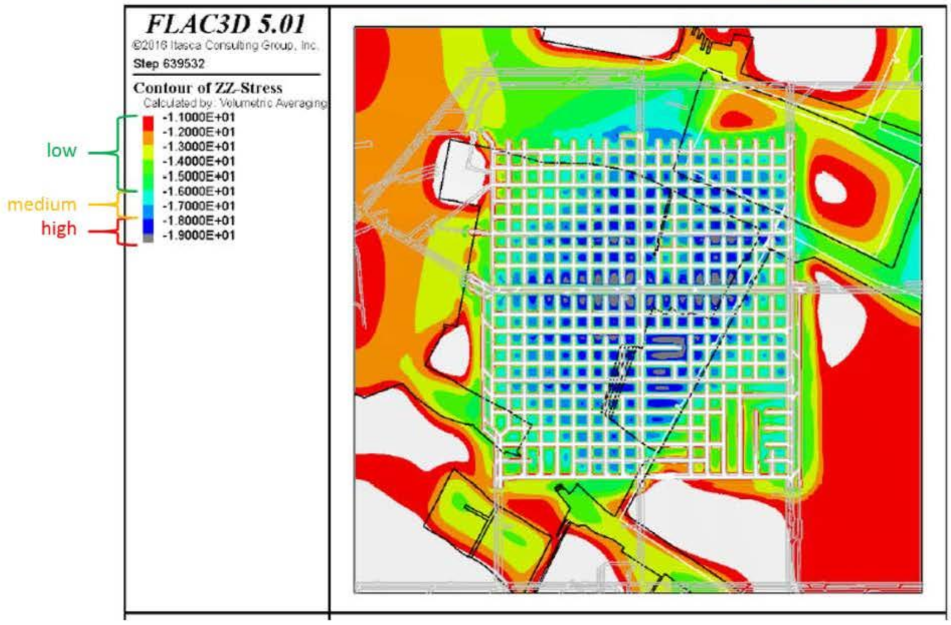


*Figure 7: Contour of ZZ-Stress from [3]*

For modelling purposes of the storage area of StocaMine, the possible deformation has been considered by configuring each 'front' as located in one of the three following areas:

- Category "green": Low deformation areas (no relevant damages limiting the waste retrieval are to be expected)
- Category "yellow": Medium deformation areas (expect occasional relevant damages which may disturb to some extent the waste retrieval)
- Category "red": High deformation areas (expect relevant damages which may disturb significantly the waste retrieval)
  *Note: During the analysis of possible retrieval approaches and retrieval time, it became clear that a further differentiation/categorization of the high deformation areas would be appropriate to quantify the quality of damages and the corresponding complementary (corrective) measures for safe retrieval. However the available data is too limited to make such further differentiation. Instead the possible level of damages and the corresponding necessary measures have been assumed in two subcategories ((a) high deformation with partial clamping of packages and (b) high deformation areas with systematic clamping of all packages with possible damage to package). In the basic modelling scenario, the ratio (a)/(b) has been set to be 80%:20% but in the sensitivity analysis (see below in chapter 6) this parameter has been tested for the full range between 100% to 0% in both directions.*

The following Figure 8 provides the map used with categorization of the storage area into areas with low, medium and high deformation.

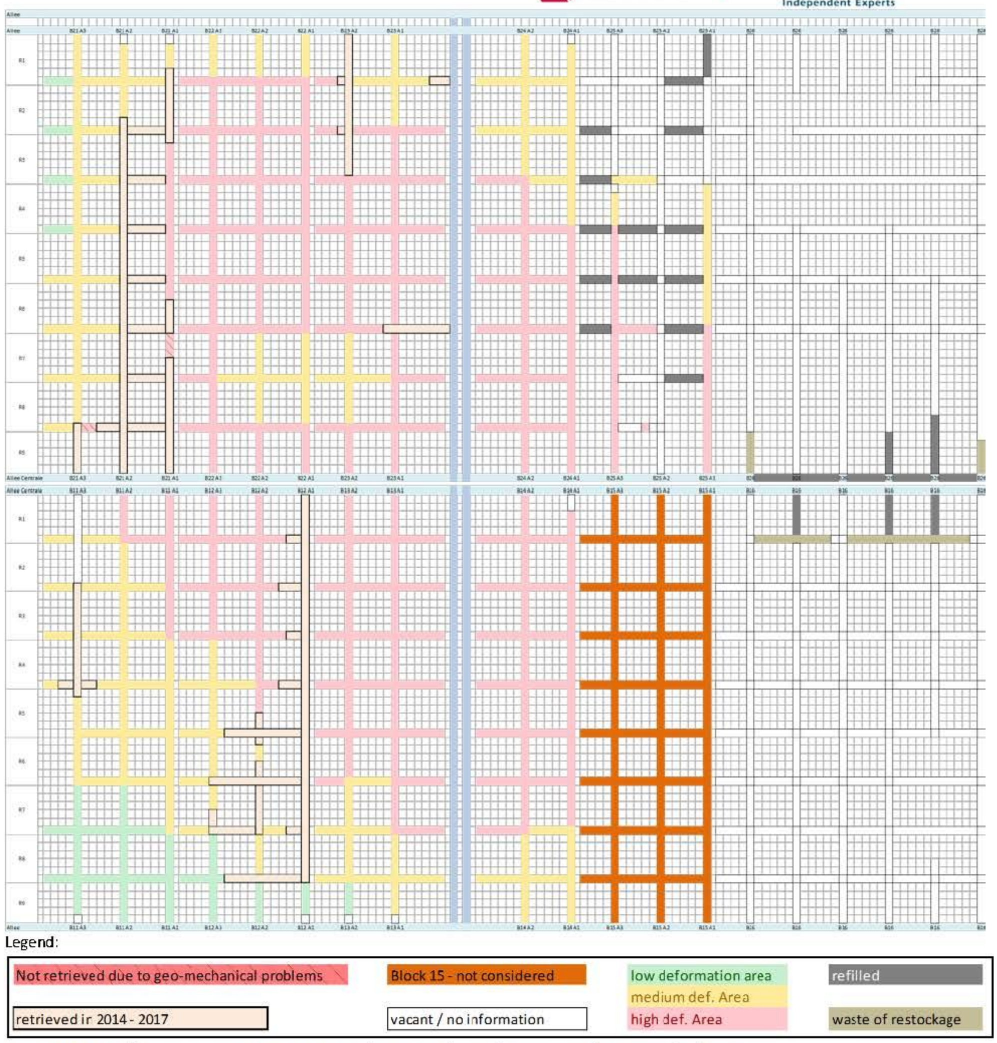


*Figure 8: Map of storage area in StocaMine with geo-mechanical categories for time calculation*

The above map/model is a reasonably accurate picture of the current (as in September 2018) geo-mechanical status. Its validity is well substantiated by available detailed studies, but it is of course limited in time because the deformations are time-dependent and increasing. One of the most adverse effects is the clamping of packages. In the worst case, convergence leads to significant damage or even destruction of packages, as illustrated in the real cases shown in Figure 9.

*Figure 9: severely clamped packages resulting from strong rock deformations, from reference [9]*

To illustrate and check the influence of time, a rapid analysis of possible progression of the possible clamping of packages over time has been made. Although the interaction processes between converging rock and packages is quite complex, different stages can be distinguished:

- free space in all directions (all vertical sides + roof): no clamping of packages needs to be considered (e-g- approx. 40 cm in vertical and 100 cm in horizontal direction).
- Free space in one direction is disappearing: Clamping starts; the package will be deformed (by compaction and/or by movement towards remaining free space).
- Free space is disappearing further in more than 2 directions: clamping leads to deformation by compaction of package, and finally also by destruction of package.

The severity of effects depends on the type of WP and content. For instance, if we consider the case of the majority of WP = big bags containing inert fine grained or powdery bulk compressible content, then a compression rate of up to 20-25% will probably neither damage the package nor significantly change the waste form. Feasibility of retrieval will start being compromised only by higher compression rates, because then the damages will be so extended that segregation of the waste material from the salt rock will not be technically possible any more.

These different stages are illustrated in the following Figure 10.

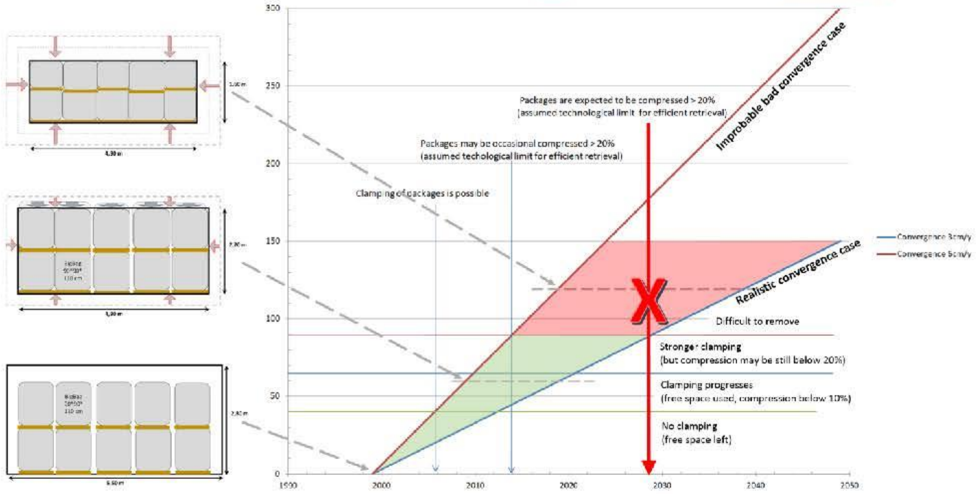


*Figure 10: Rapid analysis of convergence constraints, with clamping stages*

From this figure (based on indicative values) it can be concluded, that in high deformation areas:

- Part of the packages disposed may be already clamped under unfavourable high convergence rates (2 x 30 mm/year) since the mid 2010's, but even under high convergence rates, retrieval will be possible as long as total convergence is below 100 cm.
- From around 2029 it is likely (realistic convergence case) that all waste packages will be clamped (convergence ca. 30 mm/year)
- Even assuming that the highest manageable compression of WP is 20% (clamping with or without damage or limited damage), then the limit for retrieval corresponds to 150 cm for total convergence (no matter the convergence rate).
    - ➔ The situation may be therefore quite manageable until around the mid of 2020's with reasonable probability of success.
    - ➔ After that, successful retrieval may be still possible, but with lower efficiency and increasing risk of failure until the end of 2020's.
    - ➔ After the end of the 2020's the risk of failure will have increased so much that continuation of retrieval of packages in high deformation areas is probably not practicable

## 3.3 Core Process 1 'Restaging Retrieval Area'

Objective: have a continuous update on situation at the work places under implementation or scheduled.

Input: Already available information, experience

Output: Appropriate information for subsequent processes (mainly CP3, CP4, but also CP2, CP5, CP6)

Background: Although an intense data basis exists for the StocaMine site, any implementation of a waste retrieval project will be a risk project due to implicit and unavoidable uncertainties and continuous changes (e.g. dynamics of geo-mechanical situation). A key success factor for such type of risk projects is 'to be prepared for the unexpected' and therefore to re-evaluate continuously the risk situation and eventual risk mitigation or specific corrective measures to be taken.

Key elements:
- Investigation
- Evaluation of existing and new data/information
- Assessment of needs (safety, retrieval, logistics)
- Decision (configuration decision)

Means:
- Return of experience: use experienced people knowing the mine and its peculiarities (most important)
- Check roof, walls, floor (e.g. visual acoustic or endoscopic methods)
- Check type conditions of waste packages
- Established range of standard categories for situation and actions to be taken
- Information on resulting/remaining constraints
- Documentation

## 3.4 Core Process 2 'Prepare Safety Infrastructure'

Objective: Ensure safety of workers by technical (e.g. zoning / establishment of controlled areas, local ventilation, locks, rescue support, escape ways and the definition of personnel protective equipment (PPE)) and organisational (e.g. team instruction, rescue teams) measure.

Input: Available information about: the waste (contents, form and package), possible toxicity and possible exposure pathways; knowledge about storage (configuration, works, documentation) performed; experience for waste retrieval (including Mercurial waste retrieval performed at the site); regulatory context (mine safety, waste management, workers protection, environmental protection).

Output: Zoning (type and localisation of controlled areas), locks (localisation and configuration), PPE (configuration for each zone); emergency preparedness at the work places (e.g. methane control, roof safety control, rescue rooms, means, escape ways, safety and emergency instructions, emergency and rescue teams); ventilation for work places (e.g. secondary ventilation, air supply, minimization of dust re-suspension, dilution and evacuation of gazes and aerosols inside the zone) ⮽ safety infrastructure for works to be implemented (mainly CP 3, CP 4, CP 5 but also CP 6, CP 7, CP 8).

Background: To ensure safety of the waste retrieval and ancillary activities a specific safety infrastructure comprising technical and organisational measures needs to be ensured. Key elements for a safe retrieval are the zoning of work places where wastes will be handled to protect workers and environment. For the prevention of cross contamination from controlled areas (as defined in the zoning concept) where contaminant sources and propagation are possible, specific confinement and locks (for workers / staff, materials and waste packages) are to be configured and installed. The controlled areas need local ventilation to ensure a defined airflow direction, with a minimum volume to ensure a defined quality of the air (e.g. dilution of gazes and aerosols, air supply for workers if not arranged separately). The work places are typically under slight under-pressure to ensure dynamic confinement which is ensured by suction ventilation and the sucked air can be filtered as required. Depending on the air quality and risk of contamination and industrial risks inside the controlled areas the PPE for the workers needs to be defined (e.g. half mask, full protection, separate, air supply, helmet, safety boots, protective clothing, headlight ...). Further, the safety and emergency instruction for workers and management, the escape ways and means available for workers in emergency situations are to be identified and prepared, as well as the relevant rescue support organised and prepared (e.g. emergency and rescue rooms, emergency and rescue teams, alarm plans, emergency plans) in compliance with the applicable regulations. An important aspect is that in parallel with the CP 2 activities other activities (e.g. addressed in CP 1, CP 3, CP4, CP 5 and

CP 6) are implemented at the controlled area or at its boundaries: Possible interference with possible positive or negative interaction needs to be checked, observed, controlled in such a way to maximise positive effects and minimise negative effects.

Key elements:

- Identification and justifying of needs
- Applicable regulatory requirements (e.g. mine safety, waste management, workers protection, environmental protection)
- Ventilation configuration (e.g. concept, layout, calculations, means)
- Zoning (e.g. concept, prescription for controlled areas)
- PPE
- Emergency preparedness

Means:

- Calculate relevant ventilation requirements; direction, volume, etc.
- Check toxic contents for definition of requirements
- Definition of different zones and locks (e.g. for workers / staff, materials, waste packages) needed
- Check additional requirements of mine safety regulations
- Definition of escape ways and rescue support
- Definition of PPE at each area defined in the zoning

## 3.5 Core Process 3 Prepare 'Safe Work Areas'

Objective: Ensure a safe work area for the employees and the retrieval operations.

Input: Already available information, Outputs of CP 1 and CP 2, complementary measuring to CP 1, experience and ad-hoc expert judgement.

Output: Measures for roof and walls control and support technology. Detailed adjustment of ventilation at the work place (retrieval and repackaging area); definition of additional safety measurements as required.

Background: By the continuous changes (e.g. dynamics of geo-mechanical situation) a necessary element for safe works is the safety of the accesses to and the work place at the retrieval front at all times during local intervention. The geo-mechanical conditions in storage area of StocaMine are particularly challenging due to the high deformation rate and resulting damages in some areas: convergence reduces the open section of the access and storage corridors and the roof, wall and floor strata layers gets to be instable (e.g. bending up to breakage and rock-falls). Therefore the geo-mechanical safety conditions needs to be continuously re-assessed and adequate measures have to be defined and implemented to protect workers. Two stages of geo-mechanical safety measures are typically to be configured: immediate roof support (typically but nor mandatory: by hydraulic support posts with/without support beams or by anchoring with/without reinforcement mesh) to protect workers at the 'front' for retrieval activities and a longer term roof and wall support (typically but not mandatory: by steel frame support or by widespread anchoring with reinforcement) behind the retrieval work places and at the 'front', to ensure safe accesses and ancillary measures in the background. Efficiency of the immediate roof support measures are to be continuously re-assessed during retrieval measures (described in process CP 4).

In addition to the geo-mechanical conditions, the ventilation requirements as output of CP 2 have to be adapted to the progressing work front. The infrastructure for other ancillary measures (e.g. air supply, methane control, transport means, removal of fallen rocks, longer term geo-mechanical measures to ensure safe accesses) has to be adapted too.

An important aspect is that in parallel with the CP 3 activities other activities (e.g. addressed in CP 1, CP 2, CP4, CP 5 and CP 6) are implemented at the controlled area/red area or at its boundaries: Possible interference with possible positive or negative interaction needs to be checked, observed, controlled in such a way to maximise positive effects and minimise negative effects.

Key elements:
- Investigation
- Evaluation of measuring data
- Identification and configuration of adapted roof support
- Identification and configuration of adapted ventilation installations at the front
- Identification and configuration of adapted ancillary measures (e.g. air supply, removal of fallen rocks, transport)

Means:
- Return of experience: use experienced people knowing the mine and its peculiarities (most important)
- Check roof, walls, floor (e.g. visual acoustic or endoscopic methods)
- Configuration of immediate and longer term support to protect workers at the retrieval work places and to ensure safe accesses and ancillary activities
- Adaptation of local ventilation (e.g. extension of ventilation tubes, consideration of ancillary ventilators)
- Adaptation of ancillary measures (e.g. air supply, removal of fallen rock, transport, long term roof and wall support measures)

### 3.6 Core Process 4 'Retrieval of Wastes'

Objective: Retrieve the waste packages out of stored situation. Local transport to a lock-out device if required.

Input: Condition of waste packages; safety infrastructure provided by CP 2, safe working conditions provided by CP 3.

Output: Waste packages recovered or containing repackaged waste (including retrieval, collection and transport of packages to lock-out place for handover to next transport step outside the controlled work area. The installation of a small buffer waiting storage in the controlled/red area before hand-over could be an option to disentangle possible congestion during transport chain.

Background: Waste packages are retrieved safely out of the complex situation in storage area influenced by the geo-mechanical conditions with high deformation rates and thereby influenced stability of roof, sidewalls and floor. Safe work places and accesses are provided in CP 3 and are to be re-considered continuously during the retrieval of the packages. The waste packages may have different levels of interaction with the encasing rock as described in section 3.2: free standing (non-clamped and non-interlinked) packages (lifting and gripping is possible), partially clamped packages with little interlinking with the encasing rock (gripping is but lifting is not possible), strongly clamped and compressed packages with severe interlinking with the converging rock (lifting and gripping are not possible). Depending on the interlinking of the packages different retrieval technologies are applicable and can be considered:

- For unclamped and interlinked packages: lifting or gripping (typically very efficient e.g. with fork lifter or hydraulic carriage device with manipulator equipped with gripper),
- For partially clamped packages with little interlinking: gripping (typically very efficient e.g. with hydraulic carriage with manipulator equipped with gripper)
- For severely clamped WPs: direct lifting after gripping is not possible; packages need to be unclamped first, either by relieving some pressure from the encasing rock (e.g. with a salt/rock cutting device – see Figure 17) or by partial or complete emptying of package (e.g. by suction device with repackaging in new package, destruction of package, collection and repackaging of waste)
- For damaged packages (e.g. big bags or drums) with compromised integrity an

over-packing (e.g. in a larger big-bag or drum, which is very efficient when feasible) or a repackaging (e.g. by pneumatic transfer into a new package, which is a proven and quite efficient technology for grain sized and powdery bulk wastes in big bags or drums; in the worst case, material from heavily damaged package needs may be collected by manual or mechanical means (which is typically time-consuming) and conditioned into new packages which can be safely handled.

- For retrieval and transport of existing very heavy waste packages (few big-bags are documented having loads > 1 tons), safe handling can't be guaranteed unless the load has been reduced, for instance by partial repackaging with transfer of some of the content into a new package.

For transport of retrieved or repackaged packages this may be performed by the retrieval device (typically efficient only over short distances and limited number of packages), installed continuous transporter (e.g. conveyor belt, very efficient also for longer distances and high number of packages but require effort and time consuming installation) or mobile transport device (e.g. roll-on-roll-off transporter, quite efficient and flexible for short and longer distances) or a combination of these.

The retrieval ends with the handover of package to the next step which will require ensuring that only clean packages leave the lock and that contamination spread is prevented. For the locking out, specific out-lock devices (similar to out-bagging of contaminated materials out of hot cells, meaning the inserting of a potentially contaminated package in a clean over-pack) or a decontamination cell within the lock. As in the present case the contaminants are dust-bound, automatic decontamination should be quite an easy process (see CP 5), which may be performed within an under-pressure section in the lock (e.g. practised already in the past at StocaMine).

An important aspect is that other activities (e.g. addressed in CP 1, CP 2, CP 3, CP 5 and CP 6) will be implemented at the controlled area or at its boundaries during retrieval operations: Possible interference with possible positive or negative interaction needs to be checked, observed, controlled in such a way to maximise positive effects and minimise negative effects.

Key elements:
- Experience available (mercury retrieval)
- Package retrieval technologies
- Repackaging and over-packing technologies
- Transport technologies within controlled zone
- Waste package lock-out technologies
- Ancillary activities implemented in parallel

Means:
- Retrieval equipment (fork-lifter, hydraulic carriage with manipulator and tools, excavator, suction device, transport equipment, roof support installing devices, etc.)
- Qualified, trained and instructed workers / staff

## 3.7 Core Process 5 'Decontamination'

Objective: Ensure absence of contamination at the surface of the packages, at the mine outside the storage areas and 'red areas'. Propagation of contamination and cross-contamination are to be systematically mitigated.

Input: Output of CP 1, CP, 2, CP 3 and CP 4, applicable regulatory framework (waste management, workers protection, environmental protection)

Output: Clean waste packages leaving the controlled area. These packages include also secondary wastes produced are also packaged properly. Avoidance of any contamination leaving the controlled areas (with workers / staff, equipment). Areas released from control free of contamination.

Background: The clean outer surface of waste packages exiting the controlled are to be ensured. Further, it is necessary to ensure that any uncontrolled contamination spread in red area is efficiently mitigated.

As in the present case the contaminants are dust-bound, the following contamination management principles will be efficient:

- Mitigation of contamination can be performed by mitigation of uncontrolled contaminated dust re-suspension and transport (dust suppression or abatement at the potential sources of contaminated dust) sources,
- Decontamination of surfaces of PPE, equipment or materials leaving controlled areas by dry blasting (e.g. with pressurised air) and suction of mobilised aerosols with subsequent cleaning of sucked air (e.g. in a dust separation and air filtering unit). If dry blasting is not sufficient persistent contamination can be removed by dry or humid wiping. The decontamination may be performed in an under-pressure section within the exiting lock which can be combined with curtain doors allowing also larger vehicles to be decontaminated before their leaving. Alternatively or in complement to a lock with decontamination devices special out-lock devices may be considered for exiting contaminated materials and waste packages without decontamination but by putting them into safe over-pack (e.g. out-bagging technology as practiced for material out of hot cells but this would be probably in most cases less efficient than a decontamination lock).
- Efficient operational proof of clean surfaces by absence of dust (e.g. wipe test) and clean air by absence of aerosols.

An important aspect is that in parallel with the CP 3 activities other activities (e.g. addressed in CP 1, CP 2, CP4, CP 5 and CP 6) are implemented at the controlled area or at its boundaries: Possible interference with possible positive or negative interaction needs to be checked, observed, controlled in such a way to maximise positive effects and minimise negative effects.

Key elements:

- Experience available (mercury retrieval)
- Decontamination of persons, waste packages, devices and materials as necessary
- Lock-in/ Lock-out configuration for entering or leaving the confined controlled zone for workers / staff, waste packages, devices and materials
- No negative interference with other activities.

Means:

- Applicable regulatory framework (waste management, workers protection, environmental protection)
- Decontamination Technology (e.g. blasting devices, under-pressure section in lock, air cleaning device)
- Lock-out Technology (e.g. lock-out device installed at entry/exit of confinement, dynamic confinement with double/ multiple curtain doors)
- Documentation

## 3.8 Core Process 6 'Package Preparation'

Objective: Ensure waste packages compatible for the subsequent safe handling (e.g. transport, storage, diversion).

Input: WP exiting the red area.

Output: WP compliant for public transport ready for diversion.

Background: The conditioned WP are prepared as part of retrieval process (including packages with retrieved wastes and secondary wastes) and handed over at the border of the controlled area as clean and safe WP for further handling underground and above ground inside the company. Therefore safe handling can be assumed. The main challenge is to take it over and transport (evacuate) the package from the storage area without interfering with other processes. This will depend very much on the transport technology used inside the controlled area and the lock-out technology foreseen to transfer the package out of the controlled area.

Key elements:
- Experience available (e.g. from mercury retrieval)
- Applicable regulatory context (internal waste management – workers safety, external waste management – diversion and transport, ADR requirements)
- No negative interference with other activities.

Means:
- Retrieval, repackaging, decontamination and lock-out technologies foreseen in CP 4 and CP 5
- Internal transport means (e.g. transport vehicles) and infrastructure (e.g. buffer storages)
- Documentation

## 3.9 Core Process 7 'Package Evacuation' (Transport)

Objective: Ensure transport of waste packages out of the underground mine. WP have to be transported inside the mine, through the shaft up to the surface. The present study ends with the production of waste packages (retrieved wastes and secondary wastes produced by the operation) which are brought above ground and are (in principle) ready for transport. The further transport from StocaMine and delivery to an authorized disposal facility or further processing company with standard means (e.g. with ADR compatible transporters or transport over-pack containers) is out of scope of the present study.

Input: Approved waste management plan and regulatory authorisations; Waste categorisation.

Output: Compliant transport of waste packages according to waste management plan and authorizations and applicable regulations.

Background: The internal transport means outside the controlled areas is typically a standard underground (mining) transport vehicle (e.g. a transport vehicle with a capacity of up to 6 tons corresponding to 4 to 6 pallets with one big bag or up to 4 drums each). Buffer storages may be considered at the controlled zone boundary (up to few pallets or equivalent, use of the transport vehicle(s) as buffer storage capacity may be most efficient as one trans-loading operation can be avoided) and outside the storage area (e.g. near the shaft for a small number of pallets).
Although the waste package are sufficient for internal handling for public transport specific additional requirements are becoming relevant (ADR requirements, transport and diversion permits, transport and diversion documentation). These are industrial standard procedures, which are resolved with standard industrial procedures (e.g. standard public transport means for road, railway or ships, ISO over-packs).
An important aspect is that CP 6 activities needs to be well coordinated with the waste package source (CP 5), and the internal transport (e.g. transport towards shaft, buffer storage at shaft, and transport through shaft as part of CP 7). Possible interference with possible positive or negative interaction needs to be checked, observed, controlled in such a way to maximise positive effects and minimise negative effects.

Key elements:
- Experience available (e.g. from mercury retrieval)
- Applicable regulatory context (internal waste management – workers safety, external

waste management – diversion and transport, ADR requirements)

- No negative interference with other activities

Means:
- Internal transport means (horizontal transport to shaft, vertical transport through shaft, intermediate transport to and from possible buffer storages near the shaft underground or aboveground)
- External transport means (Standard eligible industrial transport vehicles and transport over-packs – e.g. ISO containers)

## 3.10 Core Process 8 'Setting Plugs/Closure'

Objective: Ensure safe closure of the disposal area of StocaMine as part of the mine closure.

Input: Approved closure plans and regulatory authorisations; experience from pilot barrier placed already, geological information and mine infrastructure for the placing of the plugs.

Output: Performed backfills and plugs according closure plans and authorizations.

Background: The former waste disposal area needs a sustainable effective confinement to protect the environment and biosphere. The confinement will be ensured by the encasing salt rock itself, and by engineered plugs installed into all access ways as tight barriers. This operation is time critical: the plugs can only be built in areas not yet reached by the (natural) uncontrolled mine degradation. According to the closure plan, 12 plugs have to be installed in total (see Figure 11). 5 out of the 11 can be placed in parallel with other activities at StocaMine site (e.g. waste retrieval) and the other 7 plugs are to be placed in a retreat mode (which then is hardly compatible with any further activities at the StocaMine underground facility). Possibly the implementation of these 7 remaining plugs may be accelerated to some extent by moving ahead the schedule of some of the preparatory work (e.g. contouring of the plug locations). According to current experience up to 3 plugs per year can be placed.

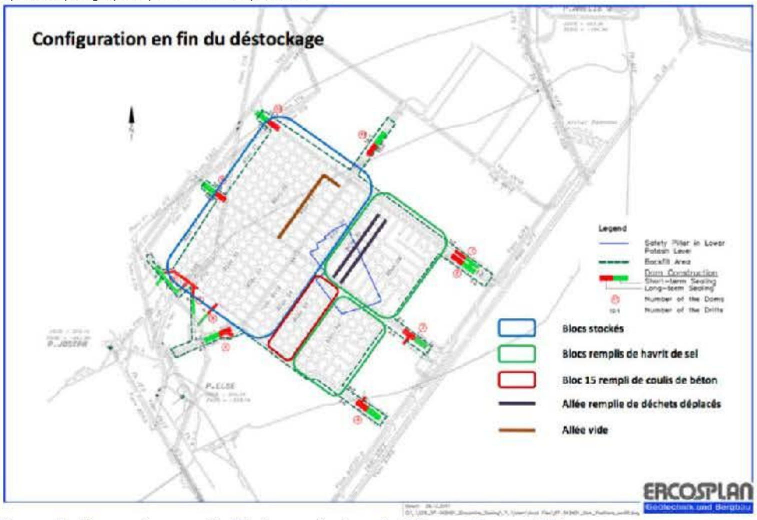


*Figure 11: Closure layout with 12 plugs to be installed (from reference [9])*

An important aspect is that part of the CP 8 activities are implemented with other activities (e.g. addressed in CP 1, CP 2, CP 3, CP 4, CP 5 and CP 7). Possible interference with possible positive or negative interaction are probably of low probability and consequence but needs to be checked, observed, controlled in such a way to maximise

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positive effects and minimise negative effects.

Key elements:
- Experience available (also from pilot plug)
- No negative interference with other activities.

Means: As described in closure plan

## 3.11 Options for Technical Approaches

In order to configure an expedited safe retrieval, different options for technical approaches to implement the described processes have been analysed and a preferred option identified which will be used for subsequent modelling of different retrieval and closure scenario.
Existing experiences from the partial retrieval of wastes in the years 2014 - 2017 are a valuable and useful asset for the present retrieval project, in addition to representing a valuable "Reference scenario" which feasibility is already demonstrated.

The technical approaches and technology used have been successively optimised in the course of retrieval implemented and to manage different boundary conditions encountered. More details are presented in reference [2] and [5] including analysis of further possible optimisation.

The main equipment used for recovering the waste packages was a telescopic forklift (type AUSA T 235 H). This device has a maximum payload (*charge utile*) of 2,300 kg with a vehicle length including forks of 4,880 mm; a width of 1,585 mm and a vehicle height of 2,012 mm (see Figure 12).


| DIMENSIONS (mm) | T 204 H | T 235 H |
|---|---|---|
| A | 2030/1960* | 2030/1960* |
| B | 275 | 275 |
| C | 1595 | 1595 |
| D | 2877 | 2877 |
| E | 849 | 1000 |
| F | 1910 | 1910 |
| G | 705 | 785 |
| H | 459 | 548 |
| I | 1200 | 1200 |
| J | 4664 | 4860 |
| L | 2990 | 3451 |
| O | 4200 | 5032 |
| P | +20° | +24° |
| R | -120° | -119° |

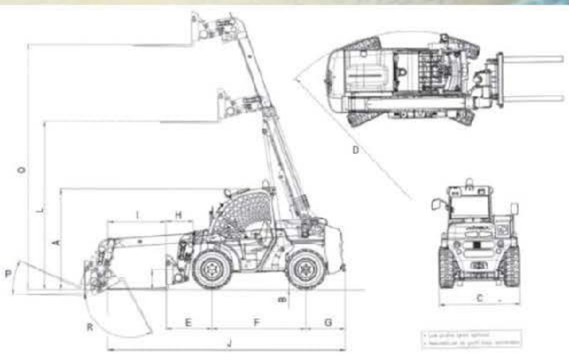


*Figure 12: AUSA Taurulift T 235 H*

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The following figure illustrates the use of this device fitted with different tools.

Legend:

Top row: Telescopic forklift with different tools (forklift, shovel, forklift in reversed mounting)
Middle row: Tools to handle drums
Bottom row: Tools for handling pops

*Figure 13: Used devices and tools used at StocaMine in the past*

The equipment proved to be very efficient as long as waste packages were NOT clamped and interlinked. The approach used in the recent past has also proved to be adaptable to changing situations with involvement of workers and additional tools as needed. However, physical works for workers under full protection in narrow underground mine conditions was dramatically lowering efficiency and became a possible roadblock for efficient retrieval of waste packages. It has been retained that further optimisation of the process is possible but was not implemented before the end of the last retrieval campaign.

The analyses of the activities show above all the following aspects, to which optimizations seem appropriate:

**Limited manoeuvrability of the telescopic fork:**

Due to the relatively rigid construction of a telescopic forklift as handling tool, the operator lacks the degree of freedom to recover waste packages located in confined or cramped arrangements (e.g. without spacing, with interlinking, at distant edges). As the packs are partly inclined or close to each other due to the deformation of the corridor, efficient recovery requires a high degree of manoeuvrability of the recovery vehicle and tool.

With the introduction of a fork adjustable in width and equipped with side-shift the flexibility could already be increased. In addition, a swing fork carriage (see Figure 14 on the left) and a rotator (see picture on the right) are available in various accessory programs from reputable manufacturers, which can further increase mobility.

*Figure 14: Useful accessories for telescopic handler: swing fork carriage (left) and rotator with grippers (right)*

Especially in combination with the swing and rotator, grippers can facilitate the handling of big bags. Such tools are also used for handling and storage packages in other underground storage facilities (see Figure 15).

*Figure 15: Grippers for big bag handling*

Such additional equipment, however, reduces the payload by its own weight.
In addition, it requires corresponding skills of the operator, who has to master the increasingly complex kinematics and kinetics (such skills may be acquired and improved through specific training on the equipment and experience in the field).

Alternatively, vehicles with higher degrees of freedom can also be used for the recovery of WP. Two examples for alternative device option are given as follows:

- Device used in the mining industry and adapted / optimised for work in underground mine conditions (Figure 16): With its movable, telescopic and additionally swingable arm it has a high flexibility and is robust. Its geometry allows also working in in low-ceiling areas.


*Figure 16: Optional equipment: mining excavator*

- Dismantling and heavy duty device adapted to work in highly contaminated environment (e.g. dismantling of nuclear facilities of chemically contaminated sites. The shown device example (Figure 17) consists of a carrier equipped with hydraulic power for locomotion (e.g. on crawlers or walking legs) and for operation of a manipulator and or other tools (e.g. hydraulic hammer, cutting saw, gripper, grinder). Such devices can be customised for different use, a process that is standard service of competent manufacturers (e.g. Brokk, TopTec).


*Figure 17: Optional equipment: dismantling device*
*(top row: carrier with manipulator and tools, bottom row: with special tools for contouring, cutting etc.)*

**The challenge of very heavy packages:**

Due to the package weights of up to 2.5 t, a typical telescopic fork lift may reach its design limits for lifting. By using additional attachments to increase mobility and flexibility, the payload is even further reduced. From the recovery point of view, it may be therefore desirable to increase the load capacity of the device. However, this is usually accompanied by larger dimensions of the vehicle which is definitively a disadvantage in narrow underground mining environment. These advantages and disadvantages must be weighed against each other in detail, depending on the recovery technique used and the resulting requirements. The other option is to change or adapt retrieval in cases of very heavy packages (e.g. partial repackaging of package inventory: e.g. producing several lighter big-bags, or drums, of lesser weight, out of the content of one 2.5 t heavy big-bag)

**Increased number of workers in full protection directly at the 'front'**

The used approach involved at certain time an increased number of workers working physically at the 'front' under full protection to compensate the limitations of the used equipment. Examples are shown in Figure 18.

*Figure 18: Increased number of workers with full protective equipment working at the front*

Although flexible, this approach also has some obvious disadvantages because working physically under full protection is hard and dangerous: not only is working time reduced by regulation, but and combination of man intervention and mechanisation may lead to dangerous situations for workers, with every additional worker increasing need for coordination and risks of misunderstanding, hence representing an additional accident risk.

**Repeated change/shifting of zoning ("red area")**

Particularly in the case of high damages (due to convergence, rock fall etc.) corrective work was required to establish and maintain safety. This was typically done with normal mining devices in normal operational mode (e.g. cutting or grinding devices, anchoring devices) after clearance of the controlled area ("red area"). The clearance requires absence or removal of any contamination and lifting / dismantling of confinement with associated efforts and time. After implementation of corrective measures in 'normal mode' a new 'control area' needs to be re-established for proceeding with removal of next waste packages/blocs, which again is associated with efforts and time. Beside the additional efforts and time, the frequent re-zoning may create confusion for workers, hence increasing risks of accidents.

**Worker turnover**

Due to the high demands on the qualification of the employees and the adaptation to the conditions on site, a qualified and well-trained team on site is an essential component for an efficient and safe retrieval.

The staff for the recovery of the packages at the front must be trained in handling toxic substances and working under full protection to reduce accident risks.
Further, the mining work to secure the work places and access corridors ('corrective action') has also to be carried out by qualified and well-trained employees to reduce accident risks. Despite all training, the work remains exhausting and dangerous. This was proven by the high number of accidents and by the high staff turnover.
Frequent change of workers is again another increased risk of accidents (learning curve restarts at a lower level).

**Qualified equipment operators**

With the increasing mechanization of retrieval processes in particular, higher skills (formation, dexterity, flexibility) for equipment operators are necessary. Due to the complex and frequently changing boundary conditions, the skills of the equipment operator will have a great influence on the success of the waste retrieval and interlinked ancillary activities (effectiveness and efficiency).

# 4. Identification of an Optimized Approach Option for Modelling Different Retrieval Scenarios

## 4.1 Description of Different Technical Approach Options for a Safe Retrieval

To perform the core processes described in the previous section, six different retrieval approaches which may be considered based on international experience have been identified and evaluated. Furthermore, the previous mercury-bearing waste retrieval has been also analysed as it can be used to analyse the retrieval of waste at StocaMine on a real case basis: it is quoted to be an approach which has been proven to be effective and practised with high safety standards except for specific complicating boundary conditions. Thus it is described as 'Reference Option' as it can be used to illustrate the possible relationship and differences with the six other retrieval approach options described.

### 4.1.1 Reference option (based on existing experience at StocaMine)

The reference option is the existing recovery situation used for mercury-bearing waste retrieval.
It is visualised in Figure 19.

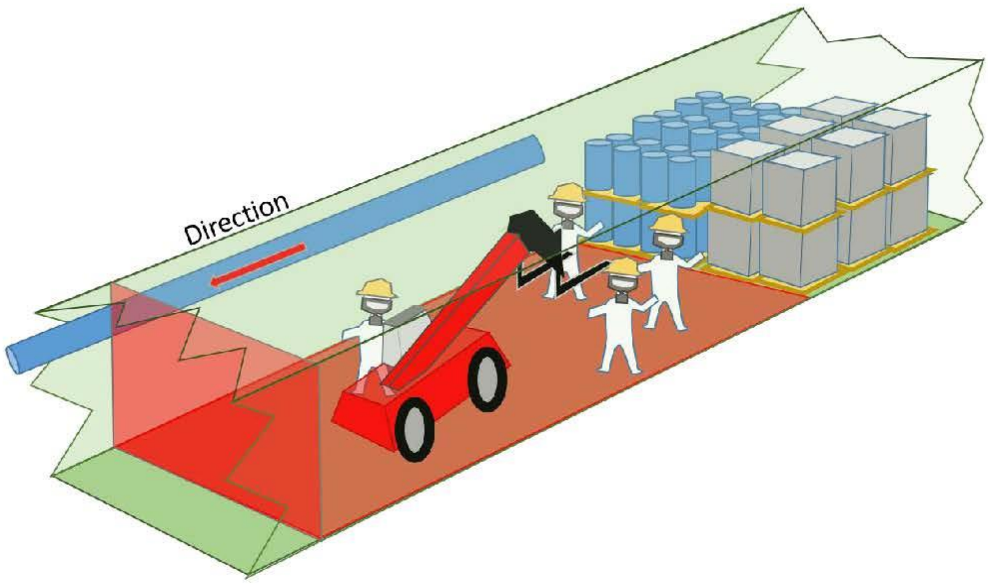


*Figure 19: Reference option: schematic design*

The retrieval work to recover the packages takes place within a "red area" near the retrieval 'front'. Contaminations can potentially occur in this area when packages were compromised during storage or during retrieval. Therefore, all workers wear personal protective equipment (e.g. protective mask due to potentially spread contamination and full protection in case of evident spread contamination. For activities that are not directly related to the recovery operation, such as rock stabilization measures or re-cutting the floor, the "red area" is dismantled (and cleared). This requires absence of contamination (e.g. proof by measurements) and, if necessary, appropriate decontamination measures. The advantage of lifting the "red area" is that full protective equipment and other protective measures against contamination (e.g. monitoring, decontamination) are not necessary for any further work in this area, which will increase productivity of workers and efficiency of works. On the other hand, decontamination and lifting of the limitations of the "red area" as well as for the re-establishment of the "red area" for the next recovery section are time consuming activities.

In the approach performed in the retrieval campaigns, several employees usually work directly next to the retrieval equipment under full protection within the "red area". This is partially due to the limited manoeuvrability and flexibility of the used equipment (e.g. to attaching the packages to lifting device without manual support). Another challenge is the recovery of clamped packages where hard physical human work is necessary if it cannot be performed by the equipment. Finally, the operator of the vehicle had only limited visibility on the situation at the 'front' and the positioning of its tools, which implied guidance needs by an additional worker standing at the front, noting that communication and sign giving under full protection, narrow conditions with limited visibility are difficult and dangerous tasks. This approach has been proven to be very efficient ((up to some 40 packages recovered per day) under good conditions but has also shown its limitations up to giving-up waste package recovery under bad conditions. Further, the accident risk is increased due to the presence of workers in the direct vicinity of the recovery vehicle and the handling of heavy packages.
On the other side, due to the extended presence of workers at the working area this approach has a remarkable flexibility as workers may not only compensate limitations of provided equipment but also perform a lot of complementary works or test new technologies and/or processes with high flexibility.

*Table 2: Pros and cons of reference option*

| Advantages | Disadvantages |
|---|---|
| High flexibility | Workers have to wear personal protective equipment with a full protective mask in 'red area'.<br>Recurring instalment and lifting of "red area" consumes time |
| Applicable for all hazardous areas as long as boundary conditions are not too bad (e.g. advanced geo-mechanical deterioration with severe clamping and interlinking of packages) | High stress on workers (physical and dangerous work, physical stress) combined with accident/incident risk (psychological stress)<br>Waste packages are not retrieved and left in areas where boundary conditions were too bad. |

### 4.1.2 Option 1 ('No constraints'):

In an ideal case, the packages are in the same condition as when they have been disposed in the underground storage: no major geo-mechanical deformations have led to clamping or interlinking of waste packages, such that the packages can be lifted on the pallets or packages may be gripped individually without obstruction. This option also considers that packages and/or pallets are not damaged. In such conditions there is no need to create a controlled 'red area' and the process can be predominantly focussed to an optimised recovery of waste packages (with the required precautions not to compromise waste packages and to ensure appropriate industrial safety) with minor ancillary works (e.g. transport, standard mine safety with minor corrective and securing works for roof, walls and floor).

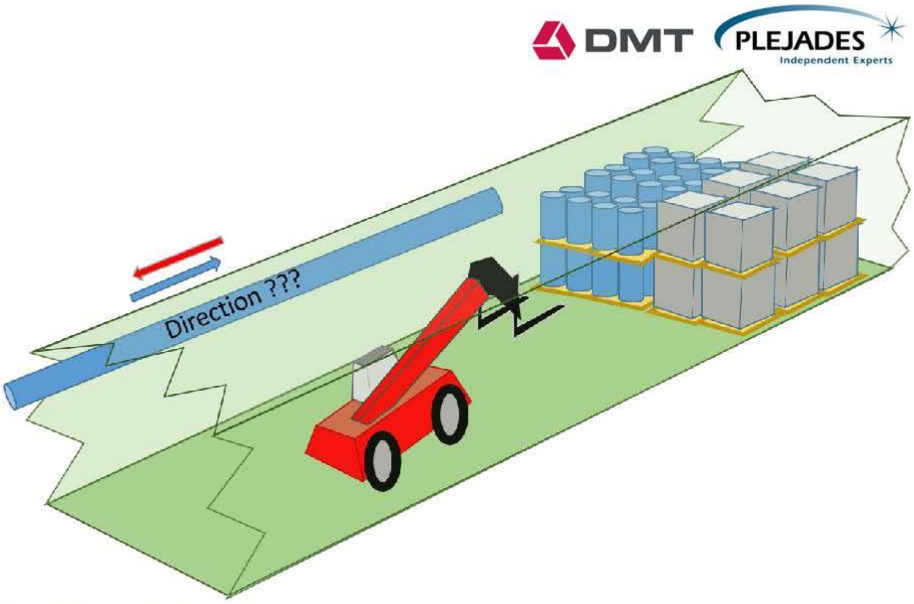


*Figure 20: Option 1: schematic design*

Such conditions were encountered during the past recovery campaign in some areas and recovery rates were noticeably good (probably up to some 40 packages per day retrieved when applied as part of the reference option). Such ideal conditions may be still encountered during future recovery campaigns but such favourable boundary conditions should be expected only for limited areas (green areas identified in section "3.2 Boundary Conditions for Modelling" and in the coming years only). Thus this option will not be applicable as standard retrieval approach but will provide a good understanding about achievable output under favourable boundary conditions and be used to benchmark the impact of less favourable conditions.

*Table 3: Pros and cons of option 1*

| Advantages | Disadvantages |
|---|---|
| flexible | Applicable only when Packages are not compromised |
| No "red areas" required | Packages must be intact, accessible and ready for handling |
| Efficient and productive technologies and processes possible | Only practicable in a small part of the storage area |
| no work under "full protection" or other major corrective/protective measures required to ensure safe retrieval | Not practicable in most of the storage area |

### 4.1.3 Option 2 ('in-Situ repackaging with local confinement')

This option considers repackaging all powdery and fine grain wastes into new big bags by pneumatic (suction) method.
This repackaging method is a standard technology in industry (used in chemical or nuclear industry). It requires a substantial depression to have sufficient air speed to disaggregate the grains and carry them by the air flow to a gas-solid separator (e.g. a cyclone) for re-deposit the solid in a new package. The air must be cleaned from residual dust after separation (e.g. by dry or wet methods, e.g. high-efficient-particle-filters (HEPA-filter)).
This technology has been tested at StocaMine within the controlled "red area" and conclusion was that

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the technology is effective but of limited efficiency (some 40 minutes for repacking a standard big bag). The limited efficiency is probably due to the difficult and low mobilisation rate of the original package inventory (due to the age the inventory may be agglomerated and or consolidated and requires physical/manual unblocking by stirring and moving the suction nozzle).

One of the boundary conditions can be simplified by installing the confinement close to the package, such that workers can operate the repackaging from outside. This approach is similar to the 'dismantling-tent-approach' practised in the nuclear industry (see parallel report of SAT Kerntechnik). A similar confinement can be also considered for waste retrieval. This would consist of a confinement screen with gloves for working inside from outside, connectors for the suction air conducts and a lock (lock-out device) for transferring materials out of or inside the confined area. The productivity can be increased by configuring nozzles to disaggregate consolidated/aggregated materials (e.g. small blade mounted on nozzle, or activation of nozzle) and by multiplying the numbers of suction units.

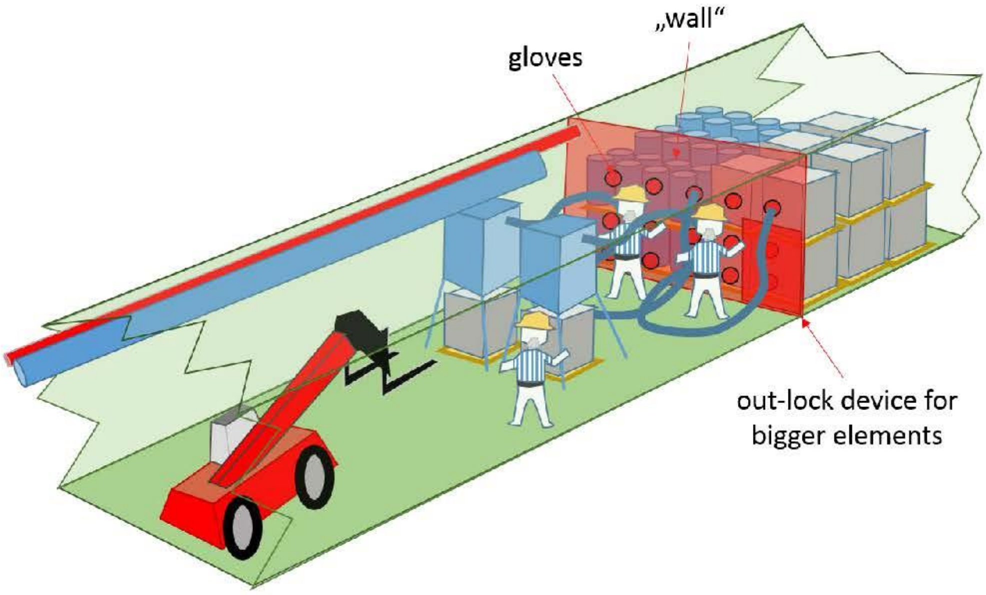


*Figure 21: Option 2: schematic design*

*Table 4: Pros and cons of option 2*

| Pros | Cons |
|---|---|
| Very small "red area"; Almost all activities can be carried out from outside ( without "full protection") | Difficult to handle larger components and pieces of wastes (e.g. cemented drums) |
| Can be also used for clamped or interlocked packages. | Type of works performed inside the confinement is limited |
| Equipment are typically not contaminated (no need of decontamination and low risk of contamination spreading) | Requires workers which are skilled in this type of works to be efficient. |
| Rock protection measures can largely take place outside the red area | Secondary wastes (e.g. old emptied packages, filters from suction air cleaning) |

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### 4.1.4 Option 3 ('Remote controlled removal within confinement')

The exposure of workers to risks may also be reduced by using of flexible remote-controlled equipment (multi-versatile devices, robots). This is practised in many industrial areas. The operator of the device can either be positioned in the immediate vicinity of the device, or control the device from a distant place (see Figure 22).


*Figure 22: Example of remote-controlled handling*

Multitasking devices typically consist of a carrier (on crawlers or wheels) powered with a hydraulic and/or electric unit, and tools that can be mounted on it. This configuration allows using different tools and thus increases the versatility of the whole device.
A lot of developments of small high performant remote technologies have taken place in the nuclear sector mainly for dismantling contaminated facilities and/or for retrieval of highly irradiated inventory. The main characteristic of the devices is their high versatility and the possibility of remote operation. The latter is a difference to highly specialised and high performance mechanical devices developed in the mining sector (e.g. tunnelling machines, tunnel cutting machines, drilling and anchoring machines).
In principle most of the work inside a controlled 'red area' can be performed by such devices and if maintenance work is organised such that it can be performed from outside (e.g. in a glove-box type compartment) the exposure of workers may be reduced to a minimum. Specific locks ensure the safe transfer of materials inside and retrieved packages (e.g. a lock-out device allowing locking out packages in clean over-packs or a double curtain lock section) and materials outside the confinement.
In case of waste retrieval at StocaMine, the configuration could consist of a machine performing the works at the retrieval front (e.g. and securing of the roof, retrieving packages and walls ,...) and a flexible and extensible intervention tunnel cabin with gloves (e.g. for maintenance, small repairs of the equipment, for minor human intervention at the front without direct exposure). The latter should minimise the need of intervention of workers inside the confinement under full protection for which a man-lock should be also foreseen.

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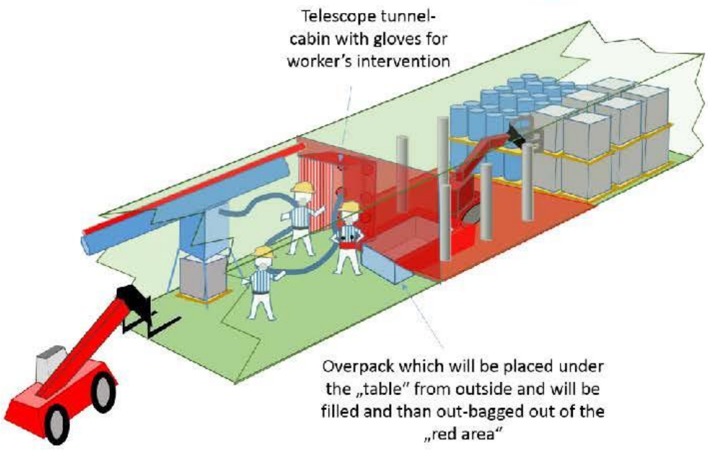


*Figure 23: Option 3: Schematic design*

The controlled "red area" may be shifted to follow the retrieval 'front' from time to time. The area gained from shifting forward the lock area towards the progressing front can be decontaminated and then be used for any other works under more 'normal' mining conditions (e.g. transport; roof, wall and floor cutting and support works). This approach may integrate the technological option of waste repackaging by pneumatic suction methods described in option 2.

*Table 5: Pros and cons of option 3*

| Advantage | Disadvantage |
|---|---|
| Deployment of workers in the "red area" is minimized. | Very complex arrangement |
| Very flexible to use, equipment carrier can carry out a wide variety of tasks due to its multi-versatility | Work with remote controlled devices requires high operator skills and may be less efficient than directly driven devices |
| Packages are placed directly in clean over-packs during lock-out | Locking in and out is a complex operation, requiring careful and skilled personnel and may slow down overall performance (bottle-neck) |
| Can also be used under worsened geo-mechanical conditions and for clamped packages | Needs very skilled and well trained teams of operators and workers |
| Long-term safety and other ancillary measures can be implemented outside the "red area" under more 'normal' environment | Although minimised, some manual intervention in 'red area' may be still necessary and secondary wastes are also generated. |
| | dust inside red area may considerably limit visibility of remote-control operator |

### 4.1.5 Option 4 ('2 remote controlled equipment with confinement')

The approach this option is similar to that of option 3 and is based on remote technology. The effectiveness and efficiency of remote works may be increased considerably if the versatility of one remote device is complemented by a second multitask device: by joint coordinated work by a lead and a supporting device very complex work sequences can be organised differently, allowing simultaneous work instead of sequential work. Thus it may be considered to provide two devices in the "red area" to perform works at the retrieval 'front'. For example several activities may be carried out in parallel (e.g. one device removing, the other handing over to lock-out) or the need for tool changes (e.g. gripping tools versus lifting tools), as both devices can be equipped differently and thus complement each other.

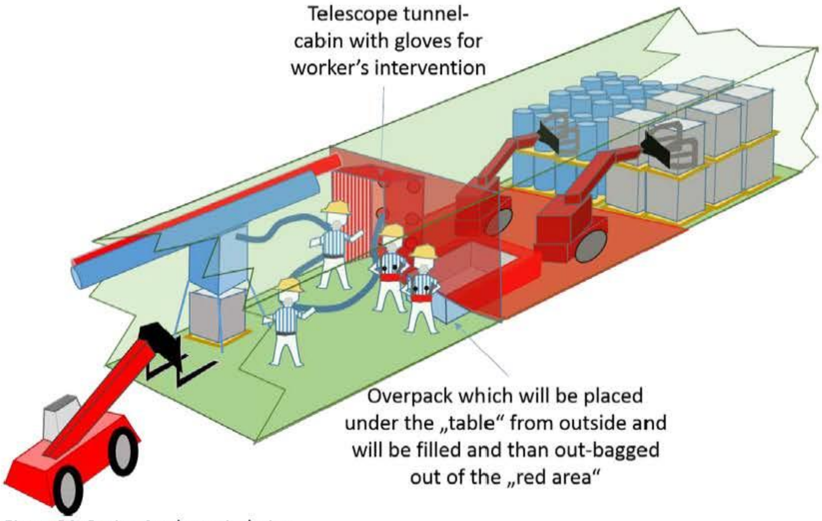


*Figure 24: Option 4: schematic design*

However, the limited width of the accesses considerably restricts the freedom of movement of the devices. As shown in Figure 25 in a plan view for two example devices, the working spaces of the devices would overlap. Obstructions occur particularly during rotary movements in the rear area. This puts additional high demands on the machine operator and reduces the effectiveness and efficiency of this option.

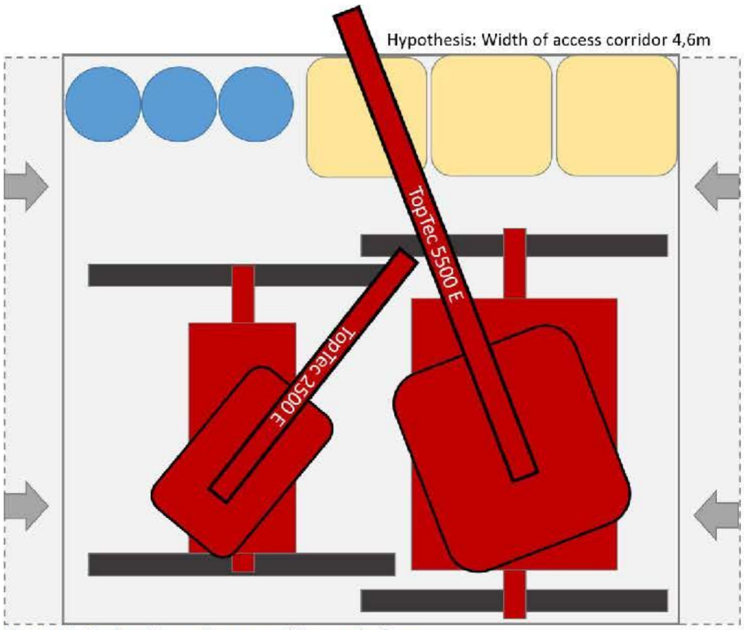


*Figure 25: Option 4: Top-view to machines at the front*

*Table 6: Pros and cons of option 4*

| Advantages | Disadvantages |
|---|---|
| Deployment of workers in the "red area" is minimized. | Very complex arrangement |
| Very flexible to use, equipment carrier can carry out a wide variety of tasks due to its multi-versatility | Work with remote controlled devices requires high operator skills and may be less efficient than directly driven devices |
| Packages are placed directly in clean over-packs during lock-out | Locking in and out is a complex operation, requiring careful and skilled personnel and may slow down overall performance (bottle-neck) |
| Can also be used under worsened geo-mechanical conditions and for clamped packages | Needs very skilled and well trained teams of operators and workers |
| Long-term safety and other ancillary measures can be implemented outside the "red area" under more 'normal' environment | Although minimised, still some intervention in 'red area' may be necessary and secondary wastes are also generated. |
| | dust inside red area may considerably limit visibility of remote-control operator |
| ***in addition to Option 3:*** | ***in addition to Option 3:*** |
| Tool carriers can complement each other, fewer tool changes required | Mutual obstruction of devices due to narrow geometry |
| Simultaneous work is possible | Even higher skills of device operators required |

### 4.1.6 Option 5 (Workers outside progressing confinement')

Combining retrieval approach option 2 with retrieval approach option 3 would allow minimisation of presence of workers and equipment in the red zone.

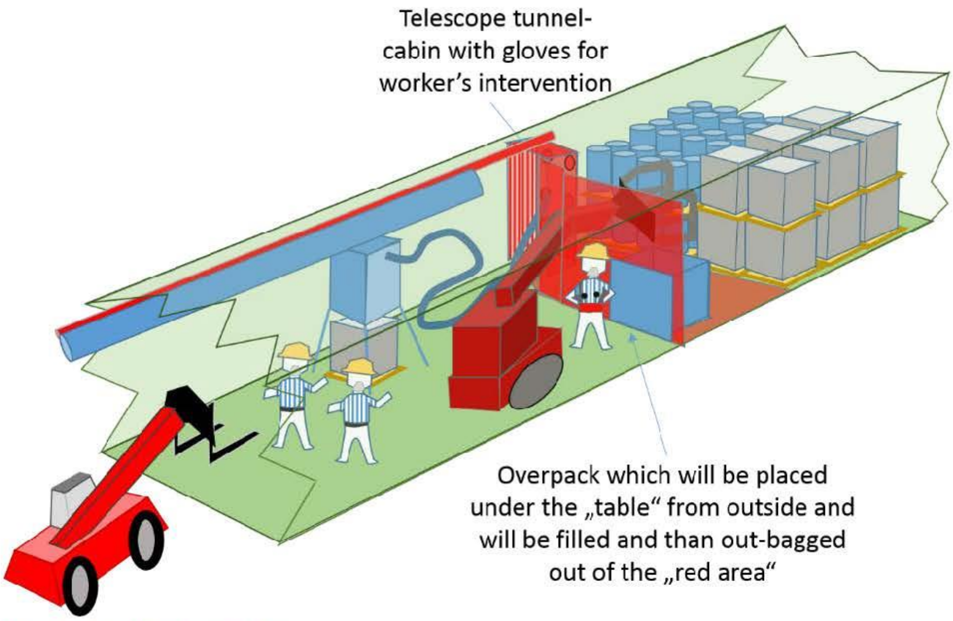


*Figure 26: Option 5: schematic design*

The confinement is installed close to the package location/front and the equipment carrier is installed outside the "red area" with possibility of control and assistance by workers without full protective equipment. Works are (predominantly) performed through the confinement from outside with equipment having an arm (boom) passing through the confinement on which different tools can be mounted. Similar to option 4, a telescopic tunnel cabin with gloves allows interventions inside the "red area" from outside. A lock is required to lock-out packages (e.g. a lock-out device for original or clean overpacked WP). The relatively narrow dimensions of the "red zone" allow the handling of packages (retrieval and transfer to the lock) with a device from outside. A the same time, the cramped conditions restrict the type and number of operations and sequences possible, and could lead to blocking during lock-out of WPs.

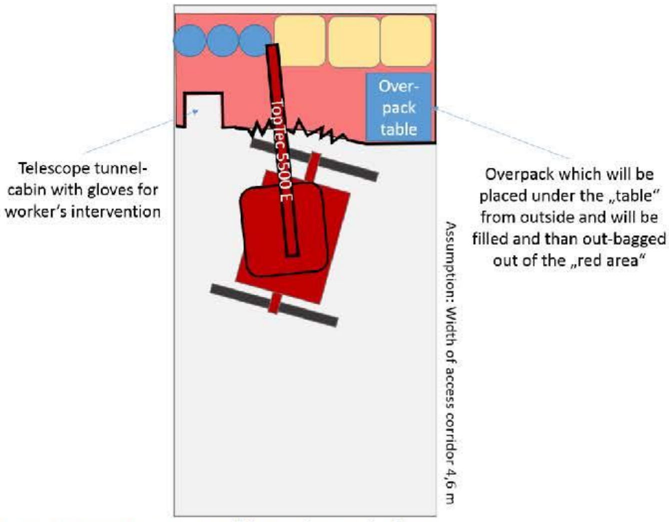


*Figure 27: Option 5: Top-view of the machine at the front*

*Table 7: Pros and cons of option 5*

| Advantage | Disadvantage |
|---|---|
| Relatively small controlled "red area" | Complex confinement configuration |
| Workers and equipment are located outside the "red area" | Limited flexibility for works inside the cramped "red area" |
| Operations can be performed predominantly by equipment and workers from outside the "red area" | Retrieval and transfer to lock are performed by the same equipment and locking out. This interferes with retrieval and slows down retrieval operations. |
| | frequent shifting of lock time consuming |

### 4.1.7 Option 6 ('Adapted mechanisation in established confinement')

Retrieval approach option 6 combines elements already introduced in previous options.

In this scenario, the retrieval works occur inside a very largely configured "red area", and are performed by equipment installed within the "red area" (similar to option 3 or 5) with assistance of workers (similar to reference option or option 5) inside the "red area". This avoids remote control of equipment (as foreseen in options 3 or 4). As all activities take place within the "red area", all workers in this area must wear full protection and can therefore only work for a limited period of time. Workers are supplied directly with fresh and conditioned fresh air through plugs and plug-in connections into air supply hoses installed in the "red zone". Because workers are supplied directly, ventilation requirements can be reduced (significantly smaller exchange volumes are required for dynamic confinement of the red area, which may reduce dust and aerosol formations – leading to better visibility and reduced contamination transfer).

The approach further allows systematic mechanisation including all heavy works to be performed by robust machines and minimising physical works of workers: like in options 3 and 4 multitask devices allow corrective measures for geo-mechanical conditions (e.g. rock cutting, putting roof support frames,

anchoring) as well as retrieval works (e.g. gripping, tearing, lifting, transfer) or transport (with a special device or vehicle transporting the retrieved packages towards (a possibly distant) lock. As the “red area” is organised as large area several devices and vehicles may manoeuver inside it simultaneously. Workers are only present to drive and control the equipment or carry out small assistance work.
Since work must be carried out continuously under full protection, the shifts must be divided in such a way that sufficient personnel capacity is always available under full protection in a rotating system (e.g. 3 columns per shift, each working up to 2 hours under full protection, 2 hours for rest or light work without protective equipment and up to 2 hours of work under full protection again).

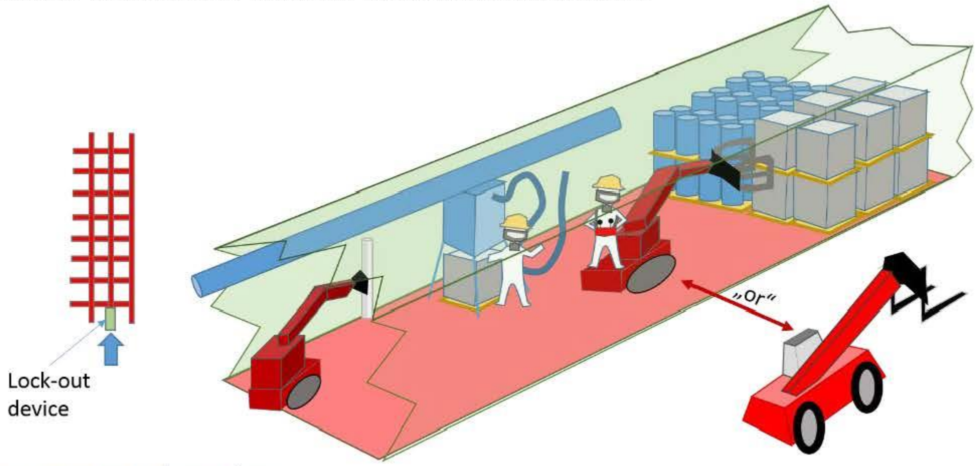


*Figure 28: Option 6: schematic design*

This retrieval approach option 6 would allow to organise a complete block as a "red area". The locks (e.g. lock-out device for packages, or a double curtain lock section) are located centrally at the entrance to the area. With such configuration, there is no need for a recurring reconstruction of the confinements of the "red zone". Also decontamination measurements and decontamination measures are only necessary for devices leaving the “red area” (e.g. decontamination may be performed in a double curtain lock section). Recovery is made similar to option 3 with a device working at the front. If packages are severely clamped or damaged, they can be repacked before any transport to the lock (e.g. like in option 2 but within the confinement). In all other cases where WP can be transported, the recovery device transfers the package to a device or vehicle who delivers the recovered package to the lock for further conditioning. For longer distances between front and lock, a more productive transport medium inside the "red area" may be considered (e.g. roller conveyor) to optimise transport times.

Inside the lock, the package are either decontaminated (e.g. when only lose surface contamination is present), over-packed (e.g. damaged or severely contaminated packages) or re-packed (e.g. severely damaged packages) for transport outside the lock.

All activities to secure the access and transport ways also take place within the "red area". In order to be able to parallel this work to the recovery process, a systematic roof support is probably provided by placing steel support frames (e.g. at the front hydraulic props with cross-beam or behind the front for longer lasting support conforming portal frames) which may be possibly better than anchoring the roof (safety, efficiency) if the support frames are placed with a device.

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*Table 8: Pros and cons of option 6*

| Advantage | Disadvantage |
|---|---|
| No frequent replacement or reconstruction of the "red area" necessary | Large "red area" |
| Workers have direct supply with clean and conditioned air, ventilation requirements are mainly triggered by dynamic confinement which may reduce dust and aerosol formation | Workers regularly under full protection.<br>Time constraint for work under full protection: change every 2 hours. |
| Physical works for workers reduced / minimised | Various and versatile equipment necessary |
| Work conditions are not changing.<br>Parallelisation of activities within the "red area" | Skilled and trained workers required to operate complex operations |

## 4.2 Analysis and identification of optimum approach

All options presented are considered to be potentially appropriate and technically feasible.
Only option 1 is limited to areas with good conditions and packages free of collateral damages. Based on experience with similar challenges (e.g. retrieval of wastes from near surface or underground disposals or from highly contaminated areas – chemical industry, nuclear industry and mining industry) a time calculation for each option including the reference option will be done to select fastest and optimum option.

For the calculation of the time required within the scope of this study, only the time-bearing activities are evaluated. Each activity is assigned a required time per unit. These units can be, for example, individual packages or a whole front. Time for activities which are not on the critical path and other factors (e.g. costs) are not considered.

In order to take into account the very different geo-mechanical situations in the different areas, the times of the activities are weighted separately for each category (red, yellow, green, see description in chapter 3.2). In addition, the frequency of occurrence is taken into account in this weighting factor, since not every activity considered must be carried out for every package.

One of the factors massively impacting retrieval time is the clamping of the packages. In order to make realistic but conservative estimates, the StocaMine storage areas with the highest mechanical stresses (categorized as "red" in § 3.2) has been further divided for the sake of modelling: It has been considered that in part of the red area, the packages in a front are not clamped, or only locally. This situation concerns currently 80% of the storage cells (in 2018), but this is bound to decrease rapidly as the convergence progresses. In the other part of the red area, the WPs are already totally clamped, hence more difficult to retrieve. Conservatively, this worst case has been estimated to 20% of the area (in 2018). The conservative ratio 80% / 20% will shift over time and eventually reach 0% / 100% before the end of the 2020s', so there is a high incentive to start retrieval as soon as possible.

The type of waste packages has also been into taken into account in the calculations.
Waste was mainly stored in big bags (BB) and 200 l drums (F) (mostly as 4 on a pallet, but not only). In addition, there are a few other types of containers and arrangements, formally grouped under the category 'autre' (other). The arrangement of these packages in the different access roads / storage cells does not follow any particular system.
A summary of all package types in the respective blocks is shown in the table below (see Figure 29).

DMT PLEJADES Independent Experts

| Post stockage | BigBag BB | Pallete 4 F (P4F) | P 2 F | P 3 F | palettes | C 3 F | Container | Andere (autre) | Sum per block |
|---|---|---|---|---|---|---|---|---|---|
| B11 | 7194 | 1545 | 4 | | | | 35 | 80 | 8858 |
| B12 | 5425 | 1590 | 11 | | | 4 | 1 | 207 | 7238 |
| B13 | 6179 | 1079 | | | | | 52 | 112 | 7422 |
| B14 | 5333 | 793 | | | | | 17 | 72 | 6215 |
| B15 | 2621 | 142 | | | | | | 64 | 2827 |
| | | | | | | | | | |
| B21 | 7446 | 1056 | 1 | 2 | 8 | 1 | 47 | 115 | 8676 |
| B22 | 8779 | 271 | | | | | 2 | 272 | 9324 |
| B23 | 6893 | 256 | | | | | 15 | 20 | 7184 |
| B24 | 5736 | 590 | | | | | 8 | 216 | 6550 |
| B25 | 1449 | 435 | 78 | | | | | | 1962 |
| | | | | | | | | | total |
| Summe inkl. 15 | 57055 | 7757 | 94 | 2 | 8 | 5 | 177 | 1158 | 66256 |
| Summe exkl. 15 | 54434 | 7615 | 94 | 2 | 8 | 5 | 177 | 1094 | 63429 |
| | | | | | | | | | |
| Summary casks | 31222 | 31028 | 188 | 6 | | | | | |
| Summary casks without B15 | 30654 | 30460 | 188 | 6 | | | | | |

*Figure 29: Analysis of packages from reference [10]*

A "reference-front" has been defined for the calculation of the times.

Derived from the quantitative statistical distribution of the packages, this model front consists of 8 big bags + 1,5 packages of the types 'P4F', 'P3F', 'P2F', C3F', 'pallets', 'container' or 'autre'. A total of 63.429 waste packages are to be retrieved to empty the mine (Bloc 15 excluded!).

Additionally to the primary waste which will be extracted at a 'front', secondary wastes will be generated during the retrieval process. This secondary waste will increase the total volume of waste for final disposal, but it will not impact time.

The time calculation takes into account waste contained in all storage sections highlighted in green, yellow or red in Figure 8 (low deformation area, medium def area, high def area), each section of which is assigned 4 fronts. In total, this amounts to 6.960 retrieval fronts.

Individual times for each work process per package (see for instance Figure 30) are based on return of experience and have also been selected to be slightly on the conservative side.

| | Reference Option (based on existing experience) | | | | | | | | | | Option 6 'Adapted mechanisation in established confinement' | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Rock mechanics | flexible (within limits) | | | | | | | | | | highly flexible | | | | | | | | | |
| Package condition | flexible (within limits) | | | | | | | | | | highly flexible | | | | | | | | | |
| Flexibility | Yes, but physical human intervention is high | | | | | | | | | | high due to human control in confined zone but with reduced physical human intervention | | | | | | | | | |
| | | weighting/scaling factor 1=100% | | | | | summary per 'front' [h] | | | | | weighting/scaling factor 1=100% | | | | | summary per 'front' [h] | | | |
| | reference unit | roof, wall, floor ok | locally support required | support required | support required & packages clamped | Time [Min.] | roof, wall, floor ok | locally support required | support required | support required & packages clamped | reference unit | roof, wall, floor ok | locally support required | support required | support required & packages clamped | Time [Min.] | roof, wall, floor ok | locally support required | support required | support required & packages clamped |
| **Retrieval from 'Front'** | | | | | | | | | | | | | | | | | | | | |
| Travel cycle time (outwards-backwards) | per package | 1 | 1 | 1,2 | 1,2 | 10 | 1,58 | 1,58 | 1,90 | 1,90 | per package | 1 | 1 | 1 | 1 | 10 | 1,58 | 1,58 | 1,58 | 1,58 |
| Pick up the package | per package | 0,75 | 1 | 1,25 | 4 | 10 | 1,19 | 1,58 | 1,98 | 6,33 | per package | 1 | 1 | 1,5 | 4 | 5 | 0,79 | 0,79 | 1,19 | 3,17 |
| Taxi / routing / rotate | per package | 1 | 1,25 | 2 | 2 | 3 | 0,48 | 0,59 | 0,95 | 0,95 | per package | 1 | 1 | 1 | 1 | 5 | 0,79 | 0,79 | 0,79 | 0,79 |
| Handover to lock-out | per package | 0 | 0 | 0 | 0 | | | | | | per package | 0 | 0 | 0 | 0 | 3 | | | | |
| Lock-out process (e.g. waiting, close overpack and prepare next one) | per package | 0 | 0 | 0 | 0 | | | | | | per package | 0 | 0 | 0 | 0 | 2 | | | | |
| Extra time / (intervention via tunnel / other works) | per package | 0 | 0 | 0 | 0 | | | | | | per package | 1 | 1 | 1 | 1 | 2 | 0,32 | 0,32 | 0,32 | 0,32 |
| **Creation and removal of zoning** | | | | | | | | | | | | | | | | | | | | |
| Installation of 'red Area' | per 'front' | 0,1 | 0,25 | 0,25 | 0,25 | 360 | 0,60 | 1,50 | 1,50 | 1,50 | per 'front' | 0 | 0 | 0 | 0 | 360 | | | | |
| Sampling / securing of evidence / free measurement | per 'front' | 0,1 | 0,25 | 0,25 | 0,25 | 60 | 0,10 | 0,25 | 0,25 | 0,25 | per 'front' | 0 | 0 | 0 | 0 | 60 | | | | |
| Remedial measures / Decontamination | per 'front' | 0,1 | 0,25 | 0,25 | 0,25 | 120 | 0,20 | 0,50 | 0,50 | 0,50 | per 'front' | 0 | 0 | 0 | 0 | 120 | | | | |
| Deconstruction / Removal / Lifting of 'red Area' | per 'front' | 0,1 | 0,25 | 0,25 | 0,25 | 180 | 0,30 | 0,75 | 0,75 | 0,75 | per 'front' | 0 | 0 | 0 | 0 | 180 | | | | |
| **Securing of roof, walls and floor** | | | | | | | | | | | | | | | | | | | | |
| Temporary support at the 'front' (e.g. props) | per 'front' | 0 | 0,2 | 1 | 1 | 75 | | 0,25 | 1,25 | 1,25 | per 'front' | 0 | 0,2 | 0,75 | 1 | 75 | | 0,25 | 0,94 | 1,25 |
| Endoscopic drillings / other checks | per 'front' | 0,5 | 1 | 1,5 | 1,5 | 30 | 0,25 | 0,50 | 0,75 | 0,75 | per 'front' | 0,7 | 0,5 | 0,7 | 0,7 | 30 | 0,30 | 0,25 | 0,35 | 0,35 |
| Long term support (e.g. steel support frame) | per 'front' | 0 | 0,2 | 1 | 1 | 90 | | 0,30 | 1,50 | 1,50 | per 'front' | 0 | 0,2 | 0,5 | 1 | 90 | | 0,30 | 0,75 | 1,50 |
| Clearance / cutting of roof, walls and floor | per 'front' | 0 | 0,1 | 0,8 | 1 | 60 | | 0,10 | 0,80 | 1,00 | per 'front' | 0 | 0,1 | 0,5 | 1 | 60 | | 0,10 | 0,50 | 1,00 |
| **Intermediate Transport (per vehicle) to repackaging** | | | | | | | | | | | | | | | | | | | | |
| Pick up/place package | per package | 0 | 0 | 0 | 0 | 4 | | | | | per package | 0 | 0 | 0 | 0 | 4 | | | | |
| Travel cycle time (outwards-backwards) | per package | 0 | 0 | 0 | 0 | 8 | | | | | per package | 0 | 0 | 0 | 0 | 8 | | | | |
| **Subsequent package management/repackaging** | | | | | | | | | | | | | | | | | | | | |
| Extra time for package handling/ repackaging | per package | 0 | 0 | 0 | 0 | 20 | | | | | per package | 0,1 | 0,2 | 0,3 | 0,5 | 20 | 0,32 | 0,63 | 0,95 | 1,58 |
| **Intermediate transport (per vehicle) to shaft** | | | | | | | | | | | | | | | | | | | | |
| Travel cycle time (outwards-backwards) | 4 packages | 0 | 0 | 0 | 0 | 20 | | | | | 4 packages | 0 | 0 | 0 | 0 | 20 | | | | |
| Pick up/place package | 4 packages | 0 | 0 | 0 | 0 | 20 | | | | | 4 packages | 0 | 0 | 0 | 0 | 20 | | | | |
| **Intermediate transport through shaft** | | | | | | | | | | | | | | | | | | | | |
| Transport cycle | 4 packages | 0 | 0 | 0 | 0 | 15 | | | | | 4 packages | 0 | 0 | 0 | 0 | 15 | | | | |
| Pick up/place package (trans-loading) | 4 packages | 0 | 0 | 0 | 0 | 5 | | | | | 4 packages | 0 | 0 | 0 | 0 | 5 | | | | |
| | | | | | | Time per 'Front' [h]: | 4,70 | 7,91 | 12,13 | 16,68 | | | | | | Time per 'Front' [h]: | 3,90 | 5,02 | 7,37 | 11,54 |
| | | | | | | Number of 'Fronts' per color (all): | 608 | 2280 | 3257,6 | 814,4 | | | | | | Number of 'Fronts' per color (all): | 608 | 2280 | 3257,6 | 814,4 |
| | | | | | | Time for all 'Fronts' [h] | 2855 | 18036 | 39512 | 13587 | | | | | | Time for all 'Fronts' [h] | 2371 | 11438 | 23998 | 9400 |
| | | | | | | | | | | Summary 73990 | | | | | | | | | | Summary 47206 |

*Figure 30: Time calculation - example of 'reference option' and 'option 6'*

As a first result of the time calculation, the interim step was to obtain the required time for the recovery of one front assigned to the respective geo-mechanical category (green, yellow, red80%, red20%).
In order to compare the options, these unit durations per front for retrieval have been multiplied by the number of fronts in their relevant categories and used for benchmarking the options.
Even if this calculated time is NOT corresponding to the total working time required, but it is well suited to determine the fastest option.
The results are summarized in the following table and show that Option 6 is by far the fastest option:

*Table 9: Time per 'front' calculation results for each option*

| | Reference option | Option 1 | Option 2 | Option 3 | Option 4 | Option 5 | Option 6 |
|---|---|---|---|---|---|---|---|
| Time per front [h], green cat. | 4,70 | 3,60 | 14,23 | 5,29 | 5,64 | 8,67 | 3,90 |
| Time per front [h], yellow cat. | 7,91 | 5,19 | 14,91 | 6,60 | 6,83 | 9,50 | 5,02 |
| Time per front [h], red cat. | 12,13 | x | 16,96 | 10,08 | 9,63 | 10,99 | 7,37 |
| Time per front [h], red cat. & clamped | 16,68 | x | 18,64 | 13,13 | 12,48 | 13,15 | 11,54 |
| **Overall leading time [h]** | **73.990** | **x** | **113.070** | **61.809** | **60.539** | **73.445** | **47.206** |
| ***Time/ref option time [%]*** | ***100 %*** | ***x*** | ***153 %*** | ***84 %*** | ***82 %*** | ***99 %*** | ***64 %*** |

⇨ Option 6 will continue to be pursued as a preferred standard option for further time estimation considerations of a fast and safe retrieval. A scenario combining Option 6 (preferred standard option) with Option 1 (for green areas only) may be considered as optimized scenario.

**Further Optimisation**

There is further optimisation potential, especially through:

- Consistent parallelisation of the 'recovery' and 'support' activities within the 'red area' by two largely independently operating teams
- Parallelisation of some activities at the front (e.g. use of two industrial vacuum cleaners, etc.)
- Customization of equipment for faster handling
- Decoupling of transport and recovery as far as possible

Further optimisations are only presented to illustrate further potential, but its implementation depends on many factors. Therefore, a reasonably conservative calculation is used as a basis to ensure a solid integral conclusion.
Such optimisation is possible and could result in additional acceleration of up to 20% but is typically the task for the supplier of equipment and/or services.

## 5. Simulation and analysis of Specific Scenario

Different scenarios have been developed to estimate and analyse the time needs for retrieval and closure including preparatory works based on the results of the option analysis. As the objective is a time estimate, the focus is given on the modelling of the critical path only (and the processes non-relevant for the critical path "time" have not been modelled).

This modelling and analysis approach may be quoted as a combination of 'operational research' with critical path analysis. The modelling and analysis cover the retrieval phase of wastes, which is main phase being subject of the present analysis, as well as the normally preparatory phase and subsequent closure phase, for which potential parallelisation with the main phase has been considered.

The following few boundary conditions have been assumed for the modelling for all scenarios:

- StocaMine has a permit to store and handle waste. A waste retrieval operation was already carried out (e.g. according reference option or option 1 in 'green areas'), so it is assumed that underground retrieval may be implemented without time-consuming authorisation procedures.
- StocaMine has a permitted safe mine closure plan. Any works related to mine closure can be started without delay as long as there will be no negative interference or interaction with optional retrieval works.
- The diversion of wastes after their retrieval is out of scope of the present analysis. It is assumed that diversion routes for any wastes retrieved do exist. Without this prerequisite, any delay in finding and authorising diversion routes for retrieved wastes may hinder the waste retrieval and block the start or continuation of retrieval accordingly.

Following identification of the fastest option, (Option 6), several scenarios for various logistics (A to D) were studied and submitted to further modelling (see Table 10). All scenarios mainly differ by the number of fronts retrieved simultaneously. In addition, Scenario D considers using a combination of Option 1 and Option 6.

*Table 10: Overview over Scenarios presented*

| Scenario | Description | Critical Path | Comments |
|---|---|---|---|
| **Scenario A**: 1 retrieval 'front' at once | Retrieval is made at 1 front at once<br><br>Preparatory work is assumed to require about 200 work days for planning, approval and procurement and additional 100 days for preparation in underground for the start of retrieval, but can be started 50 days before ending of planning, approval and procurement;<br>5 plugs will be built in parallel to retrieval activities; other closure works will be made after retrieval completion with an time assumption of 595 days | Preparatory works + Retrieval + closure | Option 6 |
| **Scenario B**: 2 retrieval 'fronts' at once | Retrieval is made at 2 fronts at once<br><br>Preparatory work is assumed to require about 200 work days for planning, approval and procurement and additional 100 days for preparation in underground for the start of retrieval, but can be started 50 days before ending of planning, approval and procurement;<br>5 plugs will be built in parallel to retrieval activities; other closure works will be made after retrieval completion with an time assumption of 595 days | Preparatory works + Retrieval + closure | Option 6 |
| **Scenario C**: 3 retrieval 'fronts' | Waste retrieval is made at 3 fronts in parallel with the 3rd front operated less efficiently to reflect possible negative interference between parallel activities<br>Preparatory work is assumed to require about 200 work days for planning, approval and procurement and additional 100 days for | Preparatory works + Retrieval + closure | Option 6 |

| | | | |
|---|---|---|---|
| | preparation in underground for the start of waste retrieval, but can be started 50 days before ending of planning, approval and procurement; 5 plugs will be built in parallel to waste retrieval activities; other closure works will be made after retrieval completion with an time assumption of 595 days. | | |
| **Scenario D**: 3 retrieval 'fronts' & enhanced parallelisation | Retrieval is made at 3 fronts at once; Retrieval of 'green' categories or at the beginning of storage areas will be retrieved in parallel with preparation under existing authorisation; Preparatory work is assumed to require about 200 work days for planning, approval and procurement and additional 100 days for preparation in underground for the start of retrieval, but can be started 50 days before ending of planning, approval and procurement; 5 plugs will be built in parallel to retrieval activities; other closure works will be made after retrieval completion with an time assumption of 595 days | Preparatory works + Retrieval + closure | Option 6 & Option 1 for areas without constraints ('green' units) |

**<u>Element included in each scenario: Preparatory works:</u>**

Detailed planning and procurement are necessary for the preparation of the waste retrieval. In addition, it is assumed that approval must be obtained for any new technical approach for waste retrieval other than the approach already used.

A time period of 200 days is estimated for these upfront activities. Further, preparatory works (installation and commissioning of specific devices such as new ventilation or transportation devices) are necessary prior to the start of the waste retrieval, which are estimated to require about 100 days. It is assumed that the underground preparations can already start 50 days before the end of the 200-day process of planning, procurement and approval.

⇨This element represents the same time in all scenarios.

**<u>Element included in each scenario: Closure activities:</u>**

12 plugs are to be placed in a time period of 4 years according the plans of MDPA.

Rapid analysis of the closure plan reveals that 5 plugs are foreseen at places which are not necessary or where they will not interact negatively with ventilation, access or rescue needs. Therefore these first 5 plugs can be installed in parallel with the waste retrieval activities while the remaining 7 plugs are to be installed only after completion of the waste retrieval activities.

The time required for the construction of a plug is conservatively assumed to be 85 days each (about 4 lugs per year). Although it is a plausible assumption that the remaining 7 plugs can be installed more efficiently than the previous ones for (*e.g. a) there will be return of experience for repetitive works and b) installation can be accelerated by preparatory works for plug installation are carried in parallel with the waste retrieval activities*) time for the installation of these remaining plugs is kept to 85 days each. Thus, in all scenarios, 595 days after the completion of waste retrieval are foreseen for the subsequent completion of the remaining 7 plugs.

⇨This element represents the same time in all scenarios.

**<u>Element included in each scenario: Compatibility with internal logistical constraints:</u>**

The boundary conditions for each scenario (Scenario A to D) need to be compatible with internal logistic constraints: staff, waste packages and materials need to be transported through the existing mine infrastructure.

Assuming the use of the mine infrastructure for 12h per day, the utilization (loading) of this infrastructure, especially the shaft, for one waste retrieval front can be estimated. To limit congestions within the transport chain as far as possible (without consideration of complementary buffer and waiting storages) it has been assumed conservatively that 3 transportation cycles per hour can be performed for the shaft and the underground transport. The results of calculation for the utilization (loading) of transport infrastructure by one waste retrieval front is summarised in Figure 31.

According to these calculations the highest utilisation (loading) is occurring during the retrieval of wastes from 'green' areas without constraints (in Scenario D). In this scenario, load calculation is particularly conservative because the averages utilisation (loading) will drop further after removal of green areas.

| | Shaft load | | | | average |
|---|---|---|---|---|---|
| staff | 0,167 | 0,167 | 0,167 | 0,167 | 0,167 |
| waste | 0,203 | 0,158 | 0,107 | 0,069 | 0,128 |
| materials | 0,056 | 0,056 | 0,056 | 0,056 | 0,056 |
| Total | 0,425 | 0,380 | 0,330 | 0,291 | 0,350 |
| | roof, wall, floor ok | localy support required | support required | support required & packages clamped | |
| | Transport load | | | | |
| staff | 0,167 | 0,167 | 0,167 | 0,167 | 0,167 |
| waste | 0,203 | 0,158 | 0,107 | 0,069 | 0,128 |
| materials | 0,056 | 0,056 | 0,056 | 0,056 | 0,056 |
| Total | 0,425 | 0,380 | 0,330 | 0,291 | 0,350 |

*Figure 31: utilization calculation for shaft and transport*

*(note: the colours in this table refer to the geo-mechanical categories shown in Figure 8)*

For the retrieval of waste from 'red' areas which represent the largest part of the total units, the utilization rate is 33%. Therefore, up to three waste retrieval fronts can be operated in parallel under logistical aspects without constraints.

**Calculated duration for scenario A to D**

For each scenario, the required overall times are summarised in Figure 32.

| | Scenario A | | | | |
|---|---|---|---|---|---|
| | Preparation | | | | |
| | 1 'front' at once | | | | |
| | Closure | | | | |
| used option | Option 6 | | | | |
| | Time [d] | Basic team | Retrieval team 1 | Retrieval team 2 | Retrieval team 3 |
| Preparation Phase | | | | | |
| Detailed planning, approval and procurement + installation | | | | | |
| time [d] | 200 | 200 | 150 | | |
| Preparation in underground for start of retrieval | | | | | |
| Advanced removal of 608 'green' fronts with option 1 | | | | | |
| Parallelisation preciding step before [d] | 50 | | | | |
| time [d] | 100 | | 100 | | |
| Retrieval Phase | | | | | |
| first 'front' [d] | 3934 | | 3934 | | |
| second 'front' [d] | 0 | | | | |
| third 'front' [d] | 0 | | | | |
| Closure Phase | | | | | |
| plugs no. 1 to 5 [d] | 425 | 425 | | | |
| plugs no. 6 to 12 [d] | 596 | | 595 | | |
| *Waste retrieval part of Teams:* | | | 4034 | 0 | 0 |
| *Retrieval time - net* (without planning time, post-closure process, methane and incident risk) | | | 16.1 | | |
| Overall time without 'contingency' [d] | | 625 | 4779 | 0 | 0 |
| [year] | | 2.5 | 19.1 | 0.0 | 0.0 |
| Contingency calculation | | | | | |
| Number of parallel workplaces | | | 0.0 | | |
| assumed number of workers | | | 10 | 0 | 0 |
| contingency for incidents/accidents | | | 77 | | |
| contingency for methane | | | 3 | | |
| Overall time including 'contingency' [d] | | | 4859 | d | |
| [year] | | | 19.4 | years | |

| | Scenario B | | | | |
|---|---|---|---|---|---|
| | Preparation | | | | |
| | 2 'fronts' at once | | | | |
| | Closure | | | | |
| used option | Option 6 | | | | |
| | Time [d] | Basic team | Retrieval team 1 | Retrieval team 2 | Retrieval team 3 |
| Preparation Phase | | | | | |
| Detailed planning, approval and procurement + installation | | | | | |
| time [d] | 200 | 200 | 150 | | |
| Preparation in underground for start of retrieval | | | | | |
| Advanced removal of 608 'green' fronts with option 1 | | | | | |
| Parallelisation preciding step before [d] | 50 | | | | |
| time [d] | 100 | | 100 | | |
| Retrieval Phase | | | | | |
| first 'front' [d] | 1920 | | 1920 | | |
| second 'front' [d] | 2014.1 | | | 2014.1 | |
| third 'front' [d] | 0 | | | | |
| Closure Phase | | | | | |
| plugs no. 1 to 5 [d] | 425 | 425 | | | |
| plugs no. 6 to 12 [d] | 595 | | 595 | | |
| *Waste retrieval part of Teams:* | | | 2020 | 2014 | 0 |
| *Retrieval time - net* (without planning time, post-closure process, methane and incident risk) | | | 8.1 | | |
| Overall time without 'contingency' [d] | | 625 | 2765 | 2014 | 0 |
| [year] | | 2.5 | 11.1 | 8.1 | 0.0 |
| Contingency calculation | | | | | |
| Number of parallel workplaces | | | 1.0 | | |
| assumed number of workers | | | 10 | 10 | 0 |
| contingency for incidents/accidents | | | 85 | | |
| contingency for methane | | | 3 | | |
| Overall time including 'contingency' [d] | | | 2853 | d | |
| [year] | | | 11.4 | years | |

| | Scenario C | | | | |
|---|---|---|---|---|---|
| | Preparation | | | | |
| | 3 'fronts' at once | | | | |
| | Closure | | | | |
| used option | Option 6 | | | | |
| | Time [d] | Basic team | Retrieval team 1 | Retrieval team 2 | Retrieval team 3 |
| Preparation Phase | | | | | |
| Detailed planning, approval and procurement + installation | | | | | |
| time [d] | 200 | 200 | 150 | | |
| Preparation in underground for start of retrieval | | | | | |
| Advanced removal of 608 'green' fronts with option 1 | | | | | |
| Parallelisation preciding step before [d] | 50 | | | | |
| time [d] | 100 | | 50 | 50 | |
| Retrieval Phase | | | | | |
| first 'front' [d] | 1341 | | 1341 | | |
| second 'front' [d] | 1341.4 | | | 1341.4 | |
| third 'front' [d] | 1251 | | | | 1390 |
| Closure Phase | | | | | |
| plugs no. 1 to 5 [d] | 425 | 531 | | | |
| plugs no. 6 to 12 [d] | 595 | | 595 | | |
| *Waste retrieval part of Teams:* | | | 1391 | 1391 | 1390 |
| *Retrieval time - net* (without planning time, post-closure process, methane and incident risk) | | | 5.6 | | |
| Overall time without 'contingency' [d] | | 731 | 2136 | 1391 | 1390 |
| [year] | | 2.9 | 8.5 | 5.6 | 5.6 |
| Contingency calculation | | | | | |
| Number of parallel workplaces | | | 2.5 | | |
| assumed number of workers | | | 10 | 10 | 8 |
| contingency for incidents/accidents | | | 95 | | |
| contingency for methane | | | 3 | | |
| Overall time including 'contingency' [d] | | | 2234 | d | |
| [year] | | | 8.9 | years | |

| | Scenario D | | | | |
|---|---|---|---|---|---|
| | Preparation | | | | |
| | 3 'fronts' at once - optimised | | | | |
| | Closure | | | | |
| used option | Option 6 + Option 1 | | | | |
| | Time [d] | Basic team | Retrieval team 1 | Retrieval team 2 | Retrieval team 3 |
| Preparation Phase | | | | | |
| Detailed planning, approval and procurement + installation | | | | | |
| time [d] | 200 | 200 | 150 | | |
| Preparation in underground for start of retrieval | | | | | |
| Advanced removal of 608 'green' fronts with option 1 | 182 | 182 | | | |
| Parallelisation preciding step before [d] | 50 | | | | |
| time [d] | 100 | | 50 | 50 | |
| Retrieval Phase | | | | | |
| first 'front' [d] | 1045 | | 1045 | | |
| second 'front' [d] | 1044.7 | | | 1044.7 | |
| third 'front' [d] | 983.22 | | | | 1092.5 |
| Closure Phase | | | | | |
| plugs no. 1 to 5 [d] | 425 | 531 | | | |
| plugs no. 6 to 12 [d] | 596 | | 595 | | |
| *Waste retrieval part of Teams:* | | | 1096 | 1095 | 1092 |
| *Retrieval time - net* (without planning time, post-closure process, methane and incident risk) | | | 4.4 | | |
| Overall time without 'contingency' [d] | | 913 | 1840 | 1095 | 1092 |
| [year] | | 3.7 | 7.4 | 4.4 | 4.4 |
| Contingency calculation | | | | | |
| Number of parallel workplaces | | | 3.0 | | |
| assumed number of workers | | | 12 | 12 | 10 |
| contingency for incidents/accidents | | | 96 | | |
| contingency for methane | | | 3 | | |
| Overall time including 'contingency' [d] | | | 1938 | d | |
| [year] | | | 7.8 | years | |

*Figure 32: Scenario calculation*

In Figure 32 three different durations are displayed for each scenario:

- The net time required for waste retrieval only is shown with grey background
- The time required for preparatory works + waste retrieval + closure is highlighted in yellow
- The time required including contingency for accidents and incidents is shown with red background at the bottom of the table.

These results, which are summarized separately in Table 11 confirm that time can be reduced significantly with simultaneous operations, but that the reduction is not linear (it means: doubling waste retrieval fronts will not cut in half the required time).

In summary, by increasing the number of retrieval work places from 1 to 3 the total required time including contingency for accidents and methane events can be reduced from some 20 years to some 8 years. Scenario D proves to be the best time-saving option.

The three essential times are summarized in the following table:

*Table 11: Scenario calculation – Time requirements*

| Time [years] | Scenario A (1 retrieval front) | Scenario B (2 retrieval fronts) | Scenario C (3 retrieval fronts) | Scenario D (3 fronts, further parallelisation) |
|---|---|---|---|---|
| **Retrieval time – net** | **16,1** | **8,1** | **5,6** | **4,4** |
| **Overall time without 'Contingency'** | **19,1** | **11,1** | **8,5** | **7,4** |
| **Overall time including 'Contingency'** | **19,4** | **11,4** | **8,9** | **7,8** |

For information, a similar time calculation for the 'reference option' with two retrieval 'fronts' (comparable to above Scenario B in combination with Option 6) results in a net retrieval time of 12,5 years, in an overall time without 'contingency' of 15,5 years and in an overall time including 'contingency' of 16,1 years.

# 6. Evaluation, Conclusions & Recommendations

The first ranked scenario D utilising the preferred option for technical retrieval approach results in a required time of about 8 years for retrieval and closure of StocaMine when starting planning at the beginning of 2020 at the latest. The evaluation is based on practical experience and reasonable assumptions.
Year 2019 could be well used for preliminary an ancillary studies, such as a detailed evaluation of the non-time-related factors and cost-benefit analysis (see § 6.3). Beginning of 2020 is considered to be a reasonable project start, as it still allows retrieval on a technical point of view, but also give some preparation time to optimise/mitigate the factors of delay (see § 6.1).

Assuming that main strategic decisions on decisions could be taken in the course of year 2019, the retrieval project could start at the beginning of 2020 and be implemented in about 8 years. This would mean a completion in 2027. Any later starting date is likely to increase the overall duration, and any start later than the mid 2020's (about 2025) would be associated with considerable technical challenges and even a risk of failure. This risk will get so high with time that retrieval (and closure) will probably become impracticable from the end of 2020s on.

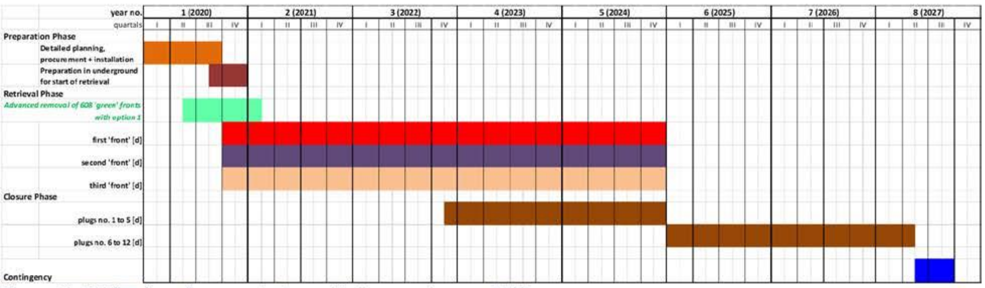


*Figure 33: GANTT chart for scenario D considering start January 2020*

This tight time line for intervention raises a number of questions including:

- Are there risks of further delays which may increase the failure of retrieval?
- Are there specific options to prevent or absorb any such further delay risks?

These two questions have been explored further to complete the understanding of the meaning of computed figures.

## 6.1 Evaluation of Delay Risks

This evaluation is made along the critical path comprising the phases: preparation, implementation of retrieval and implementation of closure.

The most expedited scenario identified is Scenario D, which already foresees a parallelisation of the preparation, the retrieval and closure phases.
A number of risks associated to each of these phases have been identified and assessed.

A comprehensive risk register has been compiled for these three project phases in the next tables (Table 12, Table 13 and Table 14).

*Table 12: Main relevant risks for delay of safe retrieval during preparation phase*

| | Description of assumption at risk | Triggering event for risk | Probability of occurrence | Consequence | Mitigation options / comments |
|---|---|---|---|---|---|
| Preparation Phase | Decision taking:<br>- For removal<br>- For implementation scheme (own or hired staff and equipment)<br>is assumed to be available during and latest by the end of 2019 | Decision delayed or blocked by controversial positions. Complementary substantiation is necessary for decision-makers or adjustment of decisions | Medium to high | All subsequent activities delayed by postponing the decision. No retrieval can take place. | Initiating complementary substantiation at an early stage (e.g. in parallel with decision process). Necessary complementary substantiation may comprise: justification of retrieval (see below), cost estimates, design and implementation outline |
| | Functional design based on present pre-conceptual outline is sufficient and is assumed to be available by about April 2020. Design is necessary for:<br>retrieval (equipment and works)<br>ancillary supporting infrastructure (e.g. for ventilation, transport, safety/rescue provisions) | No sufficient functional design available within about 3 months | Medium | All subsequent activities delayed by postponing the decision. No retrieval design can take place. | Initiation of functional design at an early stage (e.g. in parallel with decision process). The option 1 needs only minor complementary design as it has already been practised successfully.<br>The new retrieval approach according option 6 is based on existing technologies and the main challenge is for the logistics and supply of the parallel work places, which is of manageable complexity. |
| | Authorisation is assumed to be available by September 2020 | Regulatory body may require more substantiation or reject the further removal for principle reasons (see below) | Medium to high | All subsequent activities delayed by postponing the decision. Without relating authorisation no retrieval can take place. | The restart of retrieval activities with option 1 should not be a major issue except that retrieval as such needs to be substantiated.<br>Initiating complementary substantiation at an early stage to justify retrieval as such (e.g. in parallel with decision process)<br>The authorisation of new retrieval approaches is also on the critical path may require more discussions but the complementary challenges are of manageable complexity. |
| | Funding is assumed to be available by June 2020 based on decisions taken. | No sufficient funding available before tendering | High | All subsequent activities postponed until funding available. No retrieval can take place. | The retrieval will require substantial investment and operating costs. |
| | Tendering (2-step process with ca. 2+3 months) are started in Summer 2020 and completed during 2020:<br>- For retrieval equipment<br>- For ancillary supporting infrastructure (e.g. secondary ventilation, transport means, safety and rescue provisions)<br>- For retrieval works | Failure to ensure timely tendering process:<br>Will be probably one or several 2-step European tender procedures requiring ca. 2+3 months. Timely contract-award processes may fail due to:<br>- Late initiation<br>- No eligible bidders<br>- Eligible bidders are not able to deliver as expected | Medium | All subsequent activities delayed until contract award process completed. No retrieval can take place. | A procurement plan needs to be established as soon as decision will be available. Tendering procedure may be implemented in parallel with authorisation processes (at least the 1st step 'selection of qualified bidders' may be initiated in parallel with authorisation or even already with design in advanced stage). |
| | Existing mine infrastructure removal after upgrade is sufficient to cope with the anticipated | Time between decision and implementation start is not sufficient to implement necessary upgrades (if any) | Low | Availability of appropriate mine infrastructure is a key success factor (accordingly: unavailability is a key miss factor). Any delays in this issue may slow down or delay corresponding retrieval | Maximum mine infrastructure capacity is limited to shaft and access corridor availability to 12 hours per day, to 3 transport cycles per hour, to 20 $m^3/s$ of ventilation and up to 4 work places operational at once. These conservative limits may be checked and eventually adjusted accordingly after review of available equipment. The review shall be initiated shortly after decision taking. Adjust maintenance, repair and replacement plan to ensure sufficient mine infrastructure. |



*Table 13: Main relevant risks for delay of safe retrieval during preparation phase*

| | Description of assumption at risk | Triggering event for risk | Probability of occurrence | Consequence | Mitigation options / comments |
|---|---|---|---|---|---|
| Retrieval Phase | Implementation of Option 1 (for no problem areas) can be initiated shortly after decision and in parallel with remaining preparation phase | Equipment is not available (due to ageing of existing equipment)<br>Specialised staff is not available (because not foreseen in the HRM plan)<br>Conditions are worse than expected | Medium | If option 1 cannot be implemented in parallel with preparation works there is a risk of ca. 9 months of delay when retrieval of ca. 608 unproblematic 'fronts' is delayed or not implemented. | Initiate available equipment review shortly after decision taking. Adjust maintenance, repair and replacement plan to support early implementation of removal of unproblematic fronts.<br>Initiation of functional design at an early stage (e.g. in parallel with decision process): The option 1 needs only minor complementary design as it has already been practised successfully. Therefore no major obstacles than rejection in principle may be expected (see above) |
| | Scenario D cannot be implemented as foreseen | Necessary equipment is not available in time<br>Necessary staff is not available in time/ throughout implementation<br>Conditions are worse than expected<br>Parallelisation of activities are too complex for the available resources | Medium | Retrieval may take more time. Assuming a slow-down of productivity by 20-25% about 1 additional year for removal may be required.<br>This is plausible and would correspond to scenario C with lesser complexity. | Initiation of functional design at an early stage (e.g. in parallel with decision process). The new retrieval approach according option 6 is based on existing technologies and the main challenge is for the logistics and supply of the parallel work places, which is of manageable complexity. By close interaction during authorisation and tender preparation possible time constraint for equipment manufacturing and installation as well as staff training may be advanced.<br>Nevertheless the less complex scenario C may be a fall-back option. |
| | Geo-mechanical conditions (convergence, roof, walls and floor damages) are in a progressed detrimental stage. | Delay in decision and preparatory works, geo-mechanical parameters are worse than predicted | Medium | Packages are frequently clamped and damaged such that foreseen efficient retrieval cannot be implemented. | Can be compensated with corrective action: wastes from damaged packages needs to be repacked. For the majority of waste packages (big bags containing bulk grain sized or powdery bulk) repacking could be performed with 2-3 suction units within the assumed process time frames (see specific analysis below). |
| | Accidents slow down retrieval process | The accident probability and consequences are higher than anticipated. | Low | Limited consequence: retrieval operation may be stopped to recover from accident increasing overall time of retrieval. This has occurred frequently in the past (1,28 d lost per 1000 h worked) | The route cause for the major part of the accidents is due to intense physical works of workers in dangerous environment. Although the majority of retrieval and practical all of the retrieval in high deformation areas is planned to be performed with option 6 aiming for high mechanisation and minimised exposure of workers to intense physical works in dangerous conditions the relatively high accident rates have been maintained and assumed for calculation of delays (more than 3 months of contingency in total) which is considered to be largely on the safe side |
| | Methane incidents slow down retrieval process | Methane incident is occurring in the same frequency as in the past | Low | Small consequence: in the past one incident with local effect of few hours per 3 block (work day lost) due to vertical boring into the roof | The root cause of vertical boring is minimised in option 6 such that occurrence should be lower than in the past. Nevertheless same probability of occurrence and consequence has been assumed. |
| | Negative interaction with closure works initiated in parallel with retrieval works | Interaction could occur due to use of the same general infrastructure provided by the mine (e.g. transport in corridors, shaft, ventilation) | Very low | Very small consequence if appropriate planning of logistics and ancillary activities and by systematic cross-checking of possible interactions is available | Appropriate planning of logistics and ancillary activities and by systematic cross-checking of possible interactions. The parallel construction of first plugs is not on the critical path and has sufficient reserve time for giving priority for retrieval activities which are on the critical path. |

*Table 14: Main relevant risks for delay of safe retrieval during preparation phase*

| | Description of assumption at risk | Triggering event for risk | Probability of occurrence | Consequence | Mitigation options / comments |
|---|---|---|---|---|---|
| Closure Phase | Advanced closure of 5 plugs not interacting with retrieval works is not possible | Insufficient mine infrastructure to cope with simultaneous closure and retrieval<br><br>Plugs are placed in areas where relevant interaction is still possible | (very) low | The construction of some of the plugs needs to be deferred until interfering retrieval actions are completed. However, in difference to waste retrieval, the closure of plugs is currently not so time critical such that time/ space for deferral still exist | Interaction can be probably reduced by adequate planning. |
| | Closure of remaining 7 plugs will be delayed | Delay in retrieval completion<br>Delay of completion of 5 plugs | Low | Construction of remaining plugs will be deferred. However, closure of plugs is currently not so time critical path such that time/ space for deferral still exist. | As the closure is not on the critical path for retrieval delays may be probably managed. A contingency planning for timely completion of mine closure activities with time recovery options may further relax any delay situation. |
| | Closure of remaining 7 plugs will take more time | Technical and/or financial factors | Low | Completion of remaining plugs will be postponed. However, closure of plugs is currently not so time critical path such that time/ space for deferral still exist. | Same as above |

Conclusions for modelling and planning:

- The preparation phase is subject to possible roadblocks and delays which may defer overall subsequent implementation. The most important risk factors in this phase are timely availability of decisions, authorisations and funding. Any delay is detrimental but may be probably recovered if completion of preparation phase is not postponed by more than 6 months. Possible delay mitigation options are identified but their implementation will require enhanced management efforts.
- The retrieval phase is subject to possible delays mainly due to delays in the preparation phase. The most pertinent delay risk factor is associated with geo-mechanical risks: convergence and damages may be more widespread than anticipated, thus complicating and slowing down retrieval and increasing failure risks. This risk needs to be analysed in more detail which is done separately below.
- The completion of closure phase can be advanced by parallelisation of works: by advanced construction of 5 plugs which can be placed without interacting with retrieval activities. However, unlike retrieval activities, the damages in the corridors, where the plugs are to be set are likely to be much smaller than in the storage areas themselves, such that the closure activities are less time-critical than the retrieval activities. Most of time risks are already covered/buffered by the pre-conceptual layout of the scenario D. In this scenario, the only time-related factor not taken into account would be failure of advanced retrieval of 608 'non-problematic fronts' (as per Option 1), which may result in a delay of some 9 months.
- Due to contingencies, all together the above risks may be associated with possible further delays of some 6+9 months or 1 +/- 0,25 years. Reducing the contingency time loss is deemed still manageable but may increase project complexity (e.g. due to technical challenges, accident risks).

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## 6.2 Sensitivity analysis of the Scenario D time calculations

Based on the time evaluation for scenario D and the associated risk scenario described in the previous subsection a rapid sensitivity analysis is performed as follows:

**Base calculation:**
The time evaluations indicate a mere removal time of about 4,5 years and of about 8 years in total for preparation, removal and closure under the expected current geo-mechanical situation in the high convergence area (80% with no or little amount of severely clamped packages – modelled as 2 clamped WP per front /20% with most WP firmly clamped – modelled as 6 clamped packages per front).

**Sensitivity of the retrievability time of clamped packages in high deformation risk areas:**
The question if retrieval in the areas with predominantly clamped packages can be still managed in the assumed time frames can always be answered with 'yes': even if most the big bag packages are clamped, they can be unclamped by suction of the (part of the) inventory and repackaging in new packages by suction technology. This technology (which has been tested already at StocaMine) is a standard technology in industry for problematic bulk waste handling (chemical industry, nuclear industry). A complete repackaging of a 1 m³ big bag may require 30 to 60 minutes. The worst case and longest duration is needed when the clamping is so advanced that the package itself has been so damaged that the content is out and has to be entirely collected and re-packed.
In the normal case, on a technical point of view, unclamping can probably be achieved by partial (half) emptying and repackaging of any given WP. Such an operation would take about 15 to30 minutes. The limiting (time consuming) factor of this technology is the possible consolidation and efficiency of remobilisation by pneumatic methods, which may be enhanced by mechanical tools mounted to the suction nozzle facilitating the disassociation of the contents. Assuming that out of 10 big bags about 6 big bags need to be unclamped, two suction units (including the necessary separation and cleaning units) would be sufficient to achieve it (at least 3 or more unclamped packages per hour by partial repackaging). A 3rd unit may be considered to increase repackaging performance (in theory in minimum 3 complete repackaging should be possible within 1 hour).

*Table 15: Managing of possibly clamped packages in high deformation areas*

| Description | Consequences | Assumed net average retrieval time per front (Option 6) without supporting and ancillary activities |
|---|---|---|
| Free space remain around the packages in 3 direction | No clamping, clearance of the top of packages may be necessary prior to removal by lifting | Ca. 3,5 h |
| Free space around the packages has disappeared in 1 or 2 direction such that packages are clamped and interlinked | 2 to 6 packages needs to be unclamped.<br>This can be achieved by suction with partial or complete emptying of each clamped package (ca. 15 to 60 min per clamped package) | Ca. 3,9 h to 5,9 h<br>The additional time compared with the above is plausible as with 2 suction units 2-6 packages can be unclamped in 2h. Performance may be even increased by use of a 3rd suction unit |

Thus it is concluded that even under unfavourable conditions the indicated retrieval time per front is sufficient although the retrieval operation is becoming more complex and tight.

**Sensitivity of the geo-mechanical settings: when the situation is better or worse than assumed/expected:**
In difference to the base calculation the frequency (probability) of 'fronts' with frequently clamped packages has been tested in the model by varying the ratio from 0% and 100% (instead of baseline value of 20%). The effect for retrieval and closure is shown in following Figure 34:

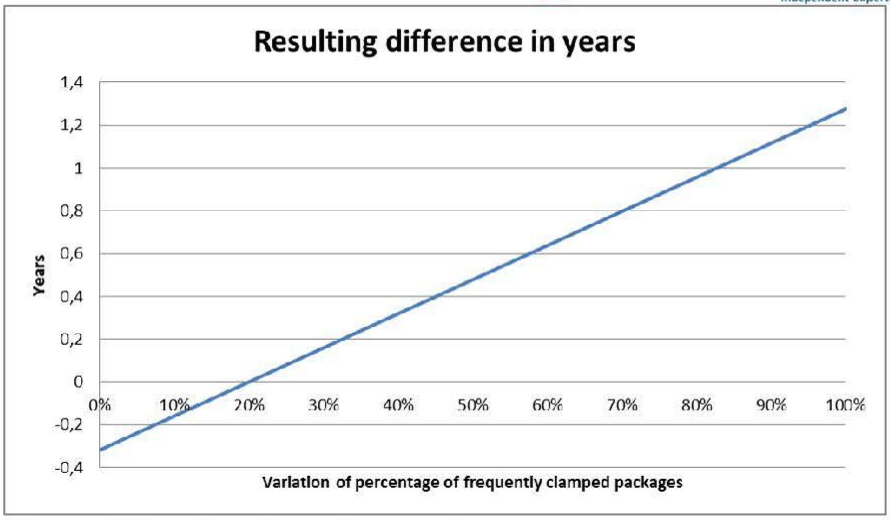


*Figure 34: Variation of clamped packages between 0% and 100%*

Conclusion:
The variation of the frequency of clamped packages leads to a variation of time for retrieval and closure between -0,3 years (reduction) to 1,3 years (increase) for Scenario D.

**Sensitivity of other risk factors:**
The potential delay risk due other risks identified in subsection 6.1 has been retained as up to 1 +/- 0,25 years if all risks materialise as described.

**Optimisation potential:**
Further parallelisation of retrieval activities could offer some optimisation potential for Scenario D.
The total optimisation potential is estimated to 5 to 20% or 1 +/- 0,6 years.
*Note: the assumption is that there are no constraints for diversion of retrieved wastes (diversion routes and transport logistics are available such as there is no bottleneck on the surface).*

**Overall conclusion:**
The sensitivity analysis confirms the relative stability of the time computing for scenario D.
In the worst case compared to the total time for preparation, retrieval and closure will be increase by about 2,55 years. In the most optimistic case, a time-reduction of about -1,9 years will be achieved. This may be summarized as a range of time deviation against base calculation of 0,325 +/- 2,225 years.

These results are shown in Figure 35. On this figure, the threshold (2025) after which risks for waste retrieval increases so rapidly that continuing retrieval is questionable (high failure probability) is also displayed. It appears that under optimistic assumptions the waste retrieval is completely before the geo-mechanical risks are increasing and that under pessimistic assumption retrieval time is reaching the time point where retrieval becomes questionable due to high failure risk in high deformation areas.

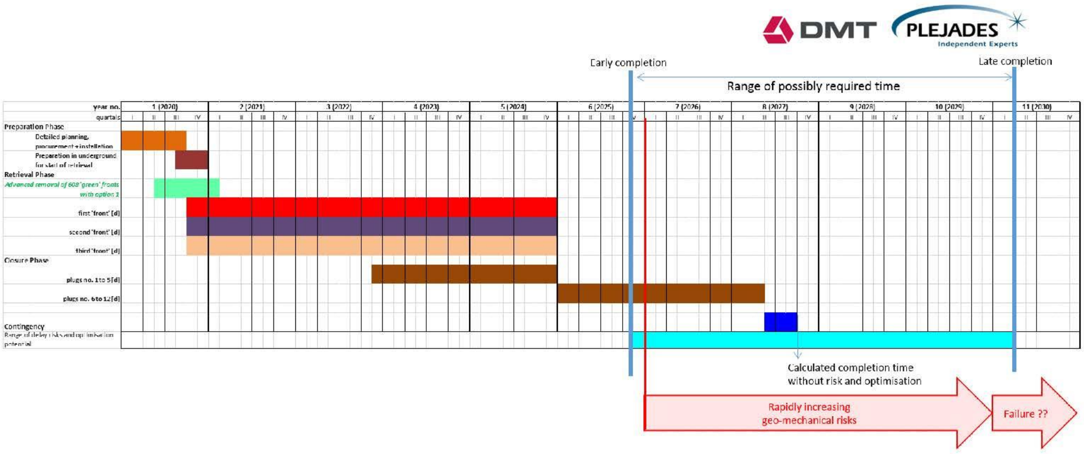


*Figure 35: Calculated completion time for Scenario D (with range of delay risks and optimisation potential) and geo-mechanical risks*

As it can be seen in the above figure that, assuming retrieval can start by the 4th quarter of 2020, the completion of retrieval could be completed by the end of the year 2024 and closure in the second quarter of 2027. Project completion may be achieved by the end of 3rd quarter of 2027 when taking into account contingencies. Under assumption that above risks materialise completion would shifted to begin of second quarter of 2030 and under most optimistic assumptions completion could occur in 2025.

This results in a range for predicted completion between end of 2025 (early completion) and beginning of 2030 (late completion).

As it can be also seen in this figure, the predicted completion date may already occur sometime during the period of rapidly increasing geo-mechanical risks and elevated failure risk.

Based on this analysis it can be concluded that from time perspective only, retrieval should be possible if

- it starts as early as possible and no later than 2020
- a systematic, effective and efficient Risk Management Plan is implemented in parallel with the works implementation including: monitoring risks (risk register), reducing probability of occurrence, reducing possible consequences and recovering for any negative effects (contingency planning) incurred by risks materialised.

## 6.3 Input for evaluation of non-time-related factors

The previous evaluations including a comprehensive risk analysis have been performed with focus of time aspects.
However in any normal project evaluation other aspects are to be considered, such as safety, risks, efforts and costs.

Typically for decision processes cost-benefit-analyses (CBA) may be a good tool to substantiate or to support any decision to be taken. Cost-benefit-analyses can be developed on monetary and non-monetary background.

In safety projects (e.g. environmental remediation, nuclear safety projects) non-monetary Cost-benefit-Analyses are quite frequently used:

- Benefit is quantified in level of safety improved: e.g. as reduction of contamination; reduction of contamination exposure; reduction of radiation or radiation exposure; etc. and in the ultimate case in reduction of life time expectancy (e.g. due to exposure reduction)
- The cost is quantified by the risks vested to achieve the benefit: e.g. amount of works implemented linked to accident and health wearing risks, amount of wastes generated and transported for diversion; dose uptake to perform works; etc. and in the ultimate case life time expectancy vested.

Assuming that the primary objectives of the safe management of wastes at StocaMine and the safe and sustainable StocaMine closure is 'safety for the general public, workers and the environment', then safety aspects to be considered in a non-monetary Cost-benefit-Analysis could consider on the cost side:

- Accident risks and health wearing risks for workers related to waste retrieval
- Waste produced = waste retrieved and transported
- Risks related to new waste diversion route (e.g. disposal at another site)

Analysis could consider on the benefit side:

- Increased safety /reduced risks related to StocaMine site due to retrieved waste

There are different approaches to use the results of such analysis in remediation projects, e.g.:

- Overall remaining risk is reduced to acceptable level for long term (sustainably)
- Risks taken (risk vested) are lower than the risks reduced (risks eliminated)
- Identify specific inventory compartments with high removal priority (e.g. waste forms not compatible with the current disposal geological environment or where the risk for removal is considerably lower than the risk when left in place) and inventory compartments with low removal priority (e.g. waste form is compatible with the disposal geologic environment which may be the case of inert solid wastes (eg REFIOM, REFIDI?) or the risk for removal is considerably higher than the risk when left in place (eg déchets amiante?)
- Check if funding is feasible.
- Beside the justification and funding of the waste retrieval from expert point of view, it should be also checked if it is not worthwhile to vest alternatively the same efforts, or even more efforts in perfecting the mine closure measures. Although the present mine closure plan can be considered as sufficient and safe as it has passed successfully authorisation procedure, there might be still complementary measures that could be added to increase the safety further (e.g. backfilling configuration, protective flooding)

The overall decision tree to check and decide measures for optimising safety of a closed underground waste storage facility is illustrated in the following figure:.

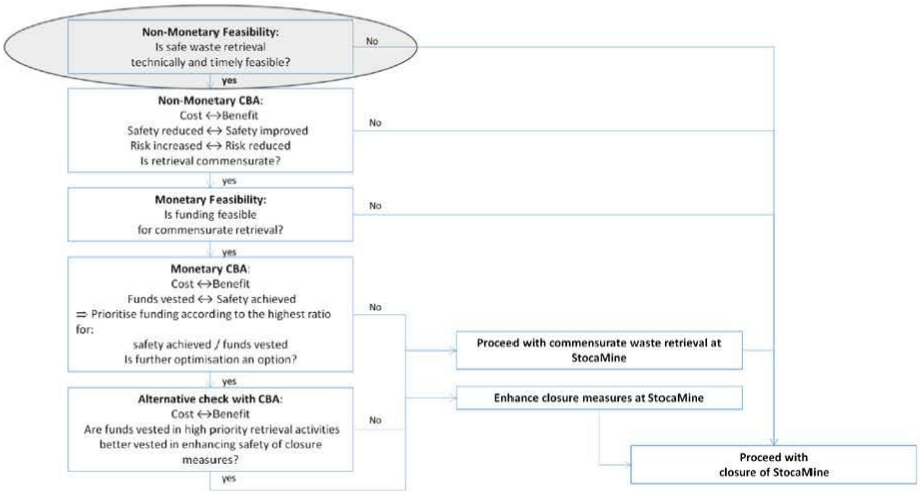


*Figure 36: Decision tree from expert point of view to ensure the configuration a safe closure of StocaMine with a commensurate waste retrieval*

The competent regulatory bodies may request such analysis to justify the proposed remediation activities by demonstrating that they are commensurate before authorisation to proceed may be given.

The above conclusions are made with reference to Scenario D and the boundary conditions assumed therein.

One may challenge these conclusions by questioning the Scenario D and the boundary conditions in the sense of more fundamental "what if?" questions such as:

### "What if ?" - questions:

- **Decision will take longer such that start of preparatory is delayed beyond begin of 2020**:
  The decision process is on the critical path. Any delay will delay start and completion of projects. Some preparatory activities may be started in parallel of a pending decision.
  → possible consequence is that any delay of decision will result in delay of start and completion of retrieval and closure of StocaMine.
- **Scenario D utilising options 1 and options 6 is too complex for implementation**:
  In such case Scenario C with less complexity may be considered. Scenario C requires about 1 year more time for retrieval.
  → possible consequence is 1 additional year
- **The operator will require more preparatory time for Scenario D** (configuration, authorisation, procurement, installation and testing):
  Currently Scenario D foresees expedited/advanced start option 1 which is quite similar to the already configured, authorised and implemented reference option and should therefore not be a major problem. Option 6 is however more complex and no corresponding StocaMine site experience and no authorisation exist yet (although many elements may be similar to the already existing reference option). If the foreseen start time of 4th quarter 2020 for retrieving waste with option 6 is too ambitious one may consider more time for preparation, but then the option of complete retrieval

becomes technically very challenging. .
→ possible consequence is 1 additional year

- **The waste routes for retrieved waste packages are not secure / will not be available**:
In such case, retrieval of wastes becomes highly questionable as this would mean transfer of packages from a relatively safe context (underground storage with only limited possibilities of adverse evolution induced by natural events or human action) to a less certain and safe context (above ground interim storage, which may even last long time with much more possibilities of adverse evolution induced by natural events or human action). However, the majority of the waste stored at StocaMine is inert or mineral waste, for which alternative storage facilities (e.g. underground storage) do exist.
→ possible consequence is reduced safety (increase of risks) for general public, workers and environment making questionable the waste retrieval
- **The diversion of retrieved waste packages requires more time**:
If preparatory time is not sufficient to organise the diversion of retrieved waste packages this puts continuation of waste retrieval at risk. This risk could be managed by setting a surface interim storage facility for retrieved wastes, which can be used not only for intermediate storage but also for sorting and routing waste package making diversion more efficient. However the design, licensing and implementation of an interim storage for hazardous waste make take unforeseeable additional time. Although it may possible that within a remediation project under severe time constraints an project related interim storage may be considered as necessary temporary measure which would justify simplified and expedited authorisation processes, it may take easily 2 years if not more resulting in an overall delay of 1-2 years or more.
→ possible consequence could be 1-2 years or more

If any situation as described in the still hypothetical questions above happened to materialise, it would result in a negative impact for this project: project risks in terms of additional delays risks with increasing deteriorating retrieval conditions or even in terms of increasing project failure risks.

## 6.4 Expert Conclusions & Recommendations

The Expert conclusions can be summarised as follows:

➔ The geo-mechanical risks will increase rapidly from the mid 2020's in the areas with high geo-mechanical deformations. By the end of 2020's (probably from 2029) the efficient retrieval of wastes will become highly questionable as geo-mechanical deformations in the critical areas will reach levels where waste packages will be severely damaged from extensive clamping, leading to interlinking with the converging rocks. At this point the waste material cannot be sorted from the rock any more.

➔ Under the boundary conditions analysed the majority of waste inventory (except for Block 15) can be realistically retrieved before the end of 2020's with high probability if the activities are configured adequately: use of adapted approach with high mechanisation, enhanced parallelisation of works, coordination with closure works, risk management plan/contingency planning.

➔ However, the waste retrieval remains anyway time critical: it requires timely decisions and initiation of next steps and systematic mitigation of any delay as the completion of retrieval and closure activities are likely to last unto the second half of the 2020's when the geo-mechanical risks are increasing rapidly.

➔ The experts conclude that other aspects than necessary retrieval time need to be taken into account to substantiate any decision related to retrieval or leaving in place remaining waste inventory.

➔ For justification and substantiation for any decision, a dedicated Cost-Benefit-Analysis (CBA) - e.g. non-monetary safety focussed CBA - is highly recommended in a first step and could also support justification of funds vested to maximise the safety achieved with them ('safety for money').

Based on the expert conclusions presented in the previous section the following recommendations are given:

**Recommendations:**

- **Achieve timely completion of the decision process**, with following decision options:
  - Proceed to safe closure of StocaMine with waste retrieval,
  - Proceed to safe closure of StocaMine as planned without retrieval of wastes,
  - Proceed to safe closure of StocaMine with retrieval of wastes to the extent that there is a benefit in terms of safety and financing can be ensured,
  - Proceed to safe closure of StocaMine by checking of enhanced measures which may replace possible waste retrieval option
    (e.g. it is safer to vest in enhanced closure measures than further in waste retrieval),
  - Decision is postponed until a more consolidated decision basis is available based on a comprehensive Cost-Benefit-Analysis.
- **Implement other actions in parallel with decision process** (while decision is pending) :
  - Continue anyway and without delay with closure preparation,
  - Implement all measures which are not conflicting with possible removal,
  - Initiation/preparation of complementary documentation which may be useful or required for decisions (e.g. safety focussed Cost-Benefit-Analysis),
  - Initiation/preparation the necessary documentation for approval for possible additional measures (e.g. for waste retrieval or enhanced mine closure measures).
- **When decision is taken, proceed with safe closure of StocaMine**
  - If waste retrieval is decided positively: initiate early removal of green areas, prepare implementation of new retrieval approach (e.g. Option 6) for other areas, proceed to authorisation, procurement, installation and testing of new equipment and training of staff, prepare all infrastructure and boundary conditions as required;
  - If waste retrieval is decided negatively: proceed to safe closure with or without measures to enhance safety;
  - Proceed to safe closure with or without measures to enhance safety anyway.

## 7. Executive summary

The findings of this study for time needs for possible retrieval can be summarised as follows:

- StocaMine is a licensed waste storage facility which has terminated waste storing operation after a severe accident in 2002.
- Since the accident, mercury-bearing wastes have already been successfully retrieved by MDPA, who is now preparing the safe closure of StocaMine according to authorised closure plans.
- Prior to further proceeding the question was raised if it would be still possible to retrieve the remaining wastes (except the block 15 where the accident happened) under the natural ongoing deteriorating geo-mechanical status. It has been assessed that considering the speed of the convergence phenomena in the mine, technical feasibility of waste retrieval will worsen every year and become compromised from the mid-2020s. The risk of failure is expected to have increased so much by the end of 2020's that any further safe waste retrieval past this date will become questionable.
- With the present study time required for recovering waste packages with different retrieval approaches were analysed and different scenario were calculated in a view of finding the most time efficient approaches.
- When starting "very soon" (beginning of 2020 at the latest), the main result is that under expedited conditions assuming rapid decision, efficient preparation, waste retrieval in 3 fronts in parallel and

advancing different works, the safe retrieval and closure should be completed around year 2027. Sensitivity analysis show possible variation of completion time in a range between 2025 and 2030. This means that under the given assumptions even under pessimistic development remaining waste retrieval and completion would be safely possible (provided there are no insurmountable administrative hurdles).

- One of the major identified risks is the lack of availability of (other) waste management routes for the WP retrieved from StocaMine. In that case, the only way to proceed with retrieval would be to implement a surface interim storage facility, which is in turn questionable in terms of safety gain.
- For all other boundary conditions except the above-mentioned waste route issue, the possible consequences may have a time-impact of 1 to 2 years which is deemed manageable.
- From expert point of view it may be important to ensure that retrieval of remaining wastes will not only be possible in technical and time aspects but also results in increased safety benefit for general public, workers and environment. A complementary analysis is highly recommended accordingly.

# Annexe 4

# Document produit par SAT pour l’étude

StocaMine – Expertise retrait partiel des déchets

# Draft Report: Handling and Repackaging of Toxic Waste from the StocaMine facility

## Expertise on State-of-the-Art practice

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# Table of contents:

## Executive Summary (1)

This expertise concerns retrieval and reconditioning of waste packages currently located in the StocaMine facility.
Based on experience on similar issues, sat Kerntechnik's expert assessment is that timely recovery of the inventory is possible in an effective manner with existing technologies and adequate logistics.
A calculation based on experience shows that, if there were no access constraints, the operations of safe recovery of 67000 waste packages could be achieved in less than 3 years. This, of course, does not take into account the time for ancillary mining activities for stabilization and access preparation.

Without compromising safety at any moment, the option allowing the quickest recovery of the content of one Block starts with setting a physical and dynamic confinement to isolate the block as "Red Area", in which all operations will occur. Access to the red zone is through a hatch to the rest of the mine, considered as "green area".

In the red area, all operators are equipped with full protection suits that can be connected to fresh air supply. This is far more efficient then working with dust masks, in addition to being more comfortable for the staff, who will operate mechanical devices such as small excavators and vacuum packing equipment, but not be required to physically touch the packages.
The red area shall be as large as possible, and can be as big as the whole block.

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## Executive Summary (2)

The main concept, already successfully applied in the chemical industry, it to use the confinement hatch separating red from green area as conditioning area in which all reconditioning and decontamination processes will occur. This area has been named "Blue area".

The blue area will ensure that contamination is not spread to the rest of the mine and/or the environment. Any package, equipment and staff exiting the blue zone will therefore be "clean" and ready to move to the surface. The hatch will therefore be larger than usual similar structures .

Once safe access to the fronts have been created, all waste packages can be retrieved quickly with a small electric-powered excavator. Packages will immediately be transferred to the "blue area". Undamaged packages will be transferred mechanically via a conveyor belt bringing them to the dust decontamination cell of the blue area. Slightly damaged drums or big bags will be moved by excavator or forklift to dedicated automatic overpacking stations in the blue area.

Considering the fact that some packages are already damaged to a point preventing transportation to the blue zone, an additional system for repacking loose waste into drums will be in operation in the red zone. Loose waste and spillages can easily be contained with this industrial aspiration unit.
Based on available information on the type of packages, the main processes (conveyor transport, overpacking, decontamination) can be automatized. This is a major time-saving aspect.

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# Executive Summary (3)

In comparison, time for treatment of non-standard packages (large containers) will be longer, but can be managed by treating all the "problem" packages in one go once the have all been collected from their storage location.

It is expected that the red area will be contaminated by retrieval operations. Decontamination of the air and surfaces will then be performed at the end of the removal operation, before the confinement and blue zone are moved to the next block.

With the proposed layout of the work stations "blue" and "red" areas and selection of equipment, it is our expertise that efficient safe removal and conditioning can be implemented.
However, the mining boundary conditions have to be carefully taken into account in the overall project planning design, and may be higher time-factors than the removal itself.

In addition to the underground operations for retrieval and repackaging, surface installations must be implemented for safe temporary storage of the packages before transport.
Part of the Bâtiment d'Exploitation of the Puits Joseph can be used as buffer station for the initial registration, weighing, documentation operations.



# Executive Summary (4)

"Just-in-time" flow (*flux tendu*), or direct transport from the Buffer area to final disposal would be ideal, but is not a realistic option because of current undecided waste route and multiplicity of waste types.

Pending acceptability in other disposal sites, the retrieved and re-conditioned packages will have to be put in interim storage at MDPA in a dedicated storage area above-ground.

Such a storage area shall have a minimum capacity of 1 year storage, or about 10 000 packages, corresponding to a floor area of 100 x 100 m. In the worst case, storage capacity up to about 70.000 packages have to be implemented and adequately protected against trespassing. In terms of risk, this necessary storage facility is considered to be a safety concern, as it is vulnerable to acts of terrorism.

Beside all technical considerations, there is also a major uncertainty about the feasibility of licensing such a facility, unless MDPA already has one for such surface installations.

# 1. Introduction (1)

This report provide a practical evaluation of optimized handling and repackaging of toxic waste packages from the Stocamine facility, keeping in mind the overall objectives:

- Protect workers and environment, and
- Avoid contamination

In both cases, the lead optimization parameter for this study was **time**. Financial aspects were not considered in the assessment, but indirect cost factors, i.e. the risk (in terms of loss of human life, loss of life expectancy) was another driving parameter for recommendation on work processes and technologies.

Specific objectives taken into account in the optimization are:

- Protect environment: confine contamination (create barrier if not existing)
- Protect workers: prevent exposure of workers from contamination by work preferably outside contaminated area, and if this is not possible protect workers adequately
- Ensure adequate confinement/containment of waste in packages, with waste being the relevant contamination source
- Ensure sufficient control of specific safety cases
- Ensure removal/confinement of any contamination spread during operation by appropriate decontamination/confinement technologies.

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# 1. Introduction (2)

The main relevant boundary conditions for safety for the selection of appropriate Handling and Repackaging processes have been identified as follows:

| Type | Description | Consequences for handling and repackaging |
|---|---|---|
| Contamination transfer | Some packages are already damaged beyond repair – Other may be damaged during retrieval operations | • A System is needed for packing loose waste<br>• Decontamination of surface of packages needed<br>• Decontamination of working area needed at the end of operations |
| Dangerous work | By nature, physical works in a very narrow environment are associated with high number of incidents/accidents | • Limit physical intervention. Use mechanical tools able to be remote-operated<br>• Limit number of staff + equipment at one working station / front |
| Dust | • High emissions of dust expected during works (dry environment, salt mine)<br>• Most materials in powder form, especially REFIOM / REFIDI and Asbestos waste | • Dust prevention systems<br>• Selection of PPE (masks at least FFP3 in any location, or full protection in “red area”)<br>• Dust emissions will considerably hinder tele-operated work by interfering with cameras: operators have to be physically present, even if they don’t do physical work |

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# 1. Introduction (3)

| Type | Description | Consequences for handling and repackaging |
| --- | --- | --- |
| Toxic waste | Some packages (drums, big-bags) are damaged- Partial to complete loss of integrity | • Selection of PPE to prevent exposure, and/or remote work<br>• Need for decontamination of spills |
| Methane presence | Pockets of methane in some of the strata can be released during works | • Ventilation for swift dilution of methane emissions<br>• Full PPE with fresh air supply favored |
| Narrow & dangerous Working environment | Access corridors, shaft have limited dimensions/capacities for transit of staff, equipment and waste | • Minimize number of workers at each working station<br>• Limit size of mechanical equipment<br>• Limit transports |

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# 1. Introduction

The description of methods applicable to the Stocamine site has been organized into the main steps related to handling and repackaging:

- How to create a confinement prior to retrieving the waste packages
- Protection of workers
- Criteria taken into account for selection of safe handling methods
- Proven and suitable re-packaging methods
- Decontamination technologies for implementation after waste removal / before mine closure
- Input parameters used to estimate the retrieval time for each option (modelling parameters)

The last chapter provides Conclusion & Recommendations based on practical experience on comparable works.

Pictures illustrating the different Handling & Repackaging steps and methods have been included for enhanced clarity.

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## 2. Creation of Confinement (1)

A confinement system has to be installed before start of work in a Block to **prevent contamination transfer** during handling / transport. The selection of appropriate confinement is also very important for the definition of the Personnel Protective Equipment to be worn in each area of the facility.

Options for confinement are described hereafter:

- Creation of barriers to mitigate spread of contamination and exposure of workers to contamination by
  - physical confinement (constructed barrier excluding contaminant transfer),
  - dynamic confinement (controlled contaminant flow with interception and/or
  - combination.
- Technical approaches for physical confinement:
  - Area confinement (Zoning),
  - Local Confinement
  - Glove Box / Confinement Tent Approach
  - Approaches for Lock-in / Lock-out personnel and materials
- Technical approaches for dynamic confinement:
  - Under-pressure, with filtering, washing etc. of exhaust

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## 2. Creation of Confinement (2)

### Suitable confinement structures with lock systems can be derived from experience in the nuclear industry

For example, barriers and Locks to "red zone", blocks, can be created with frames + foil and specific openings.

Fig: close up view of portholes equipped with gloves and with a lock-out system for 200L drums

Fig: Example of tent for decontamination of highly contaminated objects in the nuclear industry

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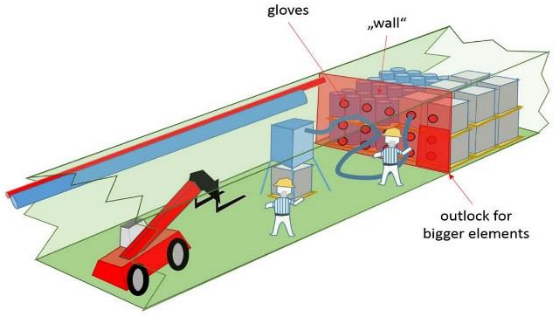
## 2. Creation of Confinement (3)

Any or a combination of the above-described confinement options can be implemented at StocaMine. The "tent" option shown previously has been considered in one of the options.




Example of confinement and work stations considered in the study

Fig: Schematic design of option with using "tent" like confinement
Source: Plejades, DMT

Though this is a proven safe method for working in severe contamination areas, it is not considered practicable in the case of StocaMine:

- Removal of all materials through the portholes is not feasible
- Time-consuming: in the end, the remaining waste packages , empty or not, have to be removed
- Such a structure would have to be moved frequently to be close to the WP

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## 2. Creation of Confinement (4)

Physical confinement that does not need to be moved frequently has been identified to be much more practicable. It is suitable for large areas, i.e. one entire block.

Main features:

- Create physical confinement for large area: "Red Area" for each Block or Allée (large areas)
- Lock/blue area made of 2 successive curtains, with dynamic confinement (underpressure)
- In the Red Zone, create underpressure (0.1 Mpa), implement fresh air supply pipe for staff.
- Repacking + decontamination done in the Hatch.

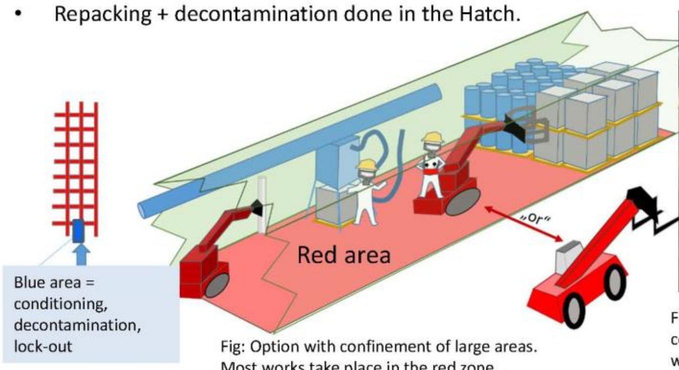


Fig: Option with confinement of large areas.
Most works take place in the red zone.
Source: Plejades-DMT [R8]

Fig: Example of curtain for physical confinement combined with dynamic confinement. This one was used in previous retrieval operations at StocaMine
Source: MDPA [R8]

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## 2. Creation of Confinement (5)

- Working Area layout including:

RED AREA

- Fresh air supply – Air duct, on which the workers can “plug” themselves every 20 m
- Dust abatement
  - Fixation
  - Suppression
- Dust and aerosols (suspended particles) extraction (separation) by
  - Gravimetric methods (e.g. cyclone),
  - Filtering (e.g. HEPA filter)
  - Extracted contaminants needs to confined
    ⇨ e.g. packaging in an appropriate waste container (secondary waste, also in drums)

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## 2. Creation of Confinement (6)

- Working Area layout including:

BLUE AREA

- Decontamination cabin for staff coming from the Red Area
- Decontamination cabin for undamaged packages (the conveyor belt runs through it)
- Overpacking station for big-bags
- Overpacking station for drums
- Dust abatement: air pumped and sent into the Red Area, where it will be cleaned during decontamination

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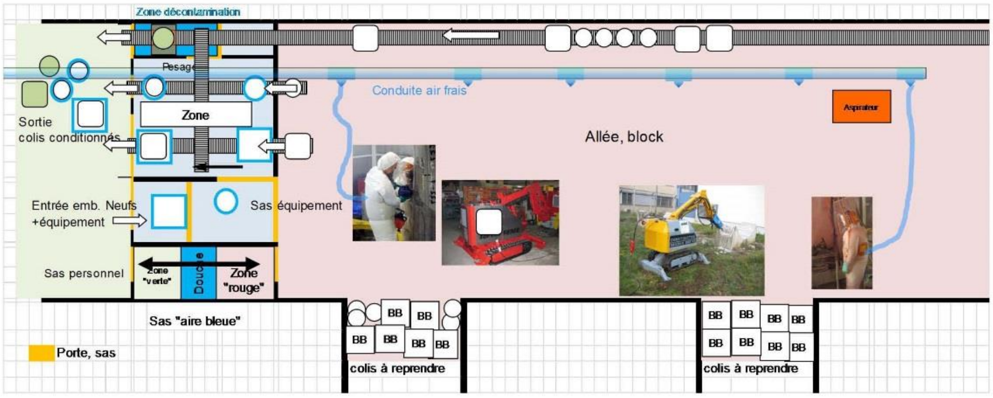
## 2. Creation of Confinement (7)

Schematic Diagram of the Working Areas:

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## 3. Protection of Workers (1)

- Depending on potential contaminant presence
- Zoning: definition of different areas with corresponding different contaminant exposure risks and workers protection requirements.
  **RED AREA**: removal area – **BLUE AREA**: process area – GREEN AREA: rest of mine

PPE depending on potential exposure (zoning)-

- Full protection
  - Protect completely outer (body surface) and inner skin (lung) by protective clothing and provision of clean air for respiration (filtering, external supply, autogenous supply of air) in red area
- Partial protection
  - protect by mitigating specific relevant exposure pathways (mask, gloves, shoes) in blue area
- Use of mechanical technologies in contaminated areas

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## 3. Protection of Workers – PPE (2)

### Personal Protective Equipment may include:

- Suits
- Gloves
- Safety shoes
- Overshoes
- Clean air supply
  - Filtering air (passive, active air filters)
  - External supply (fresh air duct installed in the "red zone", on which the staff can "plug" himself in)
  - Self-sufficient supply (limited reserve, time limited)

Fig: Operators wears full PPE with fresh air supply for working in contaminated area

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## 3. Protection of Workers (3)

Why full protection?

- Working with FFP3 masks on is very demanding and autonomy is limited to 90 minutes.
- In comparison, full protection with external air supply is more efficient and safer than masks.

Fresh air supply is organized with a duct installed inside the red zone and connected to the surface. Plugs at regular intervals – ca 20 m - of the duct ensure that operators can be connected at all working locations, without need for frequent exiting the "red area"

Fig: Operators wearing full protection are connected to an air supply duct installed inside the contaminated area.

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## 3. Protection of Workers (4) - Locks

Depending on potential exposure (zoning), locks / hatches have to be installed for entering /exiting the "red area".

Layout of the locks need to be adapted to the nature of "material" :

- Lock-in
  - Standard lock for workers and equipment
  - Lock-in of equipment
  - Lock-in of containers (big-bag, drums)
- Lock -out
  - Standard lock for workers and equipment
  - Lock-out of equipment
  - Lock-out of containers (big-bag, drums)
  - Use of specific lock-out devices

Example of physical barrier. Such material can be used to create customized locks. Source: sat KT

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## 3. Protection of Workers (5) - Locks

Depending on potential exposure (zoning), locks / hatches have to be installed for entering /exiting the "red area".

Layout of the locks need to be adapted to the nature of "material" and confinement

Fig: Example of lock-out system for drums: in this extreme case, highly contaminated (nuclear) waste is transferred to the green zone in a tight lock-out systems including repacking in drums.
Source: sat K

This system is not required in the case of StocaMine

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## 3. Protection of Workers (6) - Locks

Practicable option: A big lock area!

Locks can be less sophisticated if all work processes, including repackaging and decontamination, are done inside the red area lock.

If the contamination is mainly dust bound, a combined physical + dynamic confinement may allow relatively simple lock configurations.

**<add pic: curtains, lock-out system for equipment/ workers>**

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## 4. Reliable Packages Criteria for handling (1)

The key word for handling is that it needs to be **SAFE** at all steps.

- Criteria for internal transport
  - Safe handling
  - Safe re-conditioning (if necessary)
  - Safe loading
  - Safe transport
  - Safe unloading
  - Safe transfer storage underground level
  - Safe lifting to above ground level
  - Safe transfer storage in above ground level temporary storage
  - Safe loading for diversion disposal (including transport on public network)
- Criteria for external (public) transport
  - Safe transport according to diversion route

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## 4. Reliable Packages Criteria for handling (1)

A basic understanding is that some of the waste that needs to be retrieved from the StocaMine disposal has to be **repackaged** before transfer.

In the worst case, the initial packages at their present location are already damaged.

4 types of packages have been identified:

- Big bags, containing solid waste, that can be in powder form
- 200 L drums, which content may include fluids
- Pallets with 4x 200L drums wrapped with film
- Other, larger containers metallic, wrapped into films.

It is assumed that the last type, the non-standard packages, only represent a minority of WP to be processed.

For drums and big-bags, processes can be automatized.

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## 4. Reliable Packages Criteria for handling (2)

Description of the handling & packaging process:

**Step 1**: package removed mechanically from storage location

**Step 2**: conditioning

- Option 1: package not damaged: package loaded on conveyor belt, arrives in blue area where it is decontaminated. Package exits from other side ot blue area
- Option 2: Package slightly damaged: carried to the drum/overpacking lock-in hatch of the blue area. Automatic over-packing. Exit of the overpacked package to the other side
- Option 3: Complete loss of integrity: content, spills vacuumed + cycloned and packed in new 200 L drums. Drums sent to decontamination through the conveyor belt – Packages remains collected mechanically, carried to overpacking station.

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## 4. Reliable Packages Criteria for handling (3)

Summary: Based on the safety criteria for packages,

- Inside StocaMine:

  Option 1⇨ undamaged big-bags and undamaged drums handled "as is"- after dust removal from the surfaces

  Option 2 ⇨ Slightly damaged packages corrected by using overpack

  Option 3 ⇨ Worst case (complete loss of integrity): repacking station in the red area. Packing of loose waste into new drums.

- Criteria for external (public) transport

  ⇨ Standard transport overpack (eg. ISO container) for the waste package is sufficient

  ⇨ Public transport rules (ADR) and waste diversion prescriptions to be respected

  (declaration, signposting, licensing)

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## 5. Accessing the waste packages (1)

At StocaMine, access to waste packages (WP), even at the front of each block, is hindered by convergence phenomena and physical damage to the cavities in the salt rock.

➔ Safe Access needs to be ensured, with corrective actions when necessary. THIS ASPECT IS NOT CONSIDERED IN THIS REPORT. Beside preventing roof collapse, one important requirement is even surface of the ground (for excavator access)

➔ Once access is created, three options can theoretically be considered:

A. WP are removed/overpacked manually at the front (involves physical work) before transfer to a temporary storage area

B. Same as Option 1, where all the physical work is replaced by mechanization (mechanical tools mounted on electricity-powered excavator, operated close-by by staff staying close to the vehicle)

C. The entire package + content is extracted with remote-controlled mechanical tools, and transferred in a cart for safe repacking in a centralized repackaging station elsewhere. In this option, operators are outside in a control room.

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## 5. Accessing the waste packages (2)

For both criteria:

- SAFETY for the operators
- TIME for the total retrieval + repacking

Experience shows that Option B = combination

"**Fully Mechanical** removal from block + repackaging in nearby area" is far more safer and time-effective than options involving physical work by the operators and transfer of contaminated materials in other remote areas of the mine.


Example of electric excavator that can be used for recovering packages (Brokk 150)



## 5. Accessing the waste packages (3)

### Mechanical tools


Example of sturdy electric-powered excavator for removal and handling of packages (here with pick)
Source: sat KT


Example of pneumatic equipment that could be useful for stability and access works in the red area (TopTec 1850E)
Source: TopTec, sat KT

## 6. Proven Methods for repackaging (1)

There are 3 types of repackaging:

1. Manual Repackaging
2. Pneumatic Repackaging
3. **Overpacking**

Example of automatic repackaging station with conveyor belt

Automatic drum filling of drums with waste material

Manual preparation of new drums with outer liners to prevent contamination during filing

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## 6. Proven Methods for repackaging (2)

Safe repackaging has to be carefully prepared depending on:

- Initial package type (drums, big-bag, other)
- Waste form (solid, liquid, powder…)
- Status of package (from slight damage to total loss of integrity)

Standard techniques and handling equipment exist for drums and for big-bags.

Equipment can be adapted to any custom configuration

Example: Unit for safe collection of solid waste (soil, powders) from damaged packages

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## 5. Proven Methods for repackaging (3)

For Option 3: Loose waste in powder form / damaged packages:

Industrial vacuum cleaning systems can be used to collect and repack waste into drums

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## 6. Proven Methods for repackaging (4)

**Most of the waste handling can be remote-controlled or automated. Only a few steps, concerning the severely damaged packages (Option 3), will be manual**

Example of repackaging of loose toxic waste (chemical industry)

Repackaged soil waste material, before closing

Waste liners are closed manually to prevent spillage / leaks

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## 7. Decontamination after work (1)

- Objectives:
  - Prevent spreading of contamination outside the « red zone »
  - Prevent contamination of workers
  - Prevent contamination of equipment
  - Minimize the quantities of toxic residual material in the mine at the time of closure.

The specific situation of StocaMine has to be taken into account for defining the extent of decontamination works:

- Decontamination only concerns an contamination originating from the retrieval / handling / repackaging steps:
  - Materials trapped in confined block 15 are excluded
  - Empty blocks, non accessible blocks are excluded
- Decontamination shall not modify any stability parameters, nor interfere with the dynamic of rock-mechanical processes of convergence leading, eventually, to self-closure of the galleries.

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## 7. Decontamination after work (2)

Decontamination is time consuming:

From experience, it is always advisable to work in the cleanest possible way, to AVOID contamination

⇨ include dust suppression system during work processes (retrieval, re-packaging steps)

⇨ Since the mine will be closed, the physical confinement barriers could be left to protect the environment for the closure operation (plug installation)

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## 6. Decontamination after work (3)

The two following proven Decontamination technologies are suitable and sufficient for decontamination after Waste retrieval at StocaMine:

(1) Dry surface milling with dust suction

(2) Industrial vacuum cleaning

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## 8. Parameters for Modelling (1)

Each work process, from implementation of a barrier, to re-packing of a package by various methods, is associated with an average duration.
Values are known from previous experience of sat K in comparable situations.

Average values for each step and options are presented hereafter:

- Creation of areal + local physical barrier (blue+ red areas): ca. 20 days
- Installation of dynamic confinement: ca. 1-5 day
- Productivity under full protection: ca. 25%
  Teams in the red area replaced every 2 hours, effective work time 8h/shift
- Productivity under partial protection (air filters): ca. 65%, time limitation 90 minutes
- Manual repacking (rough estimates)
  - Dust/powder from big-bag to in big-bag: ca. 1 h per big bag
  - Dust/powder from drum to drum (turn over possible): ca. 20 min
  - Overpacking of big-bag (lifting possible): ca. 10 min
  - Overpacking of drum (turn over possible): ca. 5 min

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## 8. Parameters for Modelling (2)

- Automatized repacking + decontamination, with mechanization:
  - Retrieval & transfer (without access problems): up to 50 WP / hour
  - Retrieval & transfer (with access problems): ca. 2-6 WP (big bags or 4 drums) per hour

  In the ideal case (see next, a throughput of 120 t/day can be achieved)
- Productivity of remote equipment for specific work:
  - Per single remote move: 2 min/move or ca. 30 moves per hour
  - Per change of location: 12 min/change or ca. 5 changes per hour
- Risk of system failure increases rapidly with complexity of the system (eg: remote/video-controlled complex systems require a lot of maintenance and direct intervention of operator)

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## 8. Parameters for Modelling – Real case (3)

A recent example of waste retrieval & repacking in the chemical industry (toxic waste)

- Number of packages retrieved + re-packaged / month: 8.000-10.000 drums
- Staff involved
  - Single shift system, 8 hrs work per day
  - In total 9 workers
  - 1 Site Manager (HSE, documentation), 2 machine operators, 1 drum preparation, 2 drum filling station, 2 logistics workers
- Type of lock used: Dräger air system, fixed installation, sub-atmospheric pressure with outside active coal and dust filter system
- Type of air supply / ventilation:
  - Dräger system with 10.000 m³/h (10x air exchange per hour)
  - Air conditioning: mobile installation only when needed (9.600 m³/h, 44 kW)
  - Length of air supply hoses, number of connecting parts: max. 20 m, max. 1 connector
- Type of mechanical equipment used:
  - Truck, forklift
  - Semi-mobile excavator, Brokk BM 150 electric cutter
  - Separator and breaker unit
  - Filling station with weighing unit
  - Labeling and packing unit

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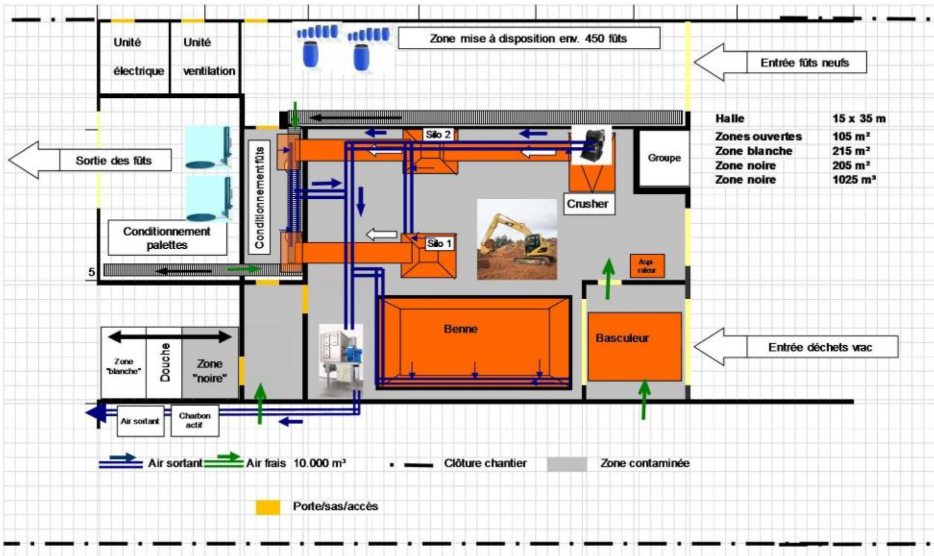
## 8. Parameters for Modelling – Real case (4)

Example of layout for repacking installation for loose toxic waste: Source: sat KT






## 9. Surface Installations & Downstream logistics (1)

- The retrieval of waste from underground will produce substantial amount of wastes. Some secondary waste will increase the total number of packages
- Realistic output rates will be typically between 10-30 big bags (or 40-120 drums) per work day
- All packages have to transit to the surface through the shaft, limited to 5 tons/charge. Evacuating the WP to the surface is considered a priority, as the shaft represents a bottleneck in the overall logistics.

Tab. 1 Vue d'ensemble sur les différents types de déchets stockés dans les blocs

| Nature des déchets | Numéro nature | Classe | Masse (t) | % massique / total | Nbr. de colis | Conditionnement |
|---|---|---|---|---|---|---|
| Sels de trempe | A1 | 0 | 2'156 | 5 | 2'164 | 99% fûts, 1% conteneurs |
| Sels de trempe non cyanurés | A2 | 0 | 1'218 | 3 | 1'191 | 98% fûts, 2% conteneurs |
| Déchets arséniés | B3 | 0 | 6'975 | 16 | 7'107 | 16% big-bags, 83% fûts, 1% conteneurs |
| Déchets mercuriels | B5 | 0 | 2'272 | 5 | 1'753 | 99% fûts, 1% conteneurs |
| Terres polluées | B6 | 0 | 5'263 | 12 | 4'627 | 95% big-bags, 4% fûts, 1% conteneurs |
| Produits phytosanitaires | B10 | 0 | 128 | 0.3 | 105 | 100% fûts |
| Déchets chromiques | C4 | 0 | 429 | 1 | 358 | 1% big-bags, 92% fûts, 7% conteneurs |
| Déchets de galvanisation | C8 | 0 | 641 | 1 | 587 | 90% big-bags, 10% fûts |
| Résidus de l'industrie | D7 | 0 | 138 | 0.3 | 324 | 100% fûts |
| Déchets de laboratoire | D12 | 0 | 169 | 0.4 | 201 | 92% fûts, 8% conteneurs |
| Résidus d'incinération | E9 | 1 | 20'714 | 47 | 38'966 | 98% big-bags, 2% fûts |
| Déchets amiantés | E13 | 1 | 3'774 | 9 | 9'821 | 83% big-bags, 12% palettes filmées 5% fûts |
| Totaux | | | 43'876 | | 67'204 | |

Fig: list of waste types and packages, before repackaging

- Once above, the logistics must be organized considering that:
  - There are different types of waste that need to be kept apart from one another
  - Final disposal sites may vary depending on the waste type and origin
  - A significant lapse of time could occur between arrival to the surface and transport to final disposal

# 9. Surface Installations & Downstream logistics (2)

All packages coming out of the shaft (Puits Joseph) have to be handled further.

At present, the final disposal location(s) are not decided, and could be multiple, in accordance to the waste and package type.

Taking into account this uncertainty, the following resources are necessary at the surface, to be implemented in close cooperation with MDPA:

1 - Buffer area close to shaft exit (in Bâtiment d'Exploitation), for the following operations:

- Control weighing (if necessary)
- registration of packages into a database, documentation
- Tracking ID for each package, Marking if each package according to ADR requirements
- Preparation of documentation

2 - Transport route to a surface storage building

- For safe and easy transport of the ready packages to interim storage

3 – Interim Surface storage building, to be built in the perimeter of MDPA (or use of existing buildings after implementation of ventilation and safety upgrades)

- Licensing aspects to be carefully planned! Underground storage is allowed, but no surface storage so far
- Re-sorting of packages must be possible (no FIFO (first in first out) or LIFO (last in first out)– flexible logistics)
- Minimum floor surface e.g. 15.000 m² corresponding to ca 1 year retrieval with handling freedom (the more the better)
- Enough space needed because of various waste types to be segregated
- Space for overpacking for transport (in ISO containers, etc)
- Ventilation, exhaust air cleaning (production of secondary waste)
- Safety hatch to prevent unauthorized access/ intrusion
- Safety measures against trespassing and external impact (fire, crash, lightning,...)

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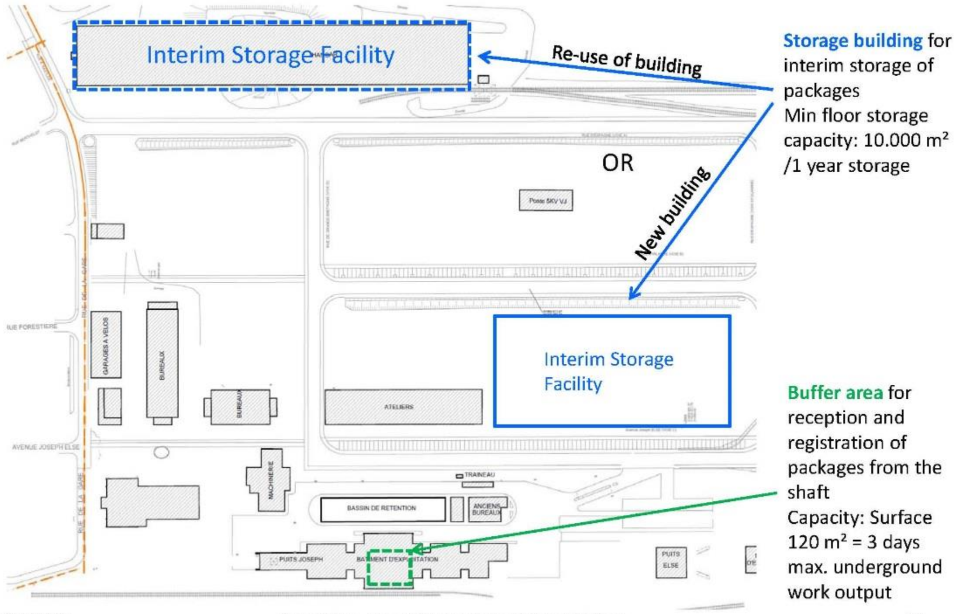
# 9. Surface Installations & Downstream logistics (3)

Actual locations of surface installations to be decided with MDPA

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## 10. Conclusion and Recommendations (1)

- **Principles from practical experience**
  - Handling and overpackaging of waste drums is a routine technology ⇨ prefer overpacking whenever possible
  - Overpacking of big-bags is also to be favored, although repackaging of waste containing big-bags is typically quite efficient for non-consolidated powders or dust
  - Work with masks reduces efficiency and productivity of workers ⇨ try to
    - Use full protection with external air supply,
    - For each front: Organize 2-hour shifts with 2 teams working in turns
    - Compensate workers reduced productivity with appropriate mechanization and logistics (to reduce workers physical intervention)
  - Simple technologies (excavator…) may be more effective and quicker (less failure risks) then remote technologies
  - Some specific remote-operated equipment with high mobility in narrow environment (e.g. TopTec 1850E) can be used for some mining-related preparation/stabilization steps
  - Decontamination is a time consuming operation which should be limited to "end of activity/block" by the overall strategic approach: only before changing work locations and moving locks.
  - Above ground, temporary storage must be flexible as to allow re-sorting of packages before transport
  - JIT (Just-in-time) logistics for transport to final disposal is the preferable option, as no new storage facility above-ground is needed.
  - Based on the current status, a new above-ground interim storage facility for the conditioned packages will probably be necessary.

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## 10. Conclusion and Recommendations (2)

- Underground configuration from practical experience (handling of dangerous/toxic waste, no mining activities)
  - **Safety first**
  - Logistics is main boundary ⇨ one single streamlined process chain is the driver for ultimate optimization
  - When time (and not cost) is the driving parameter:
    - One coherent zoning = areal zoning
    - Not too complex equipment = not remote, preferably man driven (less failure risks, more flexibility, more efficient, more recovery options)
    - Key points:
      - Mechanization (no physical work, standard industrial equipment)
      - Limit transports volume and ways
      - Streamlined logistics: Continuous (quasi continuous) transport to blue area/lock, lock-out, follow-up logistic (FIFO to the surface)

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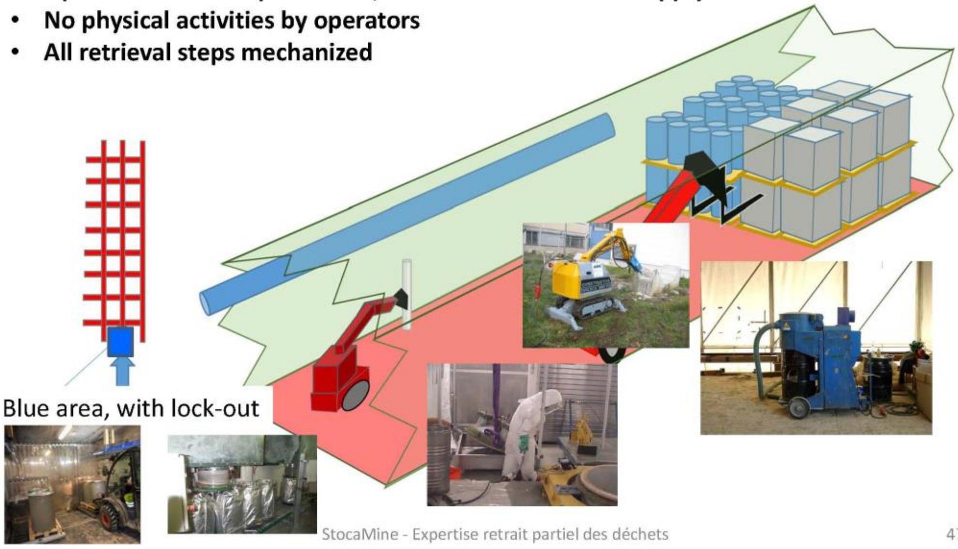
## 10. Conclusion and Recommendations (3)

### Favored configuration:

- **One big red zone / block with physical + dynamic confinement**
- **Operators with full protection, connected to fresh air supply**
- **No physical activities by operators**
- **All retrieval steps mechanized**

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## 10. Conclusion and Recommendations (4)

Under the favored handling and repackaging conditions:

- Rough estimate for **time for retrieval, handling/ re-packaging + transport** **only** (to hand-over beyond "blue" area - ca. 67 000 bundles - big bags/ 4 drums) with 2 fronts: **ca. 2-3 years**
- Safety supporting and logistic processes underground (rock mechanics, narrow environment, etc.) to be configured accordingly (time not included in the above estimate!)
- Surface installations and logistic processes above ground are necessary for temporary storage before transport to other disposal. They add a significant safety factor, and a risk of delay.

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# Annexe 5

# Document produit par LOM pour l'étude

**LABORATORIO OFICIAL J. M. MADARIAGA**

LOM

# REPORT: STOCAMINE EXPERTISE

**Report Number:** LOM 18.39290

**Date:** 2018-09-11

**Applicant:** BRGM

**File Number:** LOM 18.348S

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# INDEX



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# 1. Introduction.

This report is about the Stocamine underground ultimate waste storage in the Potash Mines of Alsace, in the area of Wittelsheim. It deals about the deliberations of the expertise group related to the idea of tackle the retrieval of all the wastes as possible from the underground storage, and letting them in conditions of being definitely storage in anywhere else, but not in the Alsace region.

The members of the expert group and the entities that they represent have not had any relationship with the Stocamine project nor with the companies, entities or bodies who have contributed to the several studies about it in the past.

The present report shows the opinion of LOM respect the task that it is entrusted with, in order to enhance the technical discussion, contribute to the public debate, and help the authorities to take a well based and very carefully thought-out decision.

## 1.1. Context[1] and scope[2] of the report.

The Stocamine project was born in the 1980s following the planned closure of the Alsace Potash Mines (MDPA). It was inspired from the experience of German underground storage sites; particularly from Herfa Neurode salt mine. The project, launched in February 1997, planned to store hazardous waste for a period of thirty years under reversible conditions, in galleries dug in the salt rock layers at 500 meters depth, under the old layers of the potash deposit exploited by MDPA.

The fire in Block 15 on 22$^{th}$ of September of 2002 stopped storage operation and questioned the working hypotheses, while about 44,000 tonnes of waste had been already stored.

The government made the decision at the end of 2012 to initiate and implement the closure of the site through the application of the procedure provided for by the French Environment Code. After a long consultation period supported by numerous studies and expertise, the regional authority signed on March the 23$^{th}$, in 2017, the prefectural decree authorizing confinement of the storage area for unlimited duration after retrieval of the wastes

[1] From BRGM "Request for technical expertise" document
[2] From LOM 18.348S offer document

containing mercury. Indeed, mercury was recognized as the most dangerous contaminant able to reach the water table in the case of the confining barriers failure and brine infiltration. The retrieval of 93% of the mercurial waste has been already achieved. In 2018, the MDPA is carrying out a pilot containment dam, and the final works are planned from 2019.

Today, consensus exists on the impossibility of retrieving the waste from the fired block 15, and thus, confinement of the storage area must be carried out in any case. However, the question remains whether or not it is possible to retrieve the waste from other blocks than n°15 under acceptable mining and environmental safety conditions. Indeed, public opinion is concerned by the long-term protection of the Alsace water table situated above Stocamine, which is considered as a priority by all stakeholders.

So far, the scenario presented by MDPA estimates the time for the retrieval operation at between 12 to 15 years. Such a long period brings real risks about the effectiveness of the final confinement to protect the Alsace water table and its realization in good conditions. However, if the duration of the retrieval operation could be shortened (e.g. 3 to 5 years instead of 12 to 15 years), the risks would not be of equal magnitude.

The government appointed the French Geological Survey (BRGM) to make an expertise on the delay put forward by the MDPA. This expertise should cover the entire retrieval chain from the current state of the galleries and their foreseeable degradation, until extraction of the wastes, their transport, and repackaging. The expertise must identify the critical steps of the retrieval operation. It will also have to study and propose different retrieval scenarios including operating from several fronts, taking into account the necessary maximum safety conditions for the workers and the need to achieve the final confinement after the retrieval operation at the best conditions.

Regarding different constraints and the sensitivity of the issue, this expertise has to be achieved by the end of September 2018.

For this purpose, BRGM would like to rely on the expertise of companies having good records on technical and operational planning in the salt mines. The requested expertise comprises the evaluation of the delay put forward by MDPA and proposal an alternative scenario for shorten this delay (if applicable).

The following items have to be considered:

- The access routes to the emplacement chambers (potential options),
- The retrieval of the wastes from the emplacement chambers (potential options),
- The necessary devices, machines, equipment, infrastructure and human resources,
- The transport flow of the wastes in the underground facility including transport to the surface,
- All necessary safety, risk prevention and health measures for workers and the environment,
- The packaging of the wastes,
- Conceptual planning and best evaluation of the time necessary for the retrieval.

The expert group members is formed by these entities: BRGM (FR), DMT (DE), PLEJADES (DE), SAT Kerntechnik (DE), UPM (ES) and LOM (ES).

Particular conditions of the group work:

- A great number of documents, studies and expertise are available to the expert group. These documents are written in French.
- The working language of the expert group will be English. However, the final document produced by the experts must be in French.
- Two site visits are expected, at least. However, additional visits can be organized at the request of the expert group.
- BRGM has evaluated the time for the achievement of this expertise to 30 working days including preparatory and support works.
- Individual entities reports must be available no later than 10 September 2018. Due to the time limitations, it is allowed that the individual reports are submitted in the working language of the expert group: English.

The scope of LOM (Spain), proposed in its offer, is to elaborate a report related to the global safety of the waste retrieval operations from STOCAMINE waste disposal, in accordance with

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different scenarios that will be envisaged by the Expert Group. The scope consists of warning and making aware of the risks that workers and public would be exposed to due to the retrieval operations, and show the way of keeping them controlled to a reasonable safety level. This report does not substitute the risk assessment that the company that could carry out the labour must elaborate following French legislation and codes.

### 1.2. Background.

There are a lot of reports, technical documents and renowned studies of Stocamine project, besides the MDPA's Stocamine project itself and BRGM analysis. Those documents come from prestigious entities, so their studies and calculus are considered as a recognized start point to get the information needed to understand the current situation in order to set a global view of the problem. Furthermore, to show the critical points to be taken into account for contributing to the deliberations about the retrieval matter. The scope of the present work cannot afford a detailed revision of all those documents.

In another hand, the two kind and well guided by BRGM and MDPA visits to the mine deposit are enough to get a quite realistic view of the current situation and difficulties that there are about the retrieval, although maybe some other technical and experience data could be necessary to develop a detailed retrieval procedure.

Finally, the LOM team experience about managing mine works is part of the knowledge that can contribute to consider real possibilities of action and to estimate the period of time requested in each option.

## 2. Essential considerations about risk assessment.

In this section, LOM shows some considerations in relation to the recovery of dangerous products stored in Joseph-Else salt mine according to the Stocamine project, which takes part in the risk evaluation of the operations of retrieval in the different scenarios that could be considered. These considerations are essential for reaching the decision whether the retrieval of wastes is worth a try.

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## 2.1. A global view and approach to the problem.

A brief review of a large amount of existing information on Stocamine project that has been accessed, plus the two visits made to the area of the Joseph-Else salt mine where the Stocamine project is developed, make a very positive first impression about the works that have been carried out by MDPA. This opinion not only refers to the storage of the hazardous waste object of the project, but also to the conceived procedure of retrieval of those with mercury content. However, some of the operations of this mercury wastes retrieval, shown to the expert group in a video, could be improved from the safety point of view.

The work entrusted to the LOM deals with the analysis of global risks of the possible retrieval operations of the whole wastes, or at least, as many stored wastes as possible. Besides, this study should not take into account the economic cost variable, but should take the period of the complete operation of waste retrieval and final closure and confinement of the mine as the main variable to be minimized. The "boundary conditions" of this "optimization problem" are, therefore, the safety and health of workers performing the operations of waste retrieval and the closure of the mine, and the safety and health of the public because of environmental risks to which they could be subjected.

A non-exhaustive review of the final closure project of Stocamine, as well as the inspection of the prototype of "closing plug or dam" for the final closure, indicate that the risks to the general public health, as a consequence of the environmental risks derived from carrying out the final storage and closure in Stocamine, are conveniently analyzed, evaluated and controlled. This opinion is based on MDPA documents, and the support of other prestigious entities. Obviously, leaving in the mine the wastes that currently are there once the closure and confinement project is executed do not entail any safety risk for people in the surface. Talking about health, the public could only be affected if the water table will be polluted by the wastes. In this sense, the measures contemplated in the closure project look efficient enough to avoid the water table contamination. Anyway, the complete retrieval of the waste is impossible to carry out due to the unfeasibility of extracting anything from the so-called "block 15". Therefore, the proper closure and confinement of the waste disposal should be done in any case and, so, this is the first and more important objective to avoid the pollution of the water table.

The uncertainty of the analysis of the risk of getting the water table polluted is very low, taking into account that the period for a hypothetical environmental interaction is a millennium. In addition, although this will happen before (due to an earthquake, cataclysms, or another non-foreseeable event), concentrations of undesired elements in the water would doubtfully reach the aquifer of upper layers or reach the surface table water level and watershed.

Moreover, the consideration of the highly improbable case of waters with undesired elements reaching the surface of the watershed would theoretically do so in concentrations valued today as not dangerous for the health of people directly or indirectly.

That is to say, that the starting position of the present safety analysis or "*safety baseline*" consists of an "absolute minimum" of the risks to which the workers of the Stocamine project are exposed, plus a risk for the environment that is well controlled, and so, for the public. Clearly, this "risk absolute minimum" for workers, in which they would only have to proceed to the final closure of the waste deposit according to the Stocamine project, must be the point of comparison of any other hypothesis from a safety point of view.

Even so, some complementary measures could be taken to improve the control of the environmental future risk, and therefore, the health risk for the public. Such measures could be the insertion of chemical barriers that would lead to the crystallization and precipitation in situ of the unwanted elements in the very rare case they were dissolved by the floodwaters of the mine. These complementary measures could be proposed both inside the closure deposit and on the outside of the closure plugs, and they could be detailed later (an example is shown in Annex II).

Likewise, a set of drillings from the surface could be designed to control the water quality of the aquifer in the area of the deposit for the next decades and centuries, complemented with another set of drillings to control the possible affluence of water in the outside of the closure dams. It seems not to be effective to drill to the inside of the closure waste deposit because this control measure could lead to letting the water inside, and so, invalidate part of the closure plugs aim and efficacy.

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Another issue to take into account, to address the problem in its entirety, is the inclusion of the final destination of the waste hypothetically extracted from Stocamine deposit as a risk factor affecting the public and the environment, avoiding the temptation of "localisms" that reduce the concept of the public to those who live near Stocamine area. In fact, this concept involves not only the risk assumed in the new final deposit, but also the exposure to some risk for all who stands in the line of transport from Wittelsheim to the final deposit site, and also, in the place where the wastes stand for a temporary storage. This risk does not exit at all if the wastes were not retrieved.

## 2.2. Risk of collapse: time plays against us.

On the other hand, the first risk factor derives from the maintenance of the storage area due to the rock stress and convergence.

The documentation consulted provides correct support studies of the mine area from a general conceptual point of view, in particular regarding the existence of marl levels that over time cause the release of large blocks of salt rock.

In addition, the mining experience of MDPA gathers a valuable baggage and experience about the behaviour of the stratigraphic series when evaluating the definitive support, both of the design of the pillars and the anchors with bolts, straps fastened with bolts, support with hydraulic or wooden pillar and props.

Besides, in many galleries of the deposit an over-excavation is needed for the retrieval because the wastes packs are actually compressed by the rock, or at least, there is very little room between gables and wastes and roof and wastes. Moreover, there is a tilting effect on the wastes due to the irregular uplifting of the galleries for, now in some cases. All over-excavation operations carried out to enlarge the galleries during the mercury wastes retrieval, even if they were to be relocated in other galleries, were carried out in accordance with an appropriate procedure in terms of the establishment a temporary support, a constant review of the working face (working front) and systematic final support elements.

This question is one of the main risks for workers and it will affect their daily safety during the retrieval operations, as it can result in a serious or fatal accident. Consequently,

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frequently checking and close supervision processes must be established and implemented in the working cycle. Of course, any operation of extracting a waste packaged or a preparatory task should not be done before the final support elements are executed, and any worker should not go further away from the last definitive supported line.

In any case, no support can be considered "definitive" in the sense of being free from the convergence of gables and roof, uplifting of the floor, or collapse by a detachment of large blocks of rock in a long time series (e. g., several years). But its design can be established for a period of time during which the mining works should be carried out. The definitive support must be dynamic, in terms of being able to withstand the plastic efforts that produce the convergence, avoiding the risk of collapse and the detachment of rock blocks. It must be designed to let the waste packages not pressed by the salt rock during the mining operations.

This means that the elapsed time is simultaneously the variable to be optimized (minimized) and a factor that increases the risk of collapse or falling down blocks of rock. To avoid it, an increasing dedication of time and resources is needed for the maintenance and support of the galleries, producing an iterative cycle that, although likely convergent, can lead to propose theoretical execution deadlines that are unrealizable practice if not taken this issue into account.

## 2.3. Risk of methane presence and explosion.

The sudden emission of methane involves two main type of risks: the risk of forming an unbreathable atmosphere and a potentially explosive atmosphere (between 5% & 15% of methane approx.).

The historical experience from Joseph-Else salt mine indicates that the methane associated with the marls and clay levels and other strata have been trapped by the salt rock. Some past incidents refers to a not very high volume of methane gave off during drilling bolt-holes (for example, during the incident[3] happened in 2017, January the 26$^{th}$, 4 $m^3$ in the first

[3] Estimations from the data available.

minute, 15 $m^3$ in eight minutes, nearly 20 $m^3$ in thirty minutes), but high enough to be considered as a relevant risk.

Moreover, the increasing strength and pressure of the rock and the stress fractures in it, leads us to think that the probability of the presence of methane will be increased as time pass, not only coming from the marls trap next to the Stocamine salt strata, but also from other marl and clay trap upper levels.

## 2.3.1. Risk of explosion.

European legislation for avoiding the risk of explosion in mining[4] determine the characteristics of the machinery and equipment that is allowed to be used in a potentially explosive atmosphere and its conditions of use. This machinery and equipment have to be certified by an independent body, named Notified Body, following the specified procedures in the legislation, codes and regulations.

These considerations lead to putting forward some questions to be analysed:

1st) Has Stocamine been classed with respect to the methane by French authorities? If yes, does the classification affect the whole mine? Is it possible the use of non-certified ATEX equipment at certain times and in certain places according to French legislation? Note that in our second visit to Stocamine a non-ATEX photo camera was not allowed to be taken into the mine.

2nd) Should all the equipment and machinery to be used in Stocamine be certified following ATEX regulation?

An affirmative answer leads to a somehow complicated process, which will take a considerable period. Another possibility is to consider the risk of the presence of methane restricted to some operations, like, for example, the drilling operations and use certified

4

- ✓ Directive 2014/34/EU of the European Parliament and of the Council of 26 February 2014 on the harmonisation of the laws of the Member States relating to equipment and protective systems intended for use in potentially explosive atmospheres.
- ✓ Council Directive 92/1047EEC of 3 December 1992 on the minimum requirements for improving the safety and health protection of workers in surface and underground mineral-extracting industries.

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machines only for these cases. Anyway, that question can be only answered and, even accepted or not, by French mine authorities, but the background of the presence of methane maybe make reasonable to protect machinery and equipment against the risk of explosion, at least in the block galleries of the mine and in the exhausted air outflow galleries.

Analysing the risk of explosion, not only electrical equipment should be taken into account, but also other possible ignition sources[5], for example: drilling operation and the interior of the suction ventilators looking for possible mechanical sparks.

Hence, it is important to characterize the content of certain minerals (for example pyrite or silex) in the rock to be drilled by a drilling machine or excavated by a continuous mining machine to prevent the mechanical sparks.

Besides, a good design, installation and control of the ventilation net and flow are needed to establish and maintain safety mine environment conditions, specifically in case of sudden emission of methane.

First, a good secondary ventilation is indispensable to avoid the setting up of a potentially explosive atmosphere.

In this way, procedures of how to re-start the secondary ventilators in case their energy supply has to be cut off must be defined, for example, if a sudden emission of methane caused the flow inside the secondary pipe exceed some percentage of methane (e.g. 2,5%) the secondary fan should be stopped.

### 2.3.2. Risk of becoming an unbreathable atmosphere.

In second the place, secondary ventilation is essential to avoid the risk of forming an unbreathable atmosphere in the mine. Considering this risk, it can be estimated that its probability of happening is very low and restricted to the place where the working faces are being developed, mainly during drilling operations.

[5]There are some references about methane explosions caused by mechanical sparks, for instance, in the blades of the secondary fans or during the drilling of rock.

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Therefore, another measure like carrying on the self-rescue breath equipment in risky zones and a proper knowledge and training of how to use it may be enough to protect workers against the risk of an unbreathable atmosphere. As it looked in our visits to Stocamine waste deposit, this safety measure is implemented by MDPA.

## 2.4. Risk of fire.

The risk of fire come mainly from the machinery, particularly from the diesel machines without forgetting the electrical machines, both due to a mechanical failure and a crash between machines or between a machine and the rock.

To prevent this risk, a good maintenance of the machinery and regular inspections must be established. Therefore, the galleries traffic must be regulated, even the machinery maximum speed.

There is also a risk of fire coming from the Mixture or keeping in contact of non-compatible hazardous wastes by mistake, and from the medium-high temperature of the rock next to the waste packs. To prevent this kind of fire risk it is necessary to inform the worker which kind of wastes are side by side and if there is a fire risk if they mixed it. It is necessary to measure the rock and environment temperature too. A very important issue regarding this risk is not to blow air inside the block gallery to avoid a local supply of oxygen that could facilitate the beginning of a fire. In this sense, it is better to implement a suction secondary ventilation instead of a blowing one.

Anyway, the galleries should be equipped with a net of water and suitable fire extinguishers.

A very useful measure in case the fire is produced, it is to have the possibility of making a partition wall with elements for regulating the airflow. For this porpoise, a valuable idea is to make in advance the frames of the partition walls in strategic places of the mine, and have prepared the material to build the partition wall with a door (if necessary) and with a tube or pipe with an adjustable closing device to regulate the airflow.

The workers also have to carry on the self-rescue breath equipment, provided with protective goggles.

There should be a firefight plan in which every measure fighting the risk of fire must be described. This plan ought to be part of the emergency plan.

## 2.5. Environmental risks during retrieval operations.

Most of the hazardous wastes deposited in Stocamine storage are stable and duly packed at the moment, so they suppose no immediately environmental risk at all. However, this status could become a source of risk due to the handling operations. The two main sources of risk are the dust or powder put on air suspension and the gasses that could be give off if some closed container is broken.

### 2.5.1. Risk of putting powder on air suspension.

The risk of putting dust on suspension due to the handling operations is greater for the big-bag package type, as there are not hermetically closed ones. It can also become worse in case the roof or the gables press the pack.

The retrieval procedure should prevent this risk by avoiding the strong shake or compress of the packs.

Once some dust is put on air suspension, the secondary ventilation net, or a specific installation, should suck the polluted air and carry it to a dust off equipment. Obviously, the dust recollected in the equipment should be considered as a newly generated waste and treated like that.

The control of this risk is one of the reasons to prefer a sucking secondary ventilation in the working face instead of a blowing one, just to avoid dust in suspension in downstream gallery airflow.

The secondary ventilation that MDPA has implemented looks to have enough capacity to afford the dust off operations.

Talking about this risk, an especial mention has to be said about asbestos wastes. This kind of waste has no impact on the environment at all, if it is left in the deposit forever, but it is a real risk for the worker's health during the handling. Considering not to handle or at least minimizing asbestos wastes seems to be a common sense choice.

### 2.5.2. Risk of gases being given off.

The risk of gases being given off seems to be present only in case of barrels or closed containers that could have a leak. Open packs are considered not to give off dangerous gases. The waste stored in Stocamine are all solid and of negligible volatility. At the atmospheric conditions of the mine, the waste cannot generate gas. Although concentrations of dangerous gases are not expected, a strategic net of appropriated meters could be designed, either fixed, or by using portable gas-meters. Anyway, the main preventing measure is the airflow to be enough for diluting the gas content down the admissible concentrations. Thinking of underground installation for separating and extracting gases from the airflow are not feasible nor necessary.

### 2.5.3. Risk of spilling wastes on the floor.

The risk of spilling wastes in the floor comes from the handling operations and during over-excavating ones. It can also be present because of the roof and gable compression.

The prevention measure must be implicit in the working procedures.

Once the waste is spilled, the retrieval operations should be stopped until the area is cleaned to prevent damage to workers. Besides, it is to be considered that the existence of spilled wastes that remain after the closure operations is worse than leaving them in their pack and place as they are now.

## 2.6. Human factor.

### 2.6.1. Workers experience and good mining practice.

Another very important issue is about the experience and training of workers. In the previous meetings, LOM has been informed about the highly probable possibility that the hypothetical waste removal tasks would be carried out by non-MDPA personnel (a company that is currently in liquidation) and lacking of mining experience. This is a very important factor of risk, which can be covered with periods of practical and theoretical training that would more than cover the legal requirement, but in any case would not cover the gap left by the lack of mining experience that may have MDPA workers or other mining personnel. This aspect also has a decisive influence on the time of completion of the work and probably leads to taking more time than the theoretically one considered. Overcoat, it has a very negative impact on the accident threat, due to the human factor.

Talking about safety and the human factor, it has to be said that even though a risk evaluation can establish a safety procedure and control measures to keep the safety of the working operations, statistics show that accidents happened. Sometimes, it can be thought that when an accident takes place it means that the risk evaluation was not "good enough", or that some unforeseeable cause appeared. However, most times the accident happened because of a chain of errors or dysfunctions committed in the conception or developing of the working operations or due to a non-proper checking of the conditions in the mine.

For instance, it can be said that when a fatal accident happens, it indicates that more than 10 serious accidents and 300 minor accidents had taken place and 600 incidents without human damage had occurred. This is known as Heinrich pyramid[6]. Evidently, these figures depend on the sector or company, but they can be assumed in mining as a reference. Talking about figures, it is very difficult to have a real statistic because incidents are not counted in many cases. Nevertheless, there are other lower levels of the pyramid, which are more difficult to be measured for the statistics. The level immediately down the number of incidents is called "*unsafe behaviours*" and, as its name suggests, refers to all non-safe comportment, performed outside the working procedure. And below this level there is another deepest one, which could be called as "*environment where unsafe behaviours are tolerated*". It has to do with the customs and labour culture of the company, the labour sector, the society of the country, etc. This last level not only involves workers, but fundamentally, the commanding chain and the decision making the staff. Of course, maybe this level is where the seed of the fatal accident begins to grow. This new modified Heinrich pyramid has its base wider than the immediately upper level, so it looks deformed as the figure in annex I.

[6] Triangle (or pyramid) of Heinrich, also studied by Bird.

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### 2.6.2. Dysfunctions: an extra risk factor.

Another factor to be taken into account, both for safety and time-lapse, is the possible dysfunctions of the procedure. Although the risk management could consider that a process is safety, some dysfunctions or unforeseen circumstances can happen during the operation for several years. This involve two important maxim: an assumption of an extra time to develop the retrieval operation and, of course, an assumption of a possibility of a fatal or serious accident happening, although “it is not planned” and “it is considered that it is prevented” (see Annex I).

## 2.7. Risks caused by not executing a proper closure and confinement of the waste deposit on time.

As it has been said before, it is impossible to remove or retrieve wastes from block 15, because of the fire and the collapse of its galleries. It is also commented that time plays against the good conditions to work in the deposit, as the creeping of the salt rock and the convergence increments the possibility of trapping the wastes packages and increment the chance of falling blocks of rock from the roof of the galleries, and the collapse.

On the other side, the re-thought possibility of facing up to the retrieval of the wastes is due to the intention to protect the environment of the area, especially the aquifer, and subsequently, to protect the population from damage to their health or economic activities in a long-term future.

Therefore, any decision to be taken do must preserve and not compromise nor endanger the proper and well-executed closure and confinement of Stocamine waste storage. Otherwise, the consequences could be so much worse than the predictable ones in the closure and confinement project. This is the reason why any waste retrieval operation, if it is finally decided to be carried out, should not delay the closure and confinement works to such an extent that those make them unviable.

In this sense, several works for the closure dams or plugs can be compatibly done during hypothetical waste retrieval operations. Moreover, they can be even done before waste

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retrieval operations start or while the decision if the waste retrieval is going to be carried out is being analysed.

Another important handicap is the period during which the decision of going on with the closure and confinement operations with facing up, or not, the waste retrieval, in relation with the estimations of the expert group. As time goes and no supporting works are done in the deposit, the situation of the mine becomes more complicated to achieve the waste retrieval and the proper closure and confinement of the waste storage could become compromised and endanger.

## 3. About stored hazardous wastes.

The different types of stored waste are classified by Stocamine into two classes:

- Class zero: waste that must be stored underground; within this group there were 37,200 packages.
- Class one: waste that can be disposed of in a Class 1 Technical Storage Centre (CET1); of this group there were 27,000.

The waste stored in Stocamine are all solid and of negligible volatility, so no gases are expected to be given off, as it has been discussed. The dust from the wastes could become on suspension only if the waste packages are handled.

Any characterization of the waste in detail is found in the abundant official documentation on Stocamine.

## 4. Ventilation requirements.

As it has begun to see in the present document, ventilation plays a fundamental role in any imaginable scenario, not only for the retrieval options, but also for the proper closure and containment of the deposit.

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## 4.1. Main ventilation airflow.

At present, Stocamine ventilation[7] system (see scheme in Annex III) is based on two fans with a total output power of 320 kW. The airflow currently circulating in the Stocamine site is around 50 $m^3/s$ (180,000 $m^3/h$). In 2006, the latter was about 28 $m^3/s$. This fact probably means that the main Stocamine airflow is not possible to be increased to more than 50 $m^3/s$ without changing all the installation.

The airflow circuit must be stable and controlled by the fans depression avoiding changing of the airflow direction due to variations on the atmospheric pressure. This action is already got. Partition walls or partition walls equipped with ventilation gates may be installed to control the airflow circuit. MDPA is supposed to have done it for the retrieval of the mercury content wastes.

Anyway, the latter airflow (50 $m^3/s$) seems to be enough for the retrieval activity and the closure and containment of the deposit. First, to guarantee the dilution of the possible pollutant gases to admissible values to be emitted to the atmosphere and maintain the underground temperature in admissible values. In the second place, but not less important, to assure that the airflow taken from the main ventilation draft for providing air to the working face by the secondary ventilation draft, do not cause air recirculation. In this sense, the rate between the main airflow and the secondary airflow has to be between 1.3 and 1.5. That is, and airflow around 35 $m^3/s$ is available for the secondary ventilation, if taken in one point of the main airflow.

## 4.2. Working face ventilation airflow (secondary ventilation).

During the mercury retrieval work[8], the wastes have been taken from the entrance of each block that gives onto the central lane of the storage, and the other access to the block (which gives onto the side access road) have to be closed to the airflow. Therefore, an additional suction ventilation system has been necessary to make the airflow reach the working area and thereby guarantee a controlled airflow.

[7] MDPA document "Evaluation logistique et technique de variantes de réversibilité du stockage", 28/10/2013.
[8] MDPA document "Evaluation logistique et technique de variantes de réversibilité du stockage", 28/10/2013.

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The airflow through the gallery during retrieval operations shall ensure (i) that the engines of the machinery can operate and that the gaseous effluents from the machinery are diluted, (ii) that the requirements of occupational hygiene (especially with respect to asbestos) are respected and (iii) the dissemination of potentially contaminated dust is minimized as much as possible.

These requirements have been calculated by MDPA[9]. It has to be emphasized that these calculus estimates a 4.9 $m^3/s$ in each working face, being the asbestos fibres the most critical factor. That could lead to a target airflow round 5 $m^3/s$ in each working face. However, in the same MDPA document, the airflow requirements for the working face are complemented by another argument:

The air circulation speed in the block galleries of the working face is fixed in a value between 0.3 m/s and 0.5 m/s. Taking into account the section of the alley around 21 $m^2$, the airflow needed is around 10 $m^3/s$ per site[10] (working face). It is said in MDPA document that the standards for fresh air renewal and the other requirements are respected with this airflow.

The secondary ventilation installation proposed by MDPA was designed with this parameter and assuming that the required airflow corresponds to the condition of a retrieval from one site at a time.

Throughout the visit to the mine, a junction in the secondary ventilation pipe was seen, and it can be seen up to junctions in the synoptic scheme of the methane incident on January of 2017, but there are doubts whether the maximum secondary airflow is limited to 10 $m^3/s$.

Besides, maybe it is not necessary to reach a speed of 0.5 m/s in the block gallery, which could make possible to establish an airflow around 6 $m^3/s$. In this sense, it is understood that decreasing the airflow requirements from 10 $m^3/s$ could raise objections by the mine authorities or workers unions. However, it has to be taken into account whether a high airflow speed could make easier the powder and dust to be put on air suspension.

[9] MDPA document "Evaluation logistique et technique de variantes de réversibilité du stockage", 28/10/2013.
[10] MDPA document "Evaluation logistique et technique de variantes de réversibilité du stockage", 28/10/2013, annex 4.3.

Therefore, it is important to contrast if the secondary fans installation is able to supply an airflow high enough to ventilate at least two sites (working faces) simultaneously. In another case, another line of secondary ventilation should be installed, included, if necessary, the excavation of a gallery to place the fan and dust off equipment.

Another issue to talk about is the decision about the direction of the secondary airflow, that is, if the secondary ventilation should be a suction or a blowing one.

MDPA has decided the suction option. It has some clear advantages against the blowing option. They are related as follows:

- The suction airflow allows the air from the working face to be treated in the dust off filter equipment and let into the exhausted main flow of the mine admissible concentrations, and consequently, to the atmosphere.
- The suction option would provide the best environmental conditions in the working face, especially in reference to dust put into suspension, overcoat during drilling or excavating operations.
- This option is better than the blowing option to reduce the risk of fire if there is an emerging fire in some waste pack. The direct impact of the fresh air in a little and specific area could facilitate the fire.
- The exhausted secondary air could be carried directly by pipe to the exhaust main airflow downstream any workplace.
- The suction airflow creates a less airspeed and less air turbulence. That is an advantage from the point of view of avoiding the dust to be put onto suspension, although it is a disadvantage to mixing the methane in case it suddenly gives off. To prevent this event, some small fans could be used to create recirculating flows for mixing and diluting the possible methane emissions during excavating or drilling operations. In this latter case, the suction pipe could be extended next to the drilling hole.

Therefore, the suction secondary ventilation is the best option.

As MDPA establishes, the entrance to each block should be through the central lane of the storage, and the other accesses to the blocks through the side access road have to be closed to the airflow.

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As the working face advances and reaches the short galleries transverse to the block galleries, they must be closed to avoid leaks of airflow and reduce the risk of fire.

## 4.3. Creating an under-pressure area.

It is very common to create under-pressure areas as a measure to avoid leaks of the air inside of buildings, factories or containers to the outside or open atmosphere. Such measures usually are implemented in case that the air inside the area could be hardly polluted and its leak could cause a considerable damage. For instance, this option is typically developed in the nuclear industry (due to the radiation associated to a possible polluted air leak) and in some areas of a hospital (due to possible leaks contaminated with bacteriological agents).

In these cases, an airflow system must be implemented to renew the air inside the under-pressure site and the entrance to it is enclosed with fixed double door-walls.

In the case at hand, the question looks different. It is said that the wastes in Stocamine are all solid and of negligible volatility. Moreover, the wastes cannot generate gas at the atmospheric conditions of the mine. It is also discussed the possibility of putting in suspension dust from the open (or broken) waste packs. In addition, it is evaluated the asbestos as the more dangerous substance to handle with, once the majority of mercury wastes has been extracted. Otherwise, the implementation in the mine of this kind of barriers to creating the under-pressure area should be mobile as the working face moves forward, so they probably involve some problems and delays of the retrieval works.

Alternatively, it has been commented that the entrance to the block galleries from the side access road has to be closed to the airflow. If the under-pressure were considered necessary, a fixed low power fan could be installed in the side access road with a pipe sucking a low airflow from the block to create a little depression. It should be considered if this installation has to be complemented with a slight dust off equipment or a filter, only in case dust in suspension were observed.

Hence, under-pressure can be created this way, if necessary, without adding extra difficulties in the working face. Of course, if some curtains in the working face are useful for other reasons, they can be installed.

## 4.4. Ventilation for closure and confinement operations.

Although this question is also a secondary ventilation, it is treated apart from the secondary ventilation of the waste retrieval operations because it needs lower requirements of airflow, as there is no possibility of asbestos in the workplace atmosphere.

The air requirements of this working faces, in where the closure plugs should be done, can be calculated as a function of the machines that operate and the needs for air renewal, particularly to maintain the admissible temperature.

The secondary ventilations of these places can be arranged in cascade, with a local low-power suction fan and a pocket dust off the installation, if necessary.

# 5. Some restrictions for the time the whole closure of the waste storage will last.

The retrieval working procedure is not evaluated in this report, as it is not its scope. However, the analysis of MDPA documentation show some matters that may be cause a lower restriction on the death line of the complete project of waste retrieval plus the closure and confinement of the waste storage.

## 5.1. Hoisting restrictions to the retrieval operations.

The capacity of the hoisting cage machine is around 12 waste packages in an hour, in the best operating conditions. There is a limit of weight of 5 tons each time. As a little amount of waste packages weight more than 2 tons (5%, for instance), the capacity of extraction is affected in the same proportion (not substantial).

Besides, it has been said that closure and confinement operations must be carried out simultaneously with the waste retrieval ones. It can be supposed that the 60% of the hoisting time available can be used for waste packages extraction.

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If we considered between 10% and 20% of uncertainty for the hoisting extraction, we can reach a figure around 6 packages per hour for the capacity of extraction, as an average.

If works are planned in two shifts, let consider 12 working hours for the hoisting. Under these hypotheses a limit for the waste packages extraction is around 70 packages per day. As there are 66.260 waste packages, the period for extracting all the packages cannot be less than approximately 4 years (considering 240 working days per year). This time only fixed a lower limitation of the time required for the waste retrieval, and it does not take into account the performance of the removal operations from the working face, nor its possible dysfunctions.

## 5.2. Other questions about total time of the closure and confinement of the waste storage.

The planning of the different variants proposed by MDPA contemplates a term of five years for its complete realization, once the selected waste packages for each scenario are removed. Since some of these tasks can be simultaneously carried out while the waste retrieval is taken place, or even before those works has begun, the death line can be reduced by two years, at least. Supposing that the closure period is correct, 3 years have to be added to the period of the complete activity. This reasoning leads to a restriction for the global activity around 7 years (as a minimum time), which should be increased because of other complementary activities. For instance, if some new secondary ventilation installation has to be implemented, if a period is needed for mining training, if new machinery has to be certified by an official body (ATEX), or if the decision making delay introduces a delay. It can be supposed an increment of 30% for these reasons, except for the latter, not evaluable).

These uncertainties could lead to a global period until the waste retrieval and the final closure and confinement of the waste storage have been achieved of 9 years at least.

# 6. Risk assessment methodology.

In this section, risk assessment methodology is shown. Every process or task by workers, and the equipment and machine used, should follow a risk assessment scheme to assure that the risks are controlled until an admissible safety level is reached.

Besides, risk assessment for every workstation, working procedure and task should be done following the French risk prevention legislation, regulations and codes by the company entrusted with the retrieval and closure activities.

A typical risk management scheme is described as follows (see figure in annex IV).

**Risk management**

**Risk evaluation**

**Risk analysis**

*Risk identification*:

Do we know which type or kind of risks workers will be exposed to? Do we know the factors that influence on the risks?

*Risk appraisal:*

Can we assign or estimate a probability of occurrence or happening for each risk? Which could be the consequences of the risk if the incident or accident finally happens?

*Risk assessment:*

Establish criteria or scale to evaluate and compare risks. Fix the admissible risk level and the minimum acceptable risk control level.

*Iterative question*: Is this process safety enough?

- If the answer is affirmative, the risk is controlled and the work can be carried out. A routine and cyclical control process must be established to check and prevent the change of the conditions in which the risk assessment has been done.
- If the answer is negative, some additional safety measures have to be established before revising the risk assessment.

Every safety measure or control process makes its impact in the time of operation, which has to be estimated for the final time-lapse result.

## 6.1. Standard risks of underground mining.

Besides the specifics risk that have been spoken about before, due to the specific effect on the safety of workers and on the time of the operations for retrieval of wastes and the closure and confinement of the storage, there is some standard risk that has to be considered. No work should start without a previous adequate risk assessment. Some kind of workers document has to be developed, in which the risk of each workplace and working procedure must be identified and assessed, in terms of the probability that the accident happens from a particular risk and the consequences that it would have. Moreover, a description of each workplace should be done, and each working procedure should be established too. Obviously, the risk evaluation should follow the European standards and French legislation, regulations and codes. Next, a brief guide of the risk evaluation is shown:

*Identification of workplace risks*.

1. - Safety conditions.

- Falling of people from one level to another different level
- Falling of people at the same level
- Falling of stones, rock blocks or plates
- Falling of objects by manipulation
- Falling of detached objects
- Footstep on objects
- Knocks and blows against stationary objects
- Blows against and contacts with moving elements of the machinery
- Blows with objects and tools
- Projection of fragments and particles
- Trapping by or between objects or machinery, or between the gables of the gallery and the machinery
- Trapping by overturning of the machinery
- Crashes, collisions or blows with or against vehicles
- Overexertion, inadequate posture or repetitive movements
- Exposure to extreme temperatures
- Thermal contacts
- Electric contacts
- Inhalation or ingestion of harmful substances
- Explosions
- Fires
- Suffocation

2. - Chemical contaminants or agents.

- Inert dust
- Harmful dust
- Harmful gases

3. - Physical contaminants or agents.

- Noise

4. - Ergonomic factors

*Assessment of the risks*.

A matrix which entries are, on one hand, the probability that the accident will occur (assessed as high, medium or low) and on the other hand the seriousness of its consequences (assessed as slight, serious or very serious). The product matrix is diagonal, symmetric and consists of five values: trivial, tolerable, moderate, important and inadmissible. In case the assessment result one of the two latter values, the works cannot start or continue at all.

*Description of the workplace, job and working procedures*.

The workplaces, jobs and procedures have to be descripted and established. They should be considered, among others, the following aspects:

- General and specific functions of the worker
- Principles that govern workers actions and proceedings
- Routinely and non-routinely tasks
- Work equipment to be used
- Chemical products used
- If the work takes place in shifts or at night
- If the job or some task could affect sensitive workers

*Measures to prevent and control the risks*.

The measures to prevent every type of risk should be analysed and established. These measures have to be taken into account to make the risk evaluation. Therefore, if these measures are not applied, the risk could become inadmissible for working.

Information, teaching, and training.

Workers must have a proper information about the risk they are exposed to, the safety measures they have to apply and the procedures that establish how to develop the working operations. In addition, they must be taught about these issues to confirm that they understand them. It is also necessary to train the workers properly about the working procedures they have to follow and the machinery they have to use.

Personal protective equipment (PPE).

The workers must be informed about the PPE they ought to use.

Plan of action in case of emergency and evacuation.

There must be a plan of action in case of emergency and an evacuating plan, following French regulation.

## 7. Recommendations.

After having highlighted the above considerations and reflections, it is considered appropriate to make the following recommendations.

- Facing up the waste retrieval entail some assumptions that have to be clearly exposed:
  - Assumption of a longer period for having completed the closure and confinement of the waste storage. The greater is the delay in being executed the closure and confinement, the greater are the possibilities of having difficulties to do it properly.
  - Assumption of a greater risk for workers, who would undergo a minimum risk status if no waste retrieval is carried out. This assumption will statistically lead to some serious accident.

- Assumption of introducing some environmental risks due to the hypothetical temporary storage of the wastes in the surface and during the transport to the definitive storage. This assumption could have public affectation in the short term.
- Assumption of having to face up the proper closure and confinement of the waste storage, since there is a unanimous consensus on the impossibility of removing the residues from the burned block 15.

- Facing up the closure and confinement of the waste storage immediately, without any more retrieval of wastes entail this assumptions:
  - Assumption that the wastes will be stored forever in Stocamine. Therefore, although long-term predictions indicate that no environmental damage will happen, maybe some complementary measures should be taken, as a control net of the water table and the water around the waste storage by drillings. Additional insertion of chemical barriers to facilitate the crystallization and precipitation in situ of the unwanted elements in the very rare foreseen case they were dissolved by the floodwaters of the mine can also be implemented.

Consequently,

- The decision of trying to retrieve as many waste packages as possible has to be well-thought and weighed up, as it entails serious implications.
- The decision of trying to retrieve as many waste packages as possible has to be taken as soon as possible, in a short-term period (probably in some months), because time puts the proper execution of the closure and confinement of the waste storage in risk.
- If the decision of retrieval all wastes or some part of them is taken, these operations should never endanger nor compromise the adequate and proper closure and confinement of the waste storage.

- Once the decision of the waste retrieval is taken and its implications assumed, some recommendations can be put forward:
  - Proceed to perform a correct risk assessment according to the established working procedure, with special attention to the risk shown in this report.

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- Look for miners or mining experienced workers, if possible.
- Give adequate information and training to the workers who will develop the retrieval operations.
- Analyse the secondary ventilation installation in detail to maximise the number of working faces.
- Re-think organization of the works in order to gain time. For instance, the relieve of workers at the working point (workplace) to avoid loosing of time in the way to it.

## 8. Conclusions.

A brief review of a large amount of existing information on Stocamine project has been done. The conception of the waste deposit and the definitive closure and confinement project seem to be well studied to avoid environmental damage in a very long term.

In other words, the decision of taking the wastes out of their current deposit lead to assume and tackle some kind of extra risks, both for workers and the public, against the hypothetical benefits of having a permanent waste disposal compound of only the block 15. Considering the current situation of the waste storage, the hypothetical benefit of facing up the waste retrieval has to be found in other arguments different from reasons based on a technical and environmental point of view.

A restriction on the period in which the waste retrieval and the closure and confinement of the storage could last is been done, considering hoisting limitations and some kind of uncertainty. It seems to be difficult to reduce this period to less than nine years.

Critical steps of the waste retrieval operations have been highlighted, in order to avoid risks when the working procedures are established.

# 9. Annexes.

## 9.1. Annex I. Accident statistic approach.

## 9.2. Annex II. Complementary measures to the closure and confinement of the waste storage: an example of precipitation and fixing barriers.

## 9.3. Annex III. Scheme of main ventilation.

## 9.4. Annex IV. Risk assessment flow chart and list of Personal protective equipment (PPE).

# ANNEX I

# Accident statistic approach

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## Modified pyramid of Heinrich.


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## European statistics on accidents at work in mining

The statistics on work accidents in mining standardized according to Eurostat criteria are shown below. In addition to the general data of the sector, the data are also exposed by mining sub-sectors according to the NACE code. The information provided is related to the number of fatal accidents at work.

**Table 1.- Number of fatal accidents per year in the MINING SECTOR (NACE B)**

**by member state of the EU**

| GEO/TIME | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 |
|---|---|---|---|---|---|---|---|---|---|
| European Union (current composition) | 119 | 107 | 82 | 112 | 78 | 71 | 72 | 73 | : |
| European Union (before the accession of Croatia) | 119 | 107 | 82 | 112 | 78 | 71 | 71 | 73 | : |
| European Union (15 countries) | 41 | 37 | 38 | 56 | 30 | 32 | 24 | 32 | : |
| Belgium | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | : |
| Bulgaria | 7 | 6 | 5 | 6 | 4 | 8 | 4 | 6 | 1 |
| Czech Republic | 7 | 4 | 4 | 7 | 7 | 4 | 10 | 6 | : |
| Denmark | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 1 | : |
| Germany (until 1990 former territory of the FRG) | 10 | 2 | 5 | 11 | 8 | 6 | 3 | 2 | 4 |
| Estonia | 4 | 0 | 0 | 0 | 1 | 1 | 1 | 2 | : |
| Ireland | 1 | 2 | 0 | 1 | 1 | 2 | 0 | 2 | : |
| Greece | 4 | 2 | 2 | 2 | 1 | 2 | 3 | 0 | : |
| Spain | 11 | 7 | 7 | 11 | 3 | 9 | 5 | 8 | 3 |
| France | 2 | 4 | 4 | 3 | 3 | 0 | 0 | 1 | : |
| Croatia | : | : | 0 | 0 | 0 | 0 | 1 | 0 | : |
| Italy | 5 | 3 | 9 | 5 | 7 | 6 | 4 | 7 | : |
| Cyprus | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Latvia | 1 | 1 | 0 | 1 | 1 | 1 | 0 | 1 | : |
| Lithuania | 2 | 1 | 1 | 1 | 0 | 1 | 0 | 0 | 1 |
| Luxembourg | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | : |
| Hungary | 0 | 1 | 0 | 0 | 1 | 1 | 2 | 0 | 0 |
| Malta | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 1 | 1 |
| Netherlands | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Austria | 0 | 1 | 1 | 1 | 0 | 2 | 0 | 3 | : |
| Poland | 31 | 41 | 26 | 29 | 27 | 18 | 25 | 16 | 27 |
| Portugal | 12 | 8 | 5 | 6 | 4 | 3 | 6 | 4 | : |
| Romania | 25 | 15 | 7 | 12 | 6 | 4 | 5 | 9 | : |
| Slovenia | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | : |
| Slovakia | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 |
| Finland | 2 | 2 | 0 | 0 | 0 | 0 | 1 | 0 | : |
| Sweden | 2 | 1 | 0 | 1 | 1 | 0 | 0 | 1 | 0 |
| United Kingdom | 4 | 5 | 3 | 12 | 2 | 2 | 2 | 3 | 3 |
| Great Britain | 4 | : | : | : | : | : | : | : | : |
| Iceland | : | : | : | 0 | 0 | 0 | : | : | : |
| Norway | 0 | 0 | 0 | 2 | 0 | 7 | 0 | 2 | 13 |
| Switzerland | 1 | 1 | 2 | 0 | 0 | 1 | 1 | 0 | 3 |

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**Table 2.- Number of fatal accidents per year in the subsector of CARBON MINING**

**by member state of the EU**

| GEO/TIME | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 |
|---|---|---|---|---|---|---|---|---|---|
| European Union (current composition) | 52 | 49 | 21 | 46 | 28 | 27 | 33 | 18 | : |
| European Union (before the accession of Croatia) | 52 | 49 | 21 | 46 | 28 | 27 | 33 | 18 | : |
| European Union (15 countries) | 6 | 5 | 2 | 13 | 3 | 7 | 4 | 3 | : |
| Belgium | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | : |
| Bulgaria | 4 | 3 | 1 | 1 | 1 | 7 | 0 | 1 | 0 |
| Czech Republic | 5 | 1 | 2 | 7 | 5 | 4 | 10 | 4 | : |
| Denmark | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | : |
| Germany (until 1990 former territory of the FRG) | 2 | 0 | 0 | 1 | 2 | 1 | 0 | 1 | 2 |
| Estonia | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | : |
| Ireland | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | : |
| Greece | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 0 | : |
| Spain | 3 | 2 | 1 | 6 | 1 | 6 | 1 | 2 | 1 |
| France | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | : |
| Croatia | : | : | 0 | 0 | 0 | 0 | 0 | 0 | : |
| Italy | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | : |
| Cyprus | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Latvia | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | : |
| Lithuania | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Luxembourg | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | : |
| Hungary | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 |
| Malta | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Netherlands | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Austria | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | : |
| Poland | 20 | 36 | 15 | 18 | 16 | 8 | 18 | 8 | 10 |
| Portugal | : | 0 | 0 | 0 | 0 | 0 | 0 | 0 | : |
| Romania | 17 | 4 | 1 | 7 | 3 | 0 | 0 | 2 | : |
| Slovenia | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | : |
| Slovakia | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 |
| Finland | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | : |
| Sweden | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| United Kingdom | 1 | 3 | 1 | 6 | 0 | 0 | 0 | 0 | 0 |
| Great Britain | : | : | : | : | : | : | : | : | : |
| Iceland | : | : | : | 0 | 0 | 0 | : | : | : |
| Norway | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 0 |
| Switzerland | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

**Table 3.- Number of fatal accidents per year in the subsector of METALLIC MINING by member state of the EU**

| GEO/TIME | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 |
|---|---|---|---|---|---|---|---|---|---|
| European Union (current composition) | 9 | 7 | 11 | 12 | 9 | 5 | 5 | 12 | : |
| European Union (before the accession of Croatia) | 9 | 7 | 11 | 12 | 9 | 5 | 5 | 12 | : |
| European Union (15 countries) | 3 | 1 | 2 | 3 | 2 | : | 0 | 1 | : |
| Belgium | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | : |
| Bulgaria | 1 | 2 | 4 | 3 | 3 | 0 | 3 | 5 | 1 |
| Czech Republic | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | : |
| Denmark | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | : |
| Germany (until 1990 former territory of the FRG) | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Estonia | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | : |
| Ireland | 1 | 0 | 0 | 1 | 0 | 1 | 0 | 0 | : |
| Greece | 1 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | : |
| Spain | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 0 |
| France | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | : |
| Croatia | : | : | 0 | 0 | 0 | 0 | 0 | 0 | : |
| Italy | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | : |
| Cyprus | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Latvia | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | : |
| Lithuania | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Luxembourg | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | : |
| Hungary | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Malta | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Netherlands | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Austria | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | : |
| Poland | 5 | 3 | 5 | 5 | 4 | 3 | 2 | 4 | 12 |
| Portugal | : | 0 | 2 | 1 | 1 | 0 | 0 | 0 | : |
| Romania | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | : |
| Slovenia | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | : |
| Slovakia | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Finland | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | : |
| Sweden | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| United Kingdom | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Great Britain | : | : | : | : | : | : | : | : | : |
| Iceland | : | : | : | 0 | 0 | 0 | : | : | : |
| Norway | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Switzerland | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

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**Table 4.- Number of fatal accidents per year in the OTHER MINING (NON METALLIC OR ENERGY) subsector by EU member state**

| GEO/TIME | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 |
|---|---|---|---|---|---|---|---|---|---|
| European Union (current composition) | 45 | 43 | 44 | 44 | 35 | 35 | 26 | 33 | : |
| European Union (before the accession of Croatia) | 45 | 43 | 44 | 44 | 35 | 35 | 25 | 33 | : |
| European Union (15 countries) | 30 | 30 | 33 | 34 | 24 | 23 | 18 | 26 | : |
| Belgium | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | : |
| Bulgaria | 2 | 1 | 0 | 1 | 0 | 1 | 1 | 0 | 0 |
| Czech Republic | 2 | 2 | 1 | 0 | 2 | 0 | 0 | 1 | : |
| Denmark | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 1 | : |
| Germany (until 1990 former territory of the FRG) | 8 | 2 | 5 | 8 | 6 | 5 | 3 | 1 | 2 |
| Estonia | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | : |
| Ireland | 0 | 2 | 0 | 0 | 1 | 1 | 0 | 2 | : |
| Greece | 2 | 1 | 2 | 2 | 1 | 1 | 0 | 0 | : |
| Spain | 8 | 5 | 6 | 4 | 2 | 3 | 4 | 5 | 2 |
| France | 2 | 4 | 4 | 2 | 2 | 0 | 0 | 1 | : |
| Croatia | : | : | 0 | 0 | 0 | 0 | 1 | 0 | : |
| Italy | 4 | 3 | 8 | 5 | 6 | 6 | 4 | 7 | : |
| Cyprus | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Latvia | 1 | 1 | 0 | 0 | 1 | 1 | 0 | 1 | : |
| Lithuania | 2 | 1 | 1 | 1 | 0 | 1 | 0 | 0 | 1 |
| Luxembourg | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | : |
| Hungary | 0 | 1 | 0 | 0 | 0 | 1 | 1 | 0 | 0 |
| Malta | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 1 | 0 |
| Netherlands | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Austria | 0 | 1 | 1 | 1 | 0 | 2 | 0 | 2 | : |
| Poland | 2 | 2 | 5 | 6 | 4 | 7 | 2 | 1 | 2 |
| Portugal | : | 8 | 3 | 5 | 3 | 3 | 6 | 4 | : |
| Romania | 4 | 4 | 3 | 2 | 2 | 1 | 3 | 3 | : |
| Slovenia | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | : |
| Slovakia | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Finland | 2 | 2 | 0 | 0 | 0 | 0 | 1 | 0 | : |
| Sweden | 2 | 1 | 0 | 1 | 1 | 0 | 0 | 1 | 0 |
| United Kingdom | 2 | 1 | 2 | 3 | 2 | 2 | 0 | 2 | 1 |
| Great Britain | : | : | : | : | : | : | : | : | : |
| Iceland | : | : | : | 0 | 0 | 0 | : | : | : |
| Norway | 0 | 0 | 0 | 2 | 0 | 1 | 0 | 1 | 2 |
| Switzerland | 1 | 1 | 2 | 0 | 0 | 1 | 1 | 0 | 3 |

As a general conclusion of these data, it can be indicated that in those countries that have certain mining activity in any of the existing sub-sectors, they have certain levels of fatal accidents in these activities that vary according to the different levels of risk.

## Spanish statistics on accidents at work in mining

Next, the information on the number of fatal accidents is presented and, in addition, the number of serious accidents in the different mining subsectors that occurred in Spain in the period 2008 - 2017.

**Table 5.- Number of fatal accidents per year and mining subsector in Spain**

| | SAND & GRAVEL | ORNAMENTAL ROCK | ENERGY MINERALS | INDUSTRIAL MINERALS | METALLIC MINERALS | TOTAL |
|---|---|---|---|---|---|---|
| 2008 | 6 | 3 | 3 | 0 | 0 | 12 |
| 2009 | 1 | 1 | 3 | 1 | 0 | 6 |
| 2010 | 2 | 2 | 2 | 1 | 1 | 8 |
| 2011 | 1 | 1 | 5 | 1 | 1 | 9 |
| 2012 | 2 | 0 | 1 | 4 | 0 | 7 |
| 2013 | 3 | 0 | 6 | 3 | 0 | 12 |
| 2014 | 1 | 3 | 0 | 1 | 0 | 5 |
| 2015 | 0 | 4 | 2 | 1 | 1 | 8 |
| 2016 | 0 | 1 | 1 | 0 | 0 | 2 |
| 2017 | 2 | 1 | 0 | 1 | 0 | 4 |

**Table 6.- Number of serious accidents per year and mining subsector in Spain**

| | SAND & GRAVEL | ORNAMENTAL ROCK | ENERGY MINERALS | INDUSTRIAL MINERALS | METALLIC MINERALS | TOTAL |
|---|---|---|---|---|---|---|
| 2008 | 9 | 4 | 13 | 2 | 0 | 28 |
| 2009 | 7 | 3 | 17 | 4 | 1 | 32 |
| 2010 | 10 | 1 | 15 | 3 | 1 | 30 |
| 2011 | 10 | 1 | 10 | 6 | 0 | 27 |
| 2012 | 3 | 2 | 7 | 2 | 0 | 14 |
| 2013 | 5 | 2 | 3 | 2 | 3 | 15 |
| 2014 | 7 | 3 | 7 | 1 | 0 | 18 |
| 2015 | 2 | 2 | 5 | 3 | 2 | 14 |
| 2016 | 5 | 3 | 7 | 1 | 2 | 18 |
| 2017 | 6 | 4 | 1 | 7 | 2 | 20 |

If the Incidence rate of fatal accidents is obtained by dividing the number of accidents by the number of workers employed in each sector (standardizing 100,000 workers), the levels of accidents between different sectors can be compared.

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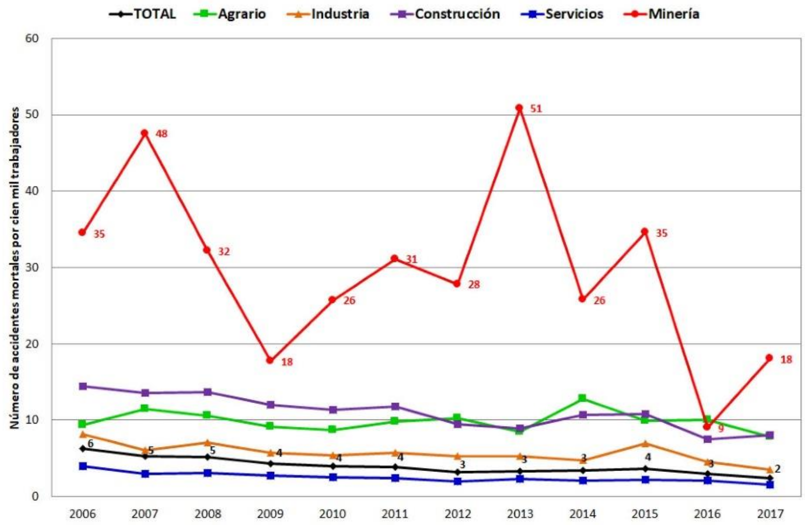
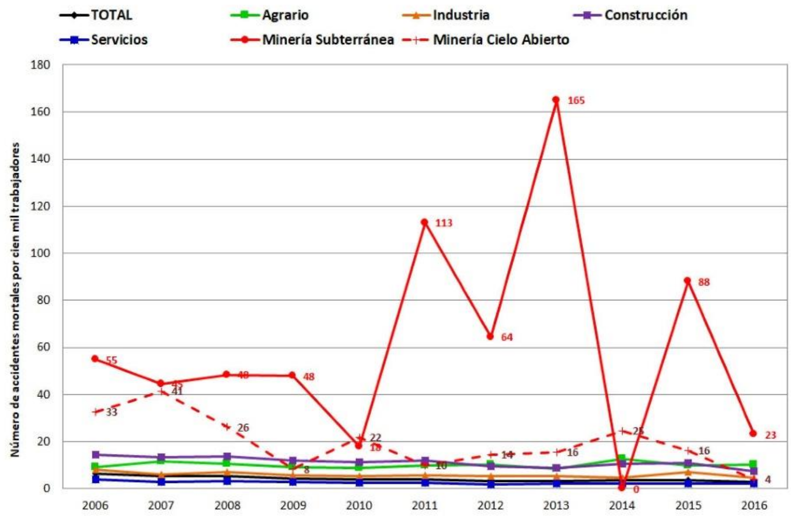
Below are several comparisons that show how, within the mining sector, underground mining presents higher levels of risk and, within this, mining of coal and industrial minerals in particular.

**Graph 1.- Evolution of fatal accident incidence rates, comparison of general mining with other sectors.**

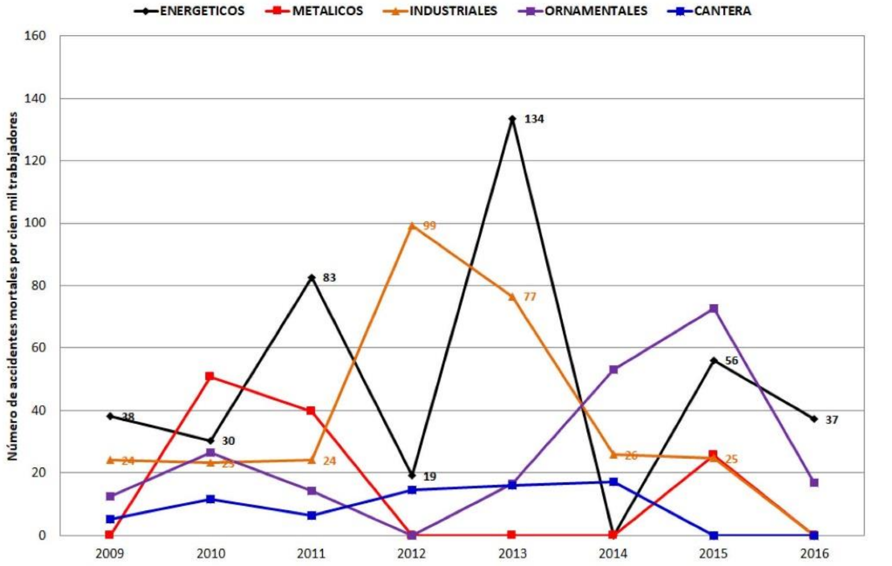



**Graph 2.- Evolution of fatal accident incidence rates, comparison of underground mining and open pit**




**mining with other sectors.**

**Graph 3.- Evolution of fatal accident incidence rates, mining subsector comparison by type of product**

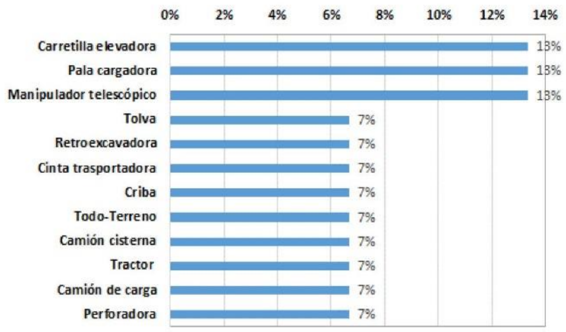



In Spain, within the production of industrial minerals, the extraction of minerals from sodium and potassium salts by underground tillage has an important weight, which is why in this sector a certain accident rate accumulates.

Carrying out an analysis by causes within the mining of industrial minerals taking as sample space the serious and fatal accidents that occurred in Spain in the period 2014-2017, the following results are obtained that characterize the main risks existing in this type of exploitation.

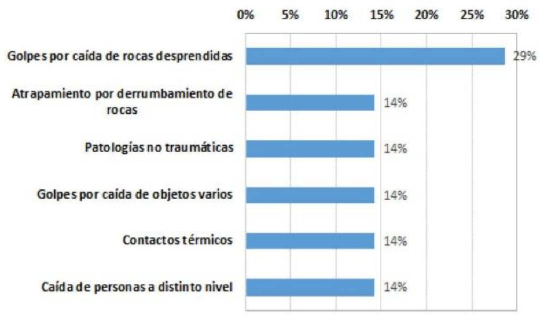
The distribution of accidents as it relates to the use of work equipment is as follows: near to the 70% of accidents are related to the working equipment.

The distribution of accidents related to the use of work equipment, classified according to the type of equipment, is as follows.




**Graph 5.- Type of work team related to the accident.**

The distribution of accidents not related to the use of work equipment, classified according to the way the accident occurred, is as follows.




**Graph 6.- How the accident occurred.**

As a general conclusion, it can be indicated that in the underground exploitations dedicated to the extraction of metallic and industrial minerals, within which the mines of extraction of sodium and potassium salts are framed, the most frequent typologies of accidents are the following:

- Among the accidents related to the use of work equipment, those related to the use of mobile machinery of various kinds (forklifts, loaders and telescopic handlers, trucks, drillers, etc.).

- Among the accidents not related to the use of work equipment, mainly those due to falling rocks detached.

# ANNEX II

## Complementary measures to the closure and confinement of the waste storage:

## An example of precipitation and fixing barriers

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Immobilization of pollutants in the environment takes place by precipitation of low-solubility salts or by sorption on mineral surfaces in rocks, soils and aquifers. Artificial remediation methods are based on the same mechanisms, and the most common techniques are sorption and precipitation by reaction with minerals abundant in Earth surface[11].

As an example of such processes, the interaction of gypsum with aqueous solution poisoned with arsenic (for instance at a concentration of 2000 ppm) was modeled with geochemical code PHREEQC12 in order to determine the driving forces operating to eliminate such pollutant (see calculations at the end of this document). As can be observed, different arsenic-bearing phases are susceptible to precipitate at ambient conditions and neutral pH.

In conclusion, an aqueous solution containing arsenic in contact with mineral fragments of gypsum results in precipitation of a number of phases bearing arsenic (see phases marked in red in the calculations). The reaction can be envisaged as a sorption process in which the sorbate is an adherent crystalline phase that consists of chemical species derived from both the aqueous solution and the dissolution of gypsum. The effectiveness of this kind of processes depends not only on the thermodynamics of the involved system but also on the spatial arrangement and crystallographic relations between substrate and overgrowth. Besides, the more initial concentration of solved pollutant, the sooner the pollutant is being borne, due to the kinetics.

CALCULATIONS

------------------
Reading data base.

---

[11] Jiménez, A., Prieto, M., Salvadó, M. A. and García Granda, S.A. (2004) Structure and crystallization behavior of the (Ba,Sr)$HAsO_4 \cdot H_2O$ solid-solution in aqueous environments. American Mineralogist 89, 601-609

Jiménez, A., Rodríguez, J.D., Prieto, M., Torre, L. and García Granda, S. (2006) Crystal structure of dicalcium sodium monohydrogen diarsenate hexahydrate, $Ca_2Na[HAsO_4][AsO_4] \cdot 6H_2O$ Z. kristallogr. NCS 221, 241-242

Rodríguez, J.D., Jiménez, A., Prieto, M., Torre, L. and García Granda, S. (2008) Interaction of gypsum with As(V)-bearing aqueous solutions: Surface precipitation of guerinite, sainfeldite, and $Ca_2Na(HAsO_4)AsO_4 \cdot 6H_2O$, a synthetic arsenate. American Mineralogist 93, 928-939.

Rodríguez, J.D., Jiménez, A., and Prieto, M. (2007) Oriented overgrowth of pharmacolite ($CaHAsO_4 \cdot 2H_2O$) on gypsum ($CaSO_4 \cdot 2H_2O$). Crystal Growth and Design 7, 2756-2763.

[12] Parkhurst and Appelo, 1999.

```
------------------
        SOLUTION_MASTER_SPECIES
        SOLUTION_SPECIES
        PHASES
        EXCHANGE_MASTER_SPECIES
        EXCHANGE_SPECIES
        SURFACE_MASTER_SPECIES
        SURFACE_SPECIES
        RATES
        END
------------------------------------
Reading input data for simulation 1.
------------------------------------
DATABASE C:\Users\Amalia\Documents\Desktop\Asistencia Tecnica LOM\Alsace\As7_wateq4fdylvite.dat
        SOLUTION 1
          temp      25 °C
          pH        7
          pe        4
          redox     pe
          units     ppm
          density   1
          As        2000
          water     1 # kg
        EQUILIBRIUM_PHASES 1
          Gypsum    0 10
          Sylvite   3 10
        end
-------------------------------------------
Beginning of initial solution calculations.
-------------------------------------------

Initial solution 1.

----------------------------Solution composition------------------------------

        Elements        Molality    Moles

        As          2.675e-02   2.675e-02

----------------------------Description of solution----------------------------

                          pH  =  7.000
                          pe  =  4.000
             Activity of water  =  1.000
          Ionic strength (mol/kgw)  =  4.357e-02
               Mass of water (kg)  =  1.000e+00
          Total alkalinity (eq/kg)  =  2.013e-02
            Total carbon (mol/kg)  =  0.000e+00
               Total CO2 (mol/kg)  =  0.000e+00
                 Temperature (°C)  =  25.00
          Electrical balance (eq)  =  -4.688e-02
 Percent error, 100*(Cat-|An|)/(Cat+|An|)  = -100.00
```

Iterations = 5
Total H = 1.110458e+02
Total O = 5.561321e+01

----------------------------Distribution of species----------------------------

| Species | Molality | Log Activity | Log Molality | Log Activity | mole V Gamma | cm³/mol |
|---|---|---|---|---|---|---|
| OH- | 1.207e-07 | 1.001e-07 | -6.918 | -7.000 | -0.081 | (0) |
| H+ | 1.164e-07 | 1.000e-07 | -6.934 | -7.000 | -0.066 | 0.00 |
| H2O | 5.551e+01 | 9.995e-01 | 1.744 | -0.000 | 0.000 | 18.07 |
| As(3) | 2.177e-10 | | | | | |
| H3AsO3 | 2.158e-10 | 2.180e-10 | -9.666 | -9.662 | 0.004 | (0) |
| H2AsO3- | 1.861e-12 | 1.543e-12 | -11.730 | -11.812 | -0.081 | (0) |
| H4AsO3+ | 1.303e-17 | 1.080e-17 | -16.885 | -16.967 | -0.081 | (0) |
| HAsO3-2 | 6.517e-20 | 3.079e-20 | -19.186 | -19.512 | -0.326 | (0) |
| AsO3-3 | 3.320e-28 | 6.143e-29 | -27.479 | -28.212 | -0.733 | (0) |
| As(5) | 2.675e-02 | | | | | |
| HAsO4-2 | 2.013e-02 | 9.511e-03 | -1.696 | -2.022 | -0.326 | (0) |
| H2AsO4- | 6.616e-03 | 5.485e-03 | -2.179 | -2.261 | -0.081 | (0) |
| AsO4-3 | 1.285e-06 | 2.378e-07 | -5.891 | -6.624 | -0.733 | (0) |
| H3AsO4 | 9.635e-08 | 9.732e-08 | -7.016 | -7.012 | 0.004 | (0) |
| H(0) | 1.402e-25 | | | | | |
| H2 | 7.009e-26 | 7.079e-26 | -25.154 | -25.150 | 0.004 | (0) |
| O(0) | 0.000e+00 | | | | | |
| O2 | 0.000e+00 | 0.000e+00 | -42.085 | -42.080 | 0.004 | (0) |

------------------------------Saturation indices------------------------------

| Phase | SI** | log IAP | log K(298 K, 1 atm) | |
|---|---|---|---|---|
| Arsenolite | -17.94 | -19.32 | -1.38 | As2O3 |
| As2O5 | -20.72 | -14.02 | 6.70 | As2O5 |
| Claudetite | -17.98 | -19.32 | -1.34 | As2O3 |
| H2(g) | -22.00 | -25.15 | -3.15 | H2 |
| H2O(g) | -1.51 | -0.00 | 1.51 | H2O |
| O2(g) | -39.12 | -42.08 - | 2.96 | O2 |

**For a gas, SI = log10(fugacity). Fugacity = pressure * phi / 1 atm.
For ideal gases, phi = 1.

-----------------------------------------
Beginning of batch-reaction calculations.
-----------------------------------------

Reaction step 1.

Using solution 1.
Using pure phase assemblage 1.

-------------------------------Phase assemblage--------------------------------

| Phase | SI | log IAP | log K(T, P) | Moles in assemblage Initial | Final | Delta |
|---|---|---|---|---|---|---|
| Gypsum | 0.00 | -4.58 | -4.58 | 1.000e+01 | 9.963 | -3.721e-02 |
| Sylvite | 0.70 | 1.60 | 0.90 | 1.000e+01 | 0 | -1.000e+01 |

-----------------------------Solution composition------------------------------

| Elements | Molality | Moles |
|---|---|---|
| As | 2.671e-02 | 2.675e-02 |
| Ca | 3.716e-02 | 3.721e-02 |
| Cl | 9.987e+00 | 1.000e+01 |
| K | 9.987e+00 | 1.000e+01 |
| S | 3.716e-02 | 3.721e-02 |

----------------------------Description of solution----------------------------

pH = 6.026 Charge balance
pe = 5.509 Adjusted to redox equilibrium
Activity of water = 0.659
Ionic strength (mol/kgw) = 1.008e+01
Mass of water (kg) = 1.001e+00
Total alkalinity (eq/kg) = 2.011e-02
Total carbon (mol/kg) = 0.000e+00
Total CO2 (mol/kg) = 0.000e+00
Temperature (°C) = 25.00
Electrical balance (eq) = -4.688e-02
Percent error, 100*(Cat-|An|)/(Cat+|An|) = -0.23
Iterations = 25
Total H = 1.111946e+02
Total O = 5.583645e+01

----------------------------Distribution of species----------------------------

| Species | Molality | Log Activity | Log Molality | Log Activity | mole V Gamma | cm³/mol |
|---|---|---|---|---|---|---|
| H+ | 1.349e-06 | 9.421e-07 | -5.870 | -6.026 | -0.156 | 0.00 |
| OH- | 4.909e-10 | 7.005e-09 | -9.309 | -8.155 | 1.154 | (0) |
| H2O | 5.551e+01 | 6.592e-01 | 1.744 | -0.181 | 0.000 | 18.07 |
| As(3) | 2.174e-10 | | | | | |
| H3AsO3 | 2.172e-10 | 2.213e-09 | -9.663 | -8.655 | 1.008 | (0) |
| H2AsO3- | 1.165e-13 | 1.663e-12 | -12.934 | -11.779 | 1.154 | (0) |
| H4AsO3+ | 7.238e-17 | 1.033e-15 | -16.140 | -14.986 | 1.154 | (0) |
| HAsO3-2 | 8.495e-26 | 3.521e-21 | -25.071 | -20.453 | 4.618 | (0) |
| AsO3-3 | 0.000e+00 | 7.458e-31 | -40.517 | -30.127 | 10.389 | (0) |
| AsS(OH)(HS)- | 0.000e+00 | 0.000e+00 | -131.057 | -129.903 | 1.154 | (0) |
| As3S4(HS)2- | 0.000e+00 | 0.000e+00 | -384.172 | -383.018 | 1.154 | (0) |
| As(5) | 2.671e-02 | | | | | |
| CaHAsO4 | 2.010e-02 | 2.048e-01 | -1.697 | -0.689 | 1.008 | (0) |
| CaH2AsO4+ | 3.404e-03 | 4.857e-02 | -2.468 | -1.314 | 1.154 | (0) |
| H2AsO4- | 3.202e-03 | 4.568e-02 | -2.495 | -1.340 | 1.154 | (0) |
| CaAsO4- | 1.823e-06 | 2.601e-05 | -5.739 | -4.585 | 1.154 | (0) |
| H3AsO4 | 7.497e-07 | 7.636e-06 | -6.125 | -5.117 | 1.008 | (0) |
| HAsO4-2 | 2.028e-07 | 8.408e-03 | -6.693 | -2.075 | 4.618 | (0) |
| AsO4-3 | 9.101e-19 | 2.232e-08 | -18.041 | -7.651 | 10.389 | (0) |
| Ca | 3.716e-02 | | | | | |
| CaHAsO4 | 2.010e-02 | 2.048e-01 | -1.697 | -0.689 | 1.008 | (0) |
| Ca+2 | 1.246e-02 | 5.207e-02 | -1.904 | -1.283 | 0.621 | (0) |
| CaH2AsO4+ | 3.404e-03 | 4.857e-02 | -2.468 | -1.314 | 1.154 | (0) |
| CaSO4 | 1.183e-03 | 1.205e-02 | -2.927 | -1.919 | 1.008 | (0) |
| CaAsO4- | 1.823e-06 | 2.601e-05 | -5.739 | -4.585 | 1.154 | (0) |
| CaHSO4+ | 4.661e-09 | 6.651e-08 | -8.332 | -7.177 | 1.154 | (0) |
| CaOH+ | 5.396e-10 | 7.700e-09 | -9.268 | -8.114 | 1.154 | (0) |
| Cl | 9.987e+00 | | | | | |
| Cl- | 9.987e+00 | 6.345e+00 | 0.999 | 0.802 | -0.197 | (0) |
| H(0) | 1.186e-27 | | | | | |
| H2 | 5.931e-28 | 6.040e-27 | -27.227 | -26.219 | 1.008 | (0) |
| K | 9.987e+00 | | | | | |
| K+ | 9.983e+00 | 6.342e+00 | 0.999 | 0.802 | -0.197 | (0) |
| KSO4- | 3.623e-03 | 5.169e-02 | -2.441 | -1.287 | 1.154 | (0) |
| O(0) | 0.000e+00 | | | | | |
| O2 | 0.000e+00 | 0.000e+00 | -41.312 | -40.304 | 1.008 | (0) |
| S(-2) | 0.000e+00 | | | | | |
| H2S | 0.000e+00 | 0.000e+00 | -66.903 | -65.895 | 1.008 | (0) |
| HS- | 0.000e+00 | 0.000e+00 | -67.965 | -66.811 | 1.154 | (0) |
| S5-2 | 0.000e+00 | 0.000e+00 | -69.901 | -70.380 | -0.479 | (0) |
| S4-2 | 0.000e+00 | 0.000e+00 | -70.047 | -70.614 | -0.567 | (0) |
| S6-2 | 0.000e+00 | 0.000e+00 | -70.251 | -70.666 | -0.415 | (0) |
| S3-2 | 0.000e+00 | 0.000e+00 | -73.374 | -74.067 | -0.693 | (0) |
| S2-2 | 0.000e+00 | 0.000e+00 | -74.480 | -75.313 | -0.833 | (0) |
| S-2 | 0.000e+00 | 0.000e+00 | -78.321 | -73.703 | 4.618 | (0) |
| AsS(OH)(HS)- | 0.000e+00 | 0.000e+00 | -131.057 | -129.903 | 1.154 | (0) |
| As3S4(HS)2- | 0.000e+00 | 0.000e+00 | -384.172 | -383.018 | 1.154 | (0) |

| | | | | | | |
|---|---|---|---|---|---|---|
| S(6) | 3.716e-02 | | | | | |
| SO4-2 | 3.235e-02 | 1.160e-03 | -1.490 | -2.936 | -1.445 | (0) |
| KSO4- | 3.623e-03 | 5.169e-02 | -2.441 | -1.287 | 1.154 | (0) |
| CaSO4 | 1.183e-03 | 1.205e-02 | -2.927 | -1.919 | 1.008 | (0) |
| HSO4- | 7.446e-09 | 1.063e-07 | -8.128 | -6.974 | 1.154 | (0) |
| CaHSO4+ | 4.661e-09 | 6.651e-08 | -8.332 | -7.177 | 1.154 | (0) |

-----------------------------Saturation indices-------------------------------

| Phase | SI** | log IAP | log K(298 K, 1 atm) | |
|---|---|---|---|---|
| Anhydrite | 0.14 | -4.22 | -4.36 | CaSO4 |
| Arsenolite | -15.39 | -16.77 | -1.38 | As2O3 |
| As2O5 | -16.39 | -9.69 | 6.70 | As2O5 |
| As2S3(am) | -189.84 | -234.74 | -44.90 | As2S3 |
| **Ca3(AsO4)2** | 2.06 | -19.15 | -21.21 | Ca3(AsO4)2 |
| **Ca3(AsO4)2:3.6H2O** | 1.18 | -19.82 | -21.00 | Ca3(AsO4)2:3.6666667H2O |
| **Ca3(AsO4)2:4.25w** | 1.08 | -19.92 | -21.00 | Ca3(AsO4)2:4.25H2O |
| Ca3(AsO4)2:4w | -0.97 | -19.88 | -18.91 | Ca3(AsO4)2:4H2O |
| Ca3(AsO4)2:6H2O | -1.31 | 20.99 | 22.30 | Ca3(AsO4)2:6H2O |
| Ca4(OH)2(AsO4)2:4w | -8.27 | -37.47 | -29.20 | Ca4(OH)2(AsO4)2:4H2O |
| **Ca5(AsO4)3OH** | 0.77 | -37.53 | -38.30 | Ca5(AsO4)3OH |
| Claudetite | -15.43 | -16.77 | -1.34 | As2O3 |
| **Farmacolite** | **0.91** | **-3.72** | **-4.63** | **CaHAsO4:2H2O** |
| **Ferrarisite** | **3.99** | **-27.50** | **-31.49** | **Ca5H2(AsO4)4:9H2O** |
| **Guerinite** | **3.19** | **-27.50** | **-30.69** | **Ca5H2(AsO4)4:9H2O** |
| Gypsum | 0.00 | -4.58 | -4.58 | CaSO4:2H2O |
| H2(g) | -23.07 | -26.22 | -3.15 | H2 |
| H2O(g) | -1.69 | -0.18 | 1.51 | H2O |
| H2S(g) | -64.90 | -65.90 | -1.00 | H2S |
| **Haidingerite** | **1.25** | **-3.54** | **-4.79** | **CaHAsO4:H2O** |
| O2(g) | -37.34 | -40.30 | -2.96 | O2 |
| Orpiment | -188.44 | -234.74 | -46.30 | As2S3 |
| Portlandite | -12.39 | 10.41 | 22.80 | Ca(OH)2 |
| Realgar | -72.54 | -92.48 | -19.94 | AsS |
| Sulfur | -47.66 | -62.69 | -15.03 | S |
| Sylvite | 0.70 | 1.60 | 0.90 | KCl |

**For a gas, SI = log10(fugacity). Fugacity = pressure * phi / 1 atm.
For ideal gases, phi = 1.

------------------
End of simulation.
------------------

# ANNEX III

# Scheme of main ventilation

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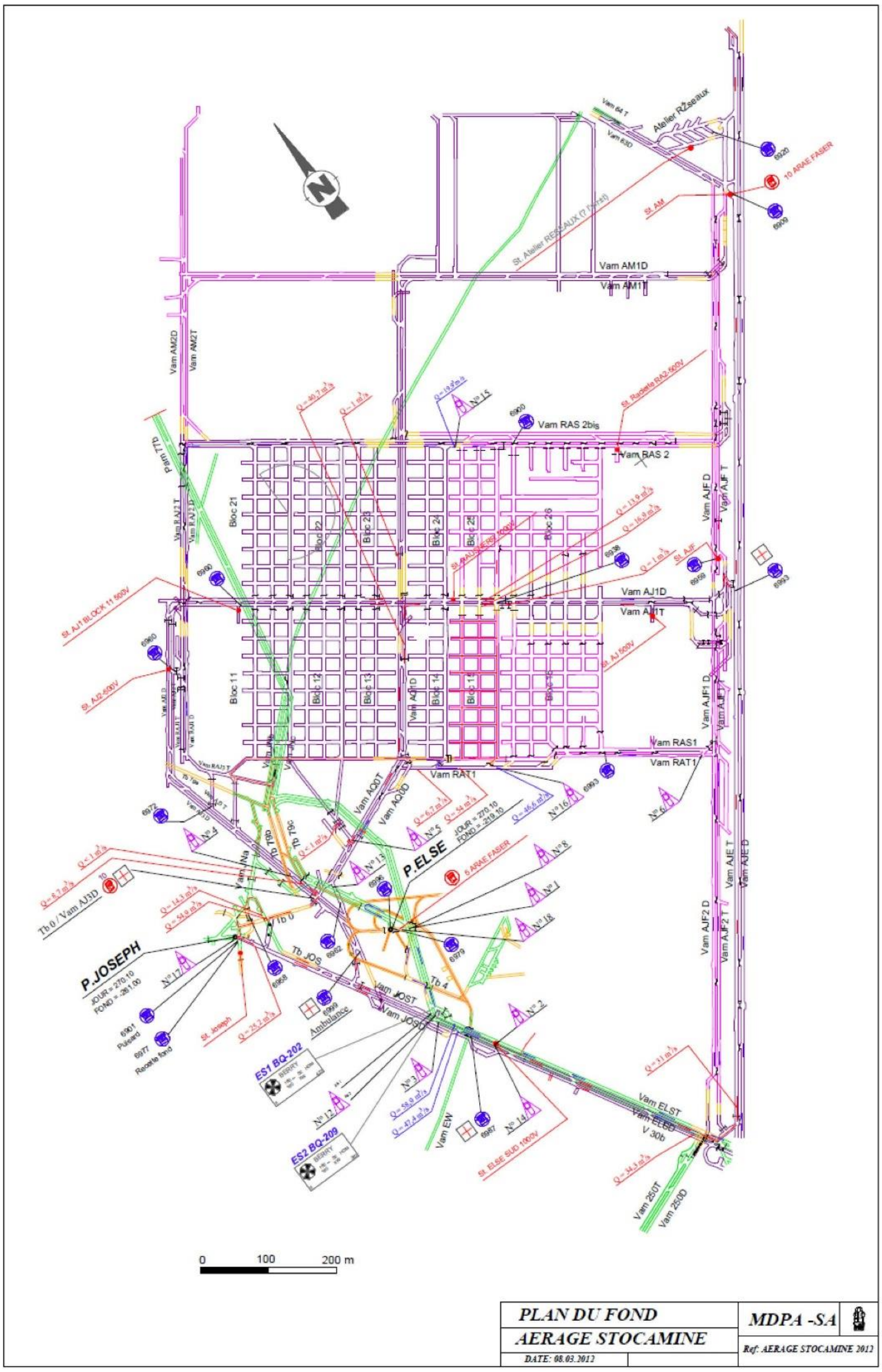


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# ANNEX IV

## Risk assessment flow chart and list of Personal protective equipment (PPE)

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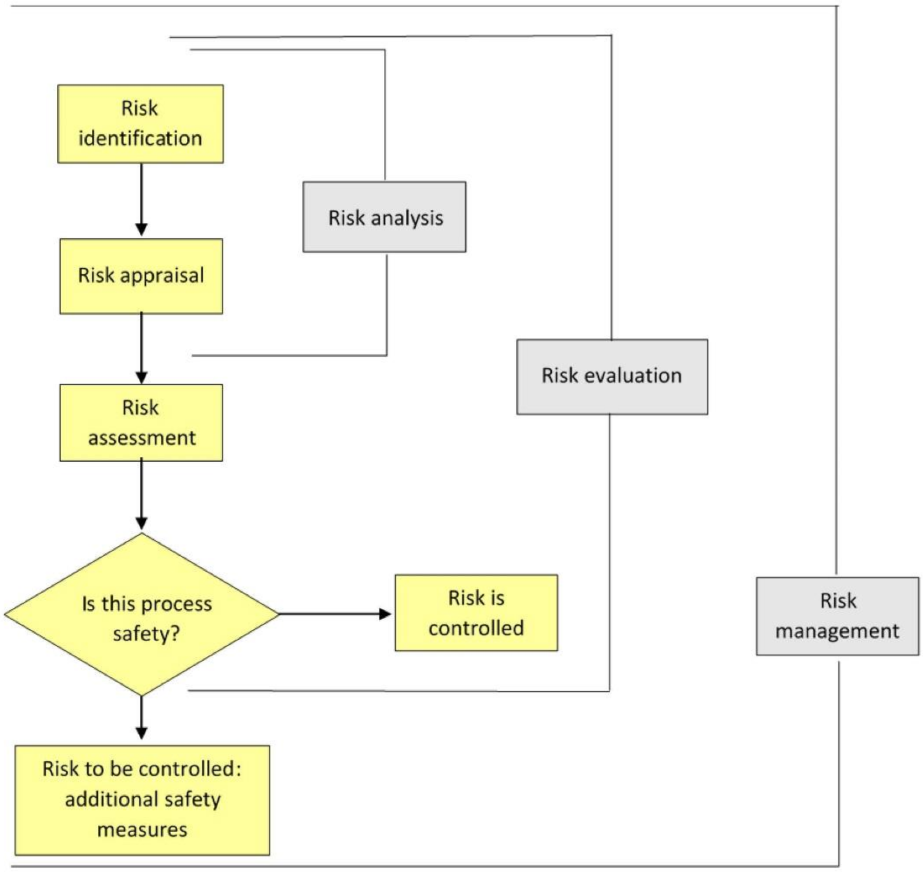
## Risk assessment flow chart




## Personal protective equipment (PPE)

The list of personal protective equipment has to be detail when working procedures had been established.

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# Annexe 6

# Document produit par le Professeur Ramirez pour l'étude

Fundación Gómez Pardo

**REPORT**

**STOCAMINE**

**To BRGM**

0

Fundación Gómez Pardo

**ÍNDEX**[1]

Páge



[1] Note of the translator: the index is not completed.

1

Fundación Gómez Pardo

**REPORT**

**STOCAMINME**

**To BRGM**

## INTRODUCTION

In February of 1997, the Stocamine Company was authorized to operate a reversible underground industrial waste storage facility in the former mine cold Amélie, belonging to Potash Mines of Alsace (MDPA), a company located in the commune of Wittlsheim in the Upper Rhin. The construction of the waste storage began around 1999, so today the oldest galleries are about 19 years old. From 1999 to 2002, approximately 44,000 tons of waste were stored. The different types of stored waste were classified by Stocamine into two classes:

- Class zero: waste that must be stored underground; within this group there were 37,200 packages.
- Class one: waste that can be disposed of in a Class 1 Technical Storage Centre (CET1); of this group there were 27,000.

The residues were deposited at a depth of 550 m, under 300 m of rock salt and Sanoisiense gypsum, in galleries opened in salt below two layers of potash exploited by MDPA.

The first waste packages began to enter in February of 1999. In 2001, 173 packages containing PCBs that had been stored in block B11 were extracted without problems because they did not meet the conditions imposed in the deposit authorization, for which another 783 packages had to be moved. The retrieval operations were carried out between 2001 and 2002 and lasted 7 months.

On the 10$^{th}$ of September of 2002, there was a fire in block B15, which contained 1775 tons of waste, that is, less than 5% of the total mass of stored waste. As a consequence of this fire, Stocamine decided to permanently stop the storage activities in September of 2003 and not to retrieve the packages from this block in any case.

2

Between May of 2014 and November of 2017, that is to say, during 43 months, 1,583 packages of the 1,753 packages containing mercury were removed from the waste storage, so that only 170 packages with mercury remain in the deposit, that is, less than 10% of those that had initially been stored. In addition, 87 packages of phytosanitary wastes were retrieved. The packages of blocks B11, B21, B13, B23, B14 and B22 remain to be retrieved, except for those already removed in 2001 and in 2014-2017, that is, about 42,000 tons (66,260 packages, representing approximately 95% of what was initially stored.

Stocamine waste storage has been the subject of numerous studies over time.

**WASTE STORAGE DESCRIPTION**

The waste storage is excavated under two layers of potash that have been exploited by long front with subsidence which has led to a subsidence in the surface that in some areas reaches 5 m. Figure 1 shows a geological section in which you can see the two layers of potash and the Stocamine waste storage. The thickness of the lower layer is about 4 m and the upper one is 1.5 m thick. A non-exploited massif about 30 m wide was left in the lower layer of potash and also another smaller one, that is located over the waste storage. The latter is about 23 m below the lower layer of potash, although a part of it that is not filled with wastes except block B15 that caught fire, is 25 m bellow the lower layer.

The part of the deposit that has been filled with waste is composed of blocks B11, B12, B13, B14, B21, B22, B23 and B24, plus the block B15. Each of these blocks is made of 3 galleries of rectangular section (5.5 m wide by 2.8 m high) excavated in salt with an approximate direction NE (called roads) and 8 galleries perpendicular to the previous ones and of the same section (called cutting lanes). Square pillars of salt (of 20 m x 20 m) were left between these galleries. The different blocks are separated one from each other by a small massif 3 m wide. The road galleries are about 220 m long and the cutting lanes, 70 m in each block. The access galleries, including the called Vam AQ and Vam AJ galleries that divide the storage, are double. They are separated by pillars of 5 m long by 3.8 m wide and 2.8 m high. The galleries are usually supported by 1.50 m long resin bolts on the roof and on the gables.

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The access to the blocks is thorough peripheral galleries and two central galleries (Vam Vam AJ-) separating blocks B1X from blocks B2X. Those that begin with the number 1 are located to the Southwest of that central gallery and those that begin with the number 2 to the Northwest. The waste storage has a rectangular shape of about 700 m x 500 m. Figure 2 shows a detailed plan of the storage in which each of the blocks and access roads can be seen, as well as Joseph and Else shafts that remain in service. A detailed plan of a block is shown in Figure 3.

The SE part of the waste storage is at level -240 m.a.s.l. and it is higher than the NW edge that is at level -295 m.a.s.l.; the height difference between the two ends of the waste storage is 45 m.

In the waste storage galleries, there are wooden pallets and a big-bag with wastes on each one; there are also pallets with metal barrels, pallets containing asbestos waste and containers.

The residual free room that was left between the waste and the roof of the gallery was 0.6 m to 1.5 m and between the waste and each gable was left about 0.5 m.

## AIM AND SCOPE OF THE STUDY

The purpose of this study is to analyse the geomechanical problems that may arise in the retrieval of the wastes still existing in the warehouse and to estimate whether the time foreseen by MDPA to remove them, from 12 to 15 years, is realistic. It is not foreseen to recover the waste from the burned block B15. To fulfil this objective, the following works have been carried out:

- Review of the reports related to the geomechanical behaviour of the waste storage issued to date.
- Visit to the mine where the waste storage is located.
- Identification of the critical stages of the waste removal operation as geomechanical problems that may arise.
- Stability of the access galleries.
- Recommendations to safely retrieval of the waste packages.
- Estimation of the time in which it is convenient to carry out the remove of those wastes.

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**GEOMECHANIC PERFORMANCE OF THE WASTE STORAGE**

During the visit several convergence measurements were made with tape measure, without great precision:

- In B24-A1: The width of the gallery is 4.8 m, the height is 2.3 m and the roof had a very low density of bolts. The lateral convergence (due to horizontal stress) has been 0.7[2] m in 18 years, that is, approximately 3.9 cm per year in one section of the gallery and 0.5 m in the same period in another section that is, 2.8 cm per year. Note that the measurements were made at the beginning of the gallery, where supposedly the convergence is less than inside it.
- In B13-A3: The gallery has also experienced a lateral convergence of 50 cm.
- In B14-A1: The lateral convergence is 50 cm too.

These measurements were taken with a tape measure and without great precision, but they coincide in order of magnitude with the most accurate data available. These values of the convergences correspond to what it has been observed about the reduced room between the roof and the waste packages, and between the latter and the gables, even those compressed by these, due to the expansion of the salt.

**TIME NECESSARY FOR THE RETRIEVAL OF ALL THE PACKAGES FROM THE WASTE STORAGE**

The total amount of packages left to be retrieve from the waste storage is about 62,000 with a weight of 42,000 tons.

In 2001, in an operation that lasted 7 months, 173 packages containing PCBs were retrieve, but 783 packages had to be moved from one place to another. If only the extracted packages are taken into account, the rhythm of retrieval was about 25 packages / month. If the whole moved packages are added to the calculus, the rate of removing packages is around 137 packages / month.

[2] Note of the translator: this figure of the original text has been changed as it is interpreted as a typing mistake.

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Since May of 2014 to November of 2017, that is, in 43 months, 1,753 packages containing mercury and 87 packages of phytosanitary products, that is, a total of 1,840 packages, were removed from the waste storage. The rhythm was, therefore, about 43 packages / month.

The MDPA staff thinks that, in a scenario of total retrieval of the waste packages (except those in the block B15), 12 packages could be extracted per day with only one retrieval work point, and 24 with two work points. If this rhythm were reached, the 62,000 packages would be retrieval in 2,600 days, that is, some 9 years[3], so if the operations were started in 2020 they would end in 2029, that is, some 30 years after the opening of the waste storage.

In this time (30 tears), the lateral convergence of the galleries would be about 61 cm, assuming an annual rhythm of 20 mm / year. As the lateral free room between the gables and the waste packages that was left when they were placed was of the order 100 cm, the retrieval would have to be done with several packages compressed by the gables[4].

If the retrieval period were 12 to 15 years, as indicated by the scenario officially proposed by MDPA, the situation would be worse. The degradation of the galleries due to the combined effect of the "creep" of the salt rock and the movement of the blocks on the roof floor and gables of the galleries will make many packages compressed and trapped.

The saline massifs, such as the one that houses the waste storage, undergo a gradual process of closing the cavities excavated in them, which had to be re-excavated to maintain the original section, as a consequence of their viscoplastic behaviour. As time goes by, the section of the galleries are reduced and the waste packages compressed and trapped. This fact hinder its removal.

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[3] Note of the translator: this figure maybe could be better 10 or 11 years, if a rate of 240 workdays per year are supposed.

[4] Note of the translator: there could be a mistake in these figures as they seem not to lead to the written conclusion, but the visit to the mine waste storage showed that several waste packages are already trap and even nearly compressed. Maybe the figure 100 cm has to be substituted by 50 cm.

The central pillar 5 m wide, left between the double road galleries, has undergone significant deformations and has been reinforced by bolts and metal strips. The section of the galleries where the waste packages have been deposited has decreased since its opening, albeit unevenly, to the point that the gables and roofs of the galleries have come into contact with the packages containing the waste in some sections. The square pillars separating the galleries have chipped to a depth of the order of 1.5 m to 2 m, especially at the corners. By means of the use of the endoscope it has been possible to see that there are layers of detachments in favour of clayey intercalations, both in the roof and in the wall of the galleries.

The height of the galleries has been reduced considerably under the joint effect of the uplifting of the floor and the flexing of the roof. The uplifting of the floor is associated with the gradual decompression of the first bank of the salt rock and it is usually accompanied by fracturing of the rock. Generally, this effect is maximum in the centre of the gallery and, in some sections of galleries, it has led to the tilting of the waste packages until touching the gables of the gallery.

An analogous movement has taken place in the roof of the galleries. In general, the descent of the roof is comparable in magnitude to the uplifting of the floor. The shortening of the pillars height is accompanied by a lateral and horizontal expansion of the pillars that accentuates the flexion of the roof layers by imposing a horizontal load on their ends. In some places of several galleries of the waste storage, it has already been established contact between the roof and packages. The movements of the roof are well visible in the empty galleries that do not contain residues, and especially in those excavated 25 m below the lower layer of potash instead of 23 m.

Because of the slight slope of the salt strata, the roof of the galleries, which is horizontal, is not located in the same salt bank rock along the entire wide or length of the galleries and so, unstable salt rock wedges are formed in the contacts between successive rock banks.

In the galleries, the two gables have approached each other with horizontal displacement rates of amplitude comparable to that of the convergence of the roof and the floor. The lateral (horizontal) convergence and vertical convergence rates have been

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measured at the ends of each of the three tracks of each block. These rates are greater at the ends of the block near the double central gallery (Cn = 2.5 cm / year and Cv = 23 cm / year) than at the ends near the non-exploited massif: it makes the load on the pillars lower. At the ends of the galleries near the non-exploited massif, the average convergence rate is about 1.7 cm per year, while the highest values are observed in blocks B15 and B25, in the vicinity of the central double gallery, where they reach 4.5 cm per year. Convergence rates of the order of 2.5 per year have been measured in the other blocks. The extreme values of the vertical convergence rates that have been measured are: 0.21% per year (0.6 cm) in a station of block B11 close to the non-exploited massif and 1.93% per year (5.4 cm)[5].

As it has been just indicated, the convergence of the waste storage is about 3 to 4 cm per year on average, but it varies greatly according to the zones, and this rate will not decrease with time, but it will remain more or less constant. The convergence is due to the movement of the saline massif towards the excavated cavity. It is also due to the detachment of banks of salt rock, which are several tens of centimetres of thickness, existing in the roof and floor of the galleries. This latter effect takes place along the very thin clay layers present in the massif. The pillars undergo a decompression and disintegration that can extend to a depth of 1.5 m to 2 m inside them, because of the constant load acting on them. This effect on the pillars is especially concentrated at their right angles, so, the square pillars will evolve into an approximately cylindrical shape in the long term.

## DIFFICULTIES OF GEOTECHNICAL ORIGIN ENCOUNTERED IN THE RETREIVAL OF MERCURY WASTES

The gallery area or stretch in which the waste packages were handled has been called the red zone and it has been considered as contaminated because of the operations carried out in it. It is separated by a curtain of transparent sheets from the green area that is considered not contaminated. A forklift truck with telescopic arms operated in the red zone. This machine was used to remove the waste packages and transport them to the curtain that separates both areas, after improving their packages. Next, the

[5] Note of the translator: it is supposed that this amount has been measured near the central road gallery.

packages were loaded and transported by a similar truck that operated in the green zone.

The galleries of the waste storage have not been able to be kept in good condition because they are occupied by the waste packages. Hence, as a line of packages were recovered, a continuous mining machine (with an horizontal drum) re-excavated the disintegrated or affected by convergence floor, gables and roof of the gallery and supported these two latter by means of bolting[6].

Frequently, when accessing the galleries to remove the residues containing mercury, it was found that the floor of the gallery had been raised and a step had even been formed in it. To eliminate it, converting it into a ramp, the same mining machine has been used, operating in the green zone.

The roof of the galleries was often cracked and with salt plates partially separated from it. The first support that could be placed in the red zone, as the packages were being removed, were hydraulic props. Its installation was done remotely so that no operator had to work under an unstable plate[7]. These props have been placed with a fairly high pressure, but trying not to break into pieces the roof plate. Once the roof was supported by the props, it was bolted with fiberglass bolts with resin. Later, already in the green zone, by means of a mining machine, the block was removed and the gallery was definitely supported by resin bolts with a 25 mm diameter steel bar.

The rate of waste removal has been strongly influenced by the mining conditions found, which have been very variable. That is the reason for being so variable.

[6] Note of the translator: In the original text it is said that the re-excavating and bolting is done "in the green zone". It seems to be an interpretation mistake, because in that case, the retrieval operations would be developed in a very risky way in reference to the falling of a rock block. Maybe it is not explained enough the limit between red and Green zones.
[7] Note of the translator: it is not explained how is this carried out. Probably, it means that the props were put without going far away the well-supported line. Obviously, good mining practise lead to a frequently revision of the roof and take remedial measures if necessary.

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**CURRENT STATE OF THE WASTE STORAGE**

The double lane central galleries that divide the waste storage in four parts are separated by a 5 m wide pillar, which is cut at the level of the waste storage galleries, and it is strongly bolted. At the cutting points, the deformations that have been measured are very large and metal strips (straps) have been placed apart from the bolts. However, the floor of these galleries are, in general, stable and consequently they are not very bolted. The length of the bolts is 1.5 m and consist of a steel bar cemented with resin.

The waste storage began to be built around 1999 and was stopped in 2002 due to the fire of block B15. Blocks B11, B12, B13, B21, B22 and B23 are about 23 m under the lower layer of potash. Blocks B14, B15 (burned) and B24 are 25 m under it. The galleries located 23 m below the potash layer have a more stable roof than those located at 25 m, since near the roof of the first there are fewer clay intercalations, which lead to the formation of blocks that can be detached.

The layers have a slope to the NO less than 10%, but in the galleries the roof does not adapt to the inclination of them, so but they cut the salt banks in a disposition which gives rise to situations of instability.

In the galleries located 23 m below the potash layer, which are the most stable, there are several clayey intercalations near the roof: one in the same roof and another about 10 cm below. These two intercalations delimit a salt bank that often undergoes small extrusions as a consequence of the vertical pressure of the ground, which in some cases results in small detachments in the salt rock between the two intercalations. However, the roof remains stable. It has been seen, using the endoscope, that above these two intercalations there is another one that is fastened with the bolts of 1.5 m in length, even in the junctions of galleries where the span (or arc hollow) is greater. In addition to the longitudinal fissures, there are also transverse fissures in the roof. In the galleries traced to -25 m there are more clayey intercalations in the ceiling, which makes them less stable.

On average, the horizontal convergence underwent by the wsate storage galleries has been about 2.1 cm per year. The vertical convergence has been similar. Some

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detachments of bolt plates have been observed because of these convergences.

The square pillars of 20 m on each side that separate the galleries of the waste storage are fissured on the sides and especially on the corners, but these fissures do not reach depth higher than 1.5 m to 2 m on the pillar. Therefore, the core of the pillar is in triaxle conditions, which allows it to resist the tensions to which it is subjected. The cracked areas of the pillars are fastened with bolts and strips (steel straps).

The beginning of several block galleries were visited and it was seen that many of the waste packages were trapped by the galleries' convergence. Since some of these points are on the edge of the waste storage and, therefore, subjected to less convergence than the central parts, it can be assumed that the waste packages are totally trapped by the salt in most of the waste storage. The galleries are mostly bolted, but the bolts do not serve to reduce the rates of convergence substantially, considering that its purpose is avoiding the detachment of salt rock blocks from the roof or gables. Due to the poor condition of the roof when the mercury-containing waste were removed, it was necessary to temporarily place props and fiberglass bolts with resin on the roof of the red zone. Then the roof was excavated about 30 cm and bolted with metal bolts of resin. In some sections of the galleries, the floor rises have reached 60 cm, which has forced to re-excavate it by means of a mining machine (with horizontal drum).

**CONCLUSIONS**

(NOTES FOR THE DRAFTING OF THE CONCLUSIONS)

- High, medium and low deformation map (also stresses).
- Reinforcement of the access galleries.
- The control of the state of the galleries must be visual or taking convergence measures.
- When rehabilitating the galleries, 2.50 m bolts and metal (steel) mesh should be used.
- Use flexible supports (mesh and bolts) in the reinforcement of deteriorated galleries.

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The support does not aim [---] avoiding[8] the visco-plastic closure of the galleries, only serves to hold blocks and avoid their falling. The bolts should be 2.5 m long in the galleries 5.5 m wide, and 1.5 m long in the 3.4 m wide galleries.

- The control of the state of the galleries must be done visually or by means of convergence and extensometer measurement. The endoscope can also be used.
- The floor uplifting of the galleries must be corrected by the mining machine.
- The waste storage cannot be divided into areas of different fracture probability since the salt rock does not fracture (except in the severe cases of floor uplifting and roof flexion)[9], but it flows with a certain rate of convergence.
- As the rate of convergence or deformation proportional to the tension, Figure 3-24 of the Itasca report can be used to define three zones of different deformation in the waste storage. In this figure the zones would be the following:
  - High. Tensions greater than 18: deformation rate of 23 to 30 mm / year.
  - Medium. Tensions between 16 and 18: deformation rates of 17 to 23 mm / year.
  - Low. Tensions between 14 and 16: deformation speeds of 10 to 17 mm / year
- The horizontal and vertical convergence rates are similar.
- In concrete places, mainly due to the uplifting of the floor, high deformations may appear in zones of low and medium deformations.

Madrid, ----------------------------

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[8] Note of the translator: the author left a blank that it has been filled with "avoiding".
[9] Note of the translator: during the visit to the waste storage several rock salt blocks fallen from the roof were seen in galleries almost collapsed.

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## ABOUT CONVERGENCE[10]

- The horizontal and vertical convergence rates are similar.
- The horizontal and vertical convergence rates values are around 1.7 cm / year next to the non-exploited massif.
- In the centre of the waste storage, the average horizontal convergence rate reaches 25 mm / year and the vertical convergence rate is about 22 to 23 mm / year. It is estimated that the galleries will be narrowed 1 m[11] between their gables[12] in 22 years, that is, in 2040[13]. It is also estimated 44 years for the narrowing 1 m[14] between the roof and the floor of the galleries, that is, in 2044[15]. These are average values, so some galleries will compress and confine the packages before those dates and others, maybe afterwards.
- 
- On the west edge of the waste storage, the average rates are: $VC_n$ = 16 mm / year and $VC_v$ = 18 mm / year. On the east edge, they are $VC_n$ = 14 mm / year and $VC_v$ = 13 mm / year. Therefore, the average rate at the edges of the waste storage is around 15 mm / year.
- The extreme values recorded have been 6 mm / year in a station of block B11-A2 next to the non-exploited massif and 54 mm / year.

[10] Note of the translator: as this part of the text is highlighted in "red colour", maybe it was considered by the author to be revisable.
[11] Note of the translator: a consideration about the amount of 0.5 m instead 1 m has been written in note number 4.
[12] Note of the translator: It refers to lateral narrowing, cause by horizontal convergence.
[13] Note of the translator: if 0.5 m of free width are considered, the period of 22 years since today will become 11 years. In this case, the estimated date would be around 2030. As this is a substantial difference, the reader could make his own interpretation.
[14] Note of the translator: it has been seen free heights between the roof of the gallery and the waste packages less than 0.5 m and 0.4 m in many cases. This fact indicates that a total convergence greater than 0.5 m has happened since 2000 (in 18 years), if the free height over the packages were 1 m when the waste packages were initially deposit.
[15] Note of the translator: the same argument that note number 13 one can be applied.

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