General Assessment of the Options and Conditions for the Backfilling Operations in Tellus’s Chandler Project

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1 Preamble

K-UTEC was assigned by Tellus to prepare a general assessment study to evaluate the possibilities of flushing or viscous slurry backfilling in their Chandler project.

The application of hydraulic backfilling is a good option to dispose suitable wastes in excavated rooms of salt mines. Suitable wastes can be liquid or solid with a grain size small enough to achieve appropriate hydraulic properties. Flushing backfill exhibits low viscosity and is transported by gravity only, while viscous slurry backfill exhibits high viscosity and needs a pump to be transported through a pipe system.

This general assessment study comprises the following main tasks:

- Review and assessment of provided documents
- Review of potential wastes, assessment of their compatibility and suggestion of waste type groups
- Estimation of the waste volume suitable for flushing backfill / viscous slurry backfill
- Conceptual layout for flushing backfill / viscous slurry backfill
- Capex and opex
- Outline of key safety or operational issues, constraints or considerations

This report is strictly based on and limited by the data provided by Tellus in 2015.

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1 In this study “hydraulic backfill” is used as a collective term for flushing backfill and viscous slurry backfill.
2 Potential wastes

2.1 Input

The following list of potential wastes for the project (Table 1) was issued to K-UTEC at the beginning of this study.

Table 1: List of potential wastes

<table>
<thead>
<tr>
<th>General Description of Waste types</th>
<th>NEPM Code</th>
<th>Listed waste types (derived from NT 2008 Waste Regulations)</th>
<th>Potential tonnes pa</th>
<th>Packaging assumptions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wastes (currently) immobilised ex soils</td>
<td>D130</td>
<td>Arsenic, or Arsenic compounds</td>
<td>5,000</td>
<td>Solid form - assume bulk, bags or drums</td>
</tr>
<tr>
<td>Wastes (currently) immobilised ex soils; Other solid wastes going to haz. waste landfill; Other mining wastes</td>
<td>D150</td>
<td>Cadmium, or cadmium compounds</td>
<td>15,000</td>
<td>Solid form - assume bulk, bags or drums</td>
</tr>
<tr>
<td>Other wastes</td>
<td>N160</td>
<td>Encapsulated, chemically fixed, solidified or polymerised wastes</td>
<td>4,000</td>
<td>Solid form - assume bulk, bags or drums</td>
</tr>
<tr>
<td>SPL² waste (arisings &amp; stockpiles) from Al smelting</td>
<td>D110</td>
<td>Inorganic fluorine compounds excluding calcium fluoride</td>
<td>30,000</td>
<td>Solid form - must be packaged in covered but breathable containers. May include bulk, bags or portable tanks suitable for liquid transport</td>
</tr>
<tr>
<td>Metal smelter &amp; refinery waste; Petroleum refining wastes</td>
<td>D220</td>
<td>Lead, or lead compounds</td>
<td>21,000</td>
<td>Solid form - as spent catalysts or smelter residues. Assume packaged in bulk, bags or drums</td>
</tr>
<tr>
<td>CSG³ wastes (dirty salt &amp; brine)</td>
<td>D300</td>
<td>Non-toxic salts</td>
<td>35,000</td>
<td>Liquid and sludge (high salt brackish and brine waters) - portable tanks. Smaller quantity of solid dirty salt wastes (bulk, bags)</td>
</tr>
<tr>
<td>HCB stockpile; Other POPs</td>
<td>M160</td>
<td>Organohalogenic compounds that are not otherwise specified in this Schedule</td>
<td>1,300</td>
<td>Solid form - the most hazardous wastes in this category will arrive in sealed drums</td>
</tr>
<tr>
<td>Contaminated soils - Cat A, B, C</td>
<td>N120</td>
<td>Soils contaminated with a listed waste listed in this Schedule</td>
<td>25,000</td>
<td>Solid form - packaged in closed vehicles</td>
</tr>
</tbody>
</table>

² SPL - spent pot liner
³ CSG – coal seam gas
2.2 Assessment of the wastes

The information about the potential wastes (Table 1) that might be disposed of in the Chandler mine is rudimentary as expected from the current stage of the project. With this information it is nevertheless possible to create groups of wastes that should have certain properties in conjunction with hydraulic backfill mixtures.

a) Wastes containing organic compounds

Potential wastes in Table 1 with the NEPM Codes N160, M160, F100, J100.

Wastes containing organic compounds are considered to have a negative effect on hydraulic backfill mixtures as:

- hydrophobic particles or drops will separate in the mixture and might create problems in the backfill lines and during placing of the backfill,
- foam might generate,
- these compounds are generally combustible,
- some organic substances exhibit an unpleasant odour, which should be avoided underground.

These wastes are not included in any further considerations.

<table>
<thead>
<tr>
<th>Lab chemicals and collection programs</th>
<th>T100</th>
<th>Waste chemical substances arising from research and development or teaching activities, including those substances which area not identified and/or are new and the effects of which on human health and/or the environment are not known</th>
<th>1,500</th>
<th>Solids and liquids in individual packaging such as drums, glass and plastic jars, winchesters (glass bottles)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Organic chemicals - difficult to treat</td>
<td>F100</td>
<td>Waste from the production, formulation and use of inks, dyes, pigments, paints, lacquers and varnish</td>
<td>2,000</td>
<td>Solids and liquids in drums, glass and plastic jars/ buckets, winchesters (glass bottles)</td>
</tr>
<tr>
<td>Oil &amp; gas extraction (incl. other CSG) wastes</td>
<td>J100</td>
<td>Waste mineral oils unfit for their original intended use</td>
<td>20,000</td>
<td>Liquids in tanks and drums. (Also small amount of solids contaminated with oil such as rags (in drums and bulk, bags))</td>
</tr>
<tr>
<td>Metal smelter and refinery wastes</td>
<td>D230</td>
<td>Zinc compounds</td>
<td>35,000</td>
<td>Solid form - assume bulk, bags or drums</td>
</tr>
</tbody>
</table>
b) Wastes containing aluminium

Potential waste in Table 1 with the NEPM Code D110.

Wastes containing aluminium have a high potential to generate hydrogen gas and toxic gases in the contact with aqueous solutions. Therefore they exhibit explosion and health risks and are not included in any further considerations.

c) Wastes with a wide-range definition

Potential waste in Table 1 with the NEPM Code T100.

The chemical composition and the health risks are not identified and not known, which makes these wastes not suitable for hydraulic backfill and they are not included in any further considerations.

d) Wastes that could act as a carrier fluid

Potential waste in Table 1 with the NEPM Code D300.

This waste is described in Table 1 to be liquid, a sludge or solid, containing not defined amounts of non-toxic salts. It might be necessary to mix this waste with water or with salt to prepare a suitable liquid for the hydraulic backfill mixture.

e) Solid wastes – potential ingredients of a backfill mixture

Potential wastes in Table 1 with the NEPM Code D130, D150, D220, N120, D230.

The general description of these wastes is quite general, which means that the materials have to be investigated further to decide on their suitability for hydraulic backfill mixtures. It is possible that some of these wastes are only suitable after adequate treatment, e.g. to achieve the right grain size distribution for the use in a hydraulic backfill mixture.

Table 2 shows the potential wastes for disposal in Chandler that might be suitable for hydraulic backfill as a summary.
Table 2: List of potential wastes suitable for hydraulic backfill

<table>
<thead>
<tr>
<th>General Description of Waste types</th>
<th>NEPM Code</th>
<th>Listed waste types</th>
<th>Potential tonnes pa</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wastes (currently) immobilised ex soils</td>
<td>D130</td>
<td>Arsenic, or Arsenic compounds</td>
<td>5,000</td>
<td>might need treatment/processing</td>
</tr>
<tr>
<td>Wastes (currently) immobilised ex soils; Other solid wastes going to haz. waste landfill; Other mining wastes</td>
<td>D150</td>
<td>Cadmium, or cadmium compounds</td>
<td>15,000</td>
<td>might need treatment/processing</td>
</tr>
<tr>
<td>Metal smelter &amp; refinery waste; Petroleum refining wastes</td>
<td>D220</td>
<td>Lead, or lead compounds</td>
<td>21,000</td>
<td>grain size suitable for hydraulic backfill has to be generated/ensured</td>
</tr>
<tr>
<td>CSG wastes (dirty salt &amp; brine)</td>
<td>D300</td>
<td>Non-toxic salts</td>
<td>35,000</td>
<td>suitable as brine saturated in NaCl; bigger amounts possible</td>
</tr>
<tr>
<td>Contaminated soils - Cat A, B, C</td>
<td>N120</td>
<td>Soils contaminated with a listed waste listed in this Schedule</td>
<td>25,000</td>
<td>might need treatment/processing</td>
</tr>
<tr>
<td>Metal smelter and refinery wastes</td>
<td>D230</td>
<td>Zinc compounds</td>
<td>35,000</td>
<td>grain size suitable for hydraulic backfill has to be generated/ensured</td>
</tr>
</tbody>
</table>

2.3 So far unconsidered possible waste types

Fly ashes are for several reasons a favoured component in hydraulic backfill mixtures. Depending on their source fly ashes are more or less toxic and are to a good part deposited underground in central Europe. The hazardous components are mainly heavy metals and dioxins.

Main sources of fly ash are the flue gas treatment facilities of:

- coal fired power stations,
- waste incineration plants (waste to energy),
- industrial processes (steel, cement, glass, ceramic production, etc.).

Fly ashes exhibit small particle sizes in a range from a few µm to a few hundred µm. With the use of fly ash in hydraulic backfill recipes the rheological properties of the mixtures can be altered and adjusted.

A very important property of some fly ashes, especially for viscous slurry backfill is the cementing capability. Fly ashes can contain Al-, Ca- and Si-compounds similar to a regular cement that react with water and therefore exhibit a hardening effect. This is very well known for fly ashes originating from hard coal combustion but fly ashes from other sources can have this property as well. When a
recipe is developed for a hydraulic backfill, fly ashes should always be considered and investigated.

During the preparation of this study we were told by Tellus that an amount of about 20'000 t/a of fly ashes may be incorporated in hydraulic backfill mixtures for the Chandler project.

3 Hydraulic backfill methods

3.1 General remarks

While backfilling in mines after extraction of a mineral has to be most economic in terms of mineral recovery, in the case of the Chandler project the mined rooms can be prepared in a way that makes them most suitable for the backfilling method. In these terms it is favourable to prepare big rooms with only one access to achieve a minimum of necessary dams. The possible room size is dictated by the geomechanical circumstances, the size of the machinery used, the work safety and hydraulic conditions. There is also the option to have the backfill rooms in a lower level than the drifts, which would reduce the dam building costs further.

3.2 Flushing backfill

A liquid is mixed with fine solids to achieve a suspension with low viscosity that can be transported in pipelines to the rooms to be backfilled. The transporting force is gravity, which means the pipelines should go down vertically in more or less deep shafts to gain velocity and pressure whereas the horizontal transport distance underground is limited due to the resistance of the piping. The rooms where the backfill is to be placed must be prepared – special dams have to be built for example. Once the backfill suspension is in place it settles and part of its fluid drains. The collection and management of this fluid is a vital part of the flushing backfill concept. For the collection of the drained fluid, pools have to be provided. The position of the pools are naturally at a lower level than the backfill rooms and possibly as far away from dry waste deposits as possible. From these pools the fluid is pumped above ground to the backfill plant and is used again for a new backfill mixture. The liquid remaining in the backfill crystallises and forms a unit together with the solids of the original suspension. Because of the fluid drain and the associated settling and shrinking it is necessary to fill a room in several steps to achieve a maximum fill rate.

Convergence compresses the backfill with time and depending on the material that was used it reaches a certain strength.

An important point about the suspension is that it must have a composition that does not harm the host rock.

A scheme of the flushing backfill method can be seen in Figure 1.
Figure 1: Flushing backfill method scheme

For the application of this method some specific requirements have to be met:

- Mining and backfill sequences have to be managed. The migration of excess liquid from the backfill must not be able to migrate from backfilled rooms to areas that are to be mined.
- The flush backfilling of completely horizontal rooms needs the construction of additional dams. It is therefore advantageous to prepare slightly inclined rooms during mining.
- This backfilling method needs a specific infrastructure: a transport pipe between the backfilling plant and the room, special dams to seal the rooms for backfilling, a collection
system for the excess liquid from the room, a collection pool for this liquid and a pumping system to get this liquid back to the backfill plant.

The costs for initial investment are comparatively lower with this method if brine tanks are already existing (e.g. old potash factories), whereas the operative costs are comparatively high (preparation of necessary infrastructure like dams and collection pools).

Figure 2 shows a flushing backfill outlet, Figure 3 the appearance of settled flushing backfill. Notice the gaps in Figure 3 between the host rock and the backfill as well as the level of the settled backfill in comparison with the original filling height, which can still be seen on the host rock walls; both effects are due to the drainage of excess fluid from the backfill.
3.3 Viscous slurry backfill

A liquid is mixed with fine solids to achieve a suspension that exhibits a lower water content than with flushing backfill and therefore yields a much higher viscosity. The mixture has to be pumped through pipelines to the room to be backfilled. This room has to be prepared, e.g. by the construction of a dam. The backfill mixture usually contains material that has hydraulic binding properties, which means that a setting reaction takes place that ties a good part of the mixture’s water chemically. Depending on the type of “binder” and its concentration, the backfill will gain strength quite rapidly.

The backfill mixture must have a composition that does not harm the host rock.

A scheme of the viscous slurry backfill method can be seen in Figure 4.

Figure 4: Viscous slurry backfill method scheme
Figure 5 shows an image of a set slurry backfill.

![Image of a set slurry backfill]

**Figure 5:** Appearance of viscous slurry backfill

Basic points about this backfilling method are:

- The backfill mixture contains less liquid, which gets partly tied to the set backfill through chemical reaction. The remaining excess liquid has to be transported away from the backfilled room by the mine air.

- The backfill mixture includes a binder. This could be a waste with hydraulic properties or a commercial binding agent (e.g. cement). Due to the setting characteristics of such a backfill mixture it has a limited processing duration.

- The backfill mixing station is usually situated above ground, parts can also be placed underground. If the binder is added to the mixture underground it has the advantage of shorter transport distances with a lower risk of pipe blockage due to accelerated hardening of the mixture.

- Depending on the pumping distances and the properties of the backfill mixture additional pumping stations (booster stations) might be necessary.

The costs for initial investment are comparatively high with this method (high performance pumps and pipes are needed) whereas the operative costs are lower than with flushing backfilling as preparative measures are not as extensive.

In Figure 6 a dam for viscous slurry backfill is shown.
4 Feasible backfill compositions and amounts

4.1 General remark

At this stage of the project it is possible to make suggestions for backfill compositions that appear to be feasible based on the information that is available about the potential waste materials at the moment. At a later stage it will be necessary to develop backfill recipes with defined properties that are adjusted to the backfilling facilities though.

4.2 Brine used for the backfill

In case of the Chandler project the fluid used in any backfill mixture has to be saturated in NaCl, which is necessary to protect the host rock from dissolving. This could be achieved by the use of liquid coal seam gas (CSG) waste (NEPM Code D300 in Table 1) that needs to be saturated in NaCl. So far we have information about CSG waste containing sodium, potassium, bicarbonate, carbonate, chloride and other ions. An exact composition naturally cannot be given as it varies widely from source to source. Our assumption for this study is that the CSG waste is saturated in NaCl – if this will not be the case salt from the mine’s production has to be admixed. If there is not enough suitable CSG waste available, salty local ground water could be saturated with NaCl of the mine and be used instead. Any addition of NaCl from the mine’s production would require additional equipment, which is not taken into consideration in this study as more information about CSG wastes is necessary to be able to estimate possible equipment sizes. We assume a concentration of total dissolved solids of 33 % for the mixing liquid.
The numbers below are based on the use of 35'000 t of CSG waste in the viscous slurry backfill, which equals a total of 70'000 t of backfill including the solid wastes. For the flushing backfill a total of 70'000 t are applied as well to make the two methods comparable.

Due to the lack of knowledge about the properties of the solid wastes at this stage of the project, the ratio of fly ash and other solid wastes in the mixtures cannot be established yet.

4.3 Flushing backfill

Flushing backfill mixtures generally contain 50 – 60 mass-% water. Because of the high concentration of total dissolved solids in the mixing liquid an estimated 70 % of the backfill mixture will be this liquid, the rest of about 30 % can be solid wastes. The final ratio of liquid to solid is of course highly dependent on the particle size distribution of the solid wastes and their properties.

We do not recommend to put any sludge into the flushing backfill mixture as sludge might prevent the placed backfill from draining.

Another assumption that has to be made is the amount of liquid that drains from the backfill mixture once it has been placed: we assume that 65 % of the employed liquid will drain. This means that after drainage is completed the remaining backfill body will consist of 45 % liquid and 55 % solid, which leads to the conclusion that

- 30'000 t of liquid CSG wastes
- 1'500 t of additional liquid CSG wastes and/or local concentrated NaCl solution
- 38'500 t of fly ash or other solid wastes (treated D130, D220, D230 from Table 1)

can be disposed of annually through flush backfilling with the assumption that 30'000 t out of the 35'000 t CSG wastes in Table 1 can be made suitable as a liquid for this backfilling method.

In the start-up phase of the backfill operation an initial amount of 90'000 t of liquid will have to be introduced, 58'500 t of which will be recycled annually by pumping drained liquid back to the surface.

If a final backfill density of 1.6 g/cm³ and a fill grade of 80 % are assumed the amount of flushing backfill given above needs a rounded excavation volume of 55'000 m³ annually.
4.4 Viscous slurry backfill

Viscous slurry backfill mixtures generally contain 40 – 50 mass-% water and a binding reagent (cementing agent). Because of the high concentration of total dissolved solids in the mixing liquid an estimated 50 % of the backfill mixture will be this liquid, the rest of about 50 % can be solids comprising waste and binder. The final ratio of liquid to solid is of course highly dependent on the particle size distribution of the solid wastes and their properties.

Another assumption that has to be made is the amount of binder that has to be added to the backfill mixture: we assume that a ratio of 5 % of the overall mixture is sufficient to produce a stable backfill material. With such a mixture an estimated

- 35'000 t of liquid CSG wastes
- 31'500 t of fly ash or other solid wastes (treated D130, D220, D230 from Table 1)

can be disposed of annually through viscous slurry backfilling with the assumption that all of the 35'000 t CSG wastes in Table 1 are suitable for this backfilling method.

The 5 % of binder to be added account for 3'500 t/a. Potential binders are ordinary cement and fly ash from the combustion of hard coal. The use of alternative fly ashes is possible, but the materials have to be analysed prior to application.

The assumption for the final backfill density of 1,6 g/cm³ and a fill grade of 80 % are the same as for the flushing backfill, which means that a rounded excavation volume of 55'000 m³ annually is also needed for the viscous slurry backfill.
5 Operational conditions

5.1 General remarks

It is assumed that the backfill facility at Chandler mine will operate two shifts per day and 180 days a year, so roughly every second day. Of course other operational arrangements can be executed and e.g. longer continuous backfill intervals yield a lower ratio of cleaning time but on the other hand a bigger storage capacity for the wastes is needed.

The above working hours for the backfill facility offer the potential of increasing the capacity by expanding the operating times.

5.2 Flushing backfill

The following assumptions for the backfilling operations are made:

- pre-mix time 1 h
- cleaning time 1 h
- personnel preparation time 1 h
- actual backfilling time within two shifts 13 h

which leads to the following numbers:

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>backfilling time:</td>
<td>2'340 h/a</td>
</tr>
<tr>
<td>backfill amount:</td>
<td>128'500 t/a</td>
</tr>
<tr>
<td></td>
<td>88'600 m³/a</td>
</tr>
<tr>
<td></td>
<td>37.9 m³/h</td>
</tr>
<tr>
<td>of which:</td>
<td></td>
</tr>
<tr>
<td>- solids</td>
<td>38'500 t/a</td>
</tr>
<tr>
<td></td>
<td>214 t/d</td>
</tr>
<tr>
<td></td>
<td>214 m³/d</td>
</tr>
<tr>
<td>- liquids</td>
<td>90'000 t/a</td>
</tr>
<tr>
<td></td>
<td>500 t/d</td>
</tr>
<tr>
<td></td>
<td>410 m³/d</td>
</tr>
<tr>
<td>liquid to be recycled:</td>
<td>58'500 t/a</td>
</tr>
<tr>
<td></td>
<td>48'000 m³/a</td>
</tr>
</tbody>
</table>
|                           | 5.5 m³/h      | (non-stop pumping)
A backfill facility for flushing backfill typically consists of the following elements that have to be dimensioned accordingly:

- silos for the storage of fine grained wastes, dusts
- tanks for the storage of mixing liquids
- dosage and transport devices for the raw materials
- intensive mixer
- homogenising mixer
- pump between units
- agitated vessel for delayed reactions, acting as a buffer
- backfill piping
- underground collection pools for drained liquid
- drained liquid pumps
- drained liquid piping
- infrastructure: construction (concrete, steel), electrics, compressed air, exhaust air management, measurement, control and monitoring devices

5.3 Viscous slurry backfill

The following assumptions for the backfilling operations are made:

- pre-mix time 4 h
- cleaning time 1 h
- personnel preparation time 1 h
- actual backfilling time within two shifts 10 h

which leads to the following numbers:

backfilling time: 1800 h/a
backfill amount: 70'000 t/a

43'800 m³/a
24.3 m³/h

of which:
- solids 35'000 t/a
  195 t/d
  195 m³/d
- liquids 35'000 t/a
  195 t/d
  160 m³/d
A backfill facility for viscous slurry backfill typically consists of the following elements that have to be dimensioned accordingly:

- silos for the storage of fine grained wastes, dusts, cement
- tanks for the storage of mixing liquids
- dosage and transport devices for the raw materials
- intensive mixer
- homogenising mixer
- pump between units
- agitated vessel for delayed reactions, acting as a buffer
- high pressure pump (piston pump)
- piping
- infrastructure: construction (concrete, steel), electrics, compressed air, exhaust air management, measurement, control and monitoring devices
6 Backfill facility component dimensions and expenditure

6.1 General remarks

We presume that the Chandler facility will be run in the most economic way for Tellus with a state of the art time management. All numbers below are based on this assumption.

It is stipulated that the storing capacity of the backfill plant is big enough to hold the solid and liquid feed materials worth two days’ backfill production (four shifts). Any adjustment to this assumption would change the capex considerably.

6.2 Flushing backfill

6.2.1 Capex

<table>
<thead>
<tr>
<th>Component</th>
<th>Amount</th>
<th>Size</th>
<th>Expenditure [€]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Silo</td>
<td>3</td>
<td>150 m³</td>
<td></td>
</tr>
<tr>
<td>Tank</td>
<td>4</td>
<td>200 m³</td>
<td></td>
</tr>
<tr>
<td>Intensive mixer</td>
<td>1</td>
<td>1’000 l</td>
<td></td>
</tr>
<tr>
<td>Homogenising mixer</td>
<td>1</td>
<td>50 m³</td>
<td></td>
</tr>
<tr>
<td>Pump</td>
<td>1</td>
<td>50 m³/h</td>
<td></td>
</tr>
<tr>
<td>Agitated vessel</td>
<td>1</td>
<td>70 m³</td>
<td></td>
</tr>
<tr>
<td>Backfill piping</td>
<td></td>
<td>DN 80</td>
<td></td>
</tr>
<tr>
<td>Drained liquid pump</td>
<td>2</td>
<td>6 m³/h</td>
<td></td>
</tr>
<tr>
<td>Drained liquid piping</td>
<td></td>
<td>DN 32</td>
<td></td>
</tr>
<tr>
<td>Infrastructure, Planning</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Overall amount</strong></td>
<td></td>
<td></td>
<td><strong>3'800'000</strong></td>
</tr>
</tbody>
</table>

6.2.2 Opex

A two shift operation of the surface backfill facility would account for five employees:

- 2 facility operators
- 2 people maintenance/sample taking
- 1 substitute

The electrical power consumption of the backfill facility including the drained liquid pumps is estimated to be 700’000 kWh/a.
The management of the backfill sequence and the organisation of necessary preparations (building of dams, placement of pipes, etc.) is part of a mining engineer’s work.

Calculations for the underground works’ operational costs can only be made once the mining operations in Chandler are planned more thoroughly.

Due to the numerous uncertainties in this phase of planning we would like to suggest an estimated amount for the overall opex [€] per m³ of backfill (70’000 t/a). This number includes all operational costs, e.g. labour, energy, additional piping, dams, consumables, but not the development (mining) of the rooms.

### 6.3 Viscous slurry backfill

#### 6.3.1 Capex

<table>
<thead>
<tr>
<th>Component</th>
<th>Amount</th>
<th>Size</th>
<th>Expenditure [€]</th>
</tr>
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<tbody>
<tr>
<td>Silo</td>
<td>2</td>
<td>200 m³</td>
<td></td>
</tr>
<tr>
<td>Silo (for cement)</td>
<td>1</td>
<td>80 m³</td>
<td></td>
</tr>
<tr>
<td>Tank</td>
<td>2</td>
<td>180 m³</td>
<td></td>
</tr>
<tr>
<td>Intensive mixer</td>
<td>1</td>
<td>1’000 l</td>
<td></td>
</tr>
<tr>
<td>Homogenising mixer</td>
<td>1</td>
<td>40 m³</td>
<td></td>
</tr>
<tr>
<td>Pump</td>
<td>1</td>
<td>40 m³/h</td>
<td></td>
</tr>
<tr>
<td>Agitated vessel</td>
<td>2</td>
<td>80 m³</td>
<td></td>
</tr>
<tr>
<td>Piston pump</td>
<td>1</td>
<td>40 m³/h</td>
<td></td>
</tr>
<tr>
<td>Backfill piping</td>
<td></td>
<td>DN 65</td>
<td></td>
</tr>
<tr>
<td>Infrastructure, Planning</td>
<td></td>
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</tr>
<tr>
<td><strong>Overall amount</strong></td>
<td></td>
<td></td>
<td><strong>3’745’000</strong></td>
</tr>
</tbody>
</table>

#### 6.3.2 Opex

A two shift operation of the surface backfill facility would account for five employees:

- 2 facility operators
- 2 people maintenance/sample taking
- 1 substitute
The electrical power consumption of the backfill facility is estimated to be 800'000 kWh/a.

The management of the backfill sequence and the organisation of necessary preparations (building of dams, placement of pipes, etc.) is part of a mining engineer’s work.

Calculations for the underground works’ operational costs can only be made once the mining operations in Chandler are planned more thoroughly.

Due to the numerous uncertainties in this phase of planning we would like to suggest an estimated amount for the overall opex per m³ of backfill. This number includes all operational costs, e.g. labour, energy, additional piping, dams, consumables, but not the development (mining) of the rooms.

7 Key safety and operational issues, constraints and considerations

7.1 Size of the backfill plant and positioning

We estimate a maximum space requirement of 1'200 m² for the backfill plant. It should be positioned as close as possible to the shaft that holds the vertical backfill piping.

7.2 Preparation of wastes for hydraulic backfill

As detailed information about the single wastes from Table 1 is not available yet, it cannot be ruled out that some wastes need preparation before they can be used in hydraulic backfill. One obvious parameter is the maximum grain size as only finely grained materials are suitable for hydraulic backfill. As a rough guidance it can be stated that the maximum grain size has to be in the millimetre range. In the end the hydraulic characteristics depend on the grain size distribution of the backfill material and the equipment has to be chosen according to the material’s properties.

Due to the early planning stage of the project, predictions about necessary conditioning steps and possible costs can’t be made and are not included in this study.

7.3 Waste analysis

For hydraulic backfills to work, particularly developed recipes have to be applied. Deviations from the recipes can for example lead to hydraulic problems, mixtures that are setting in the pipes and unwanted gas formation. Therefore all waste batches that are to be used for hydraulic backfill must have a complete declaration and they have to be analysed according to specified tests.

With the Chandler project being in a remote location we envision that the plant’s laboratory has to carry out these tests.
7.4 Release of gases

When certain wastes are mixed with liquids, gases like H$_2$ and NH$_3$ as well as unpleasant odours can be released. This naturally also happens during the production of hydraulic backfill. Preferably most of the gases are released above ground during mixing where they can be collected and expelled through a ventilation system. This can’t always be ensured though and gas release has to be accounted for also underground. The mine air system has to be planned accordingly so that no thresholds are exceeded. The areas for hydraulic backfilling should be located close to the mine air exhaust shaft because of these hazardous gases but also due to the mine air taking up moisture from backfill materials that are still damp.

7.5 Separated disposal of different waste types

Hydraulic backfills work with the incorporation of liquids. Both flushing backfill and viscous slurry backfill include physically bound liquid that can be pressed out of the matrix after the backfill's setting. The pressure that causes this, could for example be the surrounding rock’s convergence. The liquid that is set free in such an instance should not be able to reach other wastes that had been disposed in the same mine. On one hand the free liquid could destroy receptacles like steel barrels and on the other hand the liquid might react with wastes and release hazardous gases.

During disposal operation the different waste types – dry and wet – should be spatially separated that no interaction is possible. Before the underground disposal is closed the two areas must be closed off from each other by dam constructions that ensure the long-term separation of the liquids from the dry wastes.

7.6 Safety concept and long-term safety

To be able to achieve permission for underground disposal in Germany it is necessary to assess the site-specific safety and to make a long-term safety evaluation. This verifies that the waste will be separated from the biosphere permanently and reliably. The evaluation has to show this for wastes disposed in barrels, in big bags, as bulk or as hydraulic backfill equally. As hydraulic backfills include fluids the proof that the host rock’s permeability is low enough to separate these fluids permanently from the biosphere has to be made additionally.

The safety concept is based on the geological, hydrogeological and waste data and it comprises the plans of process engineering and site-specific data (e.g. local rock stress tensors).

For the long-term safety evaluation the natural and technical barriers have to be assessed as well as the impact of any possible event (scenario). The results of all analysis have to be combined in an examination of the overall system.
With our current knowledge about Australian legislation we cannot estimate how detailed such an evaluation has to be for the Chandler project. The costs are included in the planning section, which might change once more information about this subject has been gathered.

7.7 Variables of the assumed prices

The quality and the properties of wastes vary widely. If wastes always come from the same facilities a certain range of variation can be accounted for. With the change of sources the wastes change a lot. Big changes in waste properties mean that the recipes of the hydraulic backfill have to be altered, which is time consuming and it raises the expenditure per ton of backfilled waste. The flushing backfill method is not as sensitive to waste property changes as the viscous slurry backfill method, the amount of recycled liquid might change considerably though.

A big factor in the assumptions made is the suitability of the CSG wastes for providing the fluid for the hydraulic backfill mixture. If it turns out that the CSG wastes cannot be used, water would have to be mixed with rock salt to obtain saturated solutions. The facilities and materials needed for this would bring up capex and opex considerably.

It is intended to use a binding agent in the viscous slurry backfill mixture. The binding agent can be ordinary cement with considerable costs or a suitable substitute like fly ash. Some research of the Australian market would have to be made to find the best technical and economical solution.

Only after the development of a hydraulic backfill mixture incorporating the above wastes it is possible to measure its hydraulic and rheological properties, which are necessary for the dimensioning of pipes, pumps, machinery and other aggregates. After determination of these properties the maximum horizontal flow distance for the flushing backfill and the possible necessity of booster stations for viscous slurry backfill can be calculated.

It is possible to have underground mixing facilities. They are especially advantageous for viscous slurry backfills to mix the binder into the slurry short before placing. This reduces the risk of blocked piping. The capex is high for such facilities.

8 Conclusion

With the information presented to us we conclude that hydraulic backfilling might be feasible in the Chandler project. As a next step it is necessary to gather more detailed information about the potential wastes that are suitable for hydraulic backfilling and to carry out tests to develop possible hydraulic backfill mixtures. The results could be the basis for a feasibility study.
Response to Regulator's Questions
Relating to Tellus' Chandler Project
Draft Environmental Impact Statement

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Sondershausen, February 2\textsuperscript{nd}, 2017

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Head of Backfill & Waste Management Department

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1 Preamble

Tellus Holdings Ltd. (Tellus) is an infrastructure development company planning to mine commodities and use the mined voids for, amongst others, long-term (underground) storage and permanent isolation of hazardous wastes. To achieve this Tellus is currently developing two facilities in Australia in which hazardous wastes can be safely stored namely the Sandy Ridge Facility in Western Australia and the Chandler Facility in the Northern Territory, just south of Alice Springs. This report is the deliverable for the order 2016-20425-EVT, deals with the Chandler Facility and covers answers to specific questions raised by Tellus’ governmental Regulator regarding the Chandler development project.

K-UTE C has been pivotal in the European (Germany, France, The Netherlands) underground long-term hazardous waste storage projects in operation and under development since the 1970’s. K-UTE C’s specialists have been involved in underground hazardous waste storage, especially as hydraulic backfill, in former German potassium mines, e.g. Sondershausen, Teuschenthal and Bleicherode and in former German (Stassfurt) and Dutch (Hengelo) salt solution caverns during which experience was gained in both the technical and non-technical aspects (permitting, public perception, political acceptance) of long-term underground hazardous waste storage projects.

In this report the word “underground storage” is defined following the definition used in the European Union: “underground storage” means a permanent waste storage facility in a deep geological cavity such as a salt [i.e. sodium chloride] or potassium [i.e. potassium salts such as potassium chloride] mine.\textsuperscript{1} It should be noted that the term “underground storage” of (hazardous) waste has been differentiated in German Law into two categories: disposal and stowage. In general terms, “disposal” meaning the underground storage without the aim of stabilising a mined void and “stowage” meaning the underground storage with the aim of stabilising a mined void. Disposal is governed by the so-called Deponieverordnung – DepV\textsuperscript{2} and stowage is governed by the so-called Versatzverordnung - VersatzV\textsuperscript{3}, both of which are modelled after the Appendix A of the Council decision 2003/33/EC\textsuperscript{4} which deals with the safety assessment for acceptance of waste in underground storage. In the latter document, the safety philosophy for underground storage, the risk assessment process, the waste types and the waste acceptance process are described.

The lessons learnt in four decades of underground storage of (hazardous) wastes in Europe and the United States have been incorporated into these directives and laws and, as such, can form an important source of information for the Chandler project. In Chapter 2 of this report the answers to the Regulator’s questions are presented. The used sources are listed in Chapter 4.

To assist K-UTE C to answer the Regulator’s questions Tellus has forwarded selected relevant supporting documents regarding long-term safety of the Chandler Facility which are included as
Appendices to the Draft Chandler facility EIS. The following documents were forwarded by Tellus and reviewed by K-UTEC:

1. SN0113126 v. 25-03-2016 Preliminary assessment of the salt horizon geomechanics of the Chandler salt mine by Atkins
2. QRS-1809A-PC1 (v 1.0_290916) Post-closure Risk Assessment by Quintessa
3. Underground waste emplacement layout
4. TCO_1_50_20_K-UTEC_4_09 Tellus Waste Volumes with EWC codes

In general K-UTEC feels that all reports are of excellent quality, following the methodologies used in Europe to a large extent. The structure of the individual documents and their interdependence are in line with what is prescribed in European directives and German laws. K-UTEC acknowledges that the forwarded documents represent the Chandler project in its early stages and recognises that many aspects of the site-specific risk assessment will require further detailing, e.g. further support by laboratory and in-situ testing, numerical calculations, and elaborated qualitative and quantitative argumentation. K-UTEC has provided several recommendations to guide Tellus in the future stages of the project.
2 Response to Regulator’s questions

Tellus has forwarded the questions presented in Table 1, in relation to the proposed hydraulic backfilling of rooms in the planned Chandler Facility, to K-UTEC to be answered on the basis of K-UTEC’s experience in similar projects in Europe.

Table 1 Questions from Tellus’s Regulator concerning the proposed hydraulic backfill

<table>
<thead>
<tr>
<th>Number</th>
<th>Question</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Details of the hydraulic backfilling method proposed (i.e. flushing, viscous slurry or both), wastes considered suitable and associated infrastructure (i.e. plant location, design, function and operation)</td>
</tr>
<tr>
<td>2</td>
<td>Details of environmental (and safety) advantages, possible emissions from reactions of the waste material when mixed with brine, and any risks associated with the backfill mixture not reaching the required composition and being backfilled into a disposal room (e.g. groundwater contamination)</td>
</tr>
<tr>
<td>3</td>
<td>How this method ensures a low permeability seal to prevent leakage of liquid waste material from the salt cavern</td>
</tr>
<tr>
<td>4</td>
<td>A review of lessons learnt from other jurisdictions (e.g. Europe and USA)</td>
</tr>
</tbody>
</table>

Each of these questions is answered in the following paragraphs, in line with the order and content of the questions as given in Table 1.
2.1 Question 1

“Details of the hydraulic backfilling method proposed (i.e. flushing, viscous slurry or both), wastes considered suitable and associated infrastructure (i.e. plant location, design, function and operation)”

To backfill the mined voids of the Chandler Facility, two methods have been envisaged: mechanical and hydraulic backfill, it is noted Tellus use the term packaged waste placement to describe mechanical backfill. Mechanical backfill is best suited for containerised and packaged wastes and hydraulic backfill is particularly suitable for fine grained waste materials, i.e. with an approximate particle size distribution between coarse silt and coarse sand. Advantages of hydraulic backfill over mechanical backfill, where relevant, are described in paragraph 2.2. The objective of the Chandler Facility is to use both mechanical and hydraulic backfill to store wastes in the mined voids/rooms.

In terms of production and emplacement, two types of hydraulic backfill can be distinguished, i.e. flushing backfill and viscous backfill, the main difference being the percentage of fluid contained in the backfill mixture transported underground through pipelines. At this stage in the Chandler project a definite choice for one of the two types cannot, and should not, be made as insufficient information on the exact available wastes materials is available. Even with more detailed information on the available waste materials, designating certain wastes to one or both backfill types is only possible based on laboratory testing and subsequent classification. K-UTEC has noted that Tellus have assumed the viscous backfill method in their pre-feasibility study and EIS and accepts that this is a reasonable planning assumption subject to further analysis when more information becomes available on the types of wastes to be backfilled.

As hydraulic backfill can, generally speaking, be emplaced more efficiently than mechanical backfill due the absence of vehicle transportation and a very high filling rate (utilization) of the mined rooms, it might be beneficial to the Chandler project to maximise the use of hydraulic backfill as a waste emplacement method. An opportunity presents itself to enable the production and emplacement of both flushing and viscous backfill to maximise the range of waste types emplaced hydraulically.

2.1.1 Viscous backfill (current assumption)

Characteristics for the viscous backfill is that the mixture composition contains just enough fluid as to produce a pumpable and flowable backfill suspension. The fluid should be saturated (with salt) for a geological repository in a salt host rock either by itself or through the presence of salts within the waste inventory to avoid any dissolution of the host rock. It is common for binding agents to be
added to viscous backfill in order to bind the major part of the fluid contained in the mixture. When certain waste materials have sufficient binding properties, such as fly ash from waste incineration, no additional binding agents are needed. It is conceivable that such a mixture, without additional binding agents, could be developed for the Chandler Facility due to the expected availability of fly ashes (NEPM code N150, see Table 2). The experiences in Europe with such combustion residues show good binding properties for viscous backfill recipes and thereby minimise or even eliminate the need for additional binding agents from primary resources, i.e. cement.

An overview of the viscous backfilling process is presented in Figure 1 ("P" denoting a pump).

![Figure 1: Process overview for viscous backfill](image-url)

Although Figure 1 shows no fluid being drained from the emplaced backfill mixture, i.e. all fluid is bound within the backfill by the wastes with fluid binding properties, in practice some excess fluid can be expected on top of the backfill. This fluid might appear due to the minor settlement of solids within the backfill mixture after emplacement in the room. The excess fluid can be managed by simply letting it "dry out", i.e. the fluid evaporates due to the constant mine ventilation air being led through the backfill storage rooms and the expected high temperatures of the Chandler facility. As only water contained in the fluid evaporates, this process does not spread any contaminants in the mine’s ventilation system nor in the above ground environment. Further details on the backfill preparation process, plant and related infrastructure is given in paragraph 2.1.3.
2.1.2 Flushing backfill

The flushing backfill contains more fluid than the viscous backfill and the fluid needs to be saturated for a geological repository in salt to avoid dissolution of the mine’s host rock. The fluid is basically only used as a transport medium for the waste and drains from the emplaced backfill to be re-used again for the production of more flushing backfill mixture. Contrary to viscous backfill, the recipe for flushing backfill is less critical as setting/hardening of the mixture is not necessarily required.

Similar to viscous backfill, the actual mixture recipe(s) will constantly change reflecting the waste supply to the Chandler Facility over its lifetime. For the emplacement of flushing backfill the particle size distribution is critical because the solid parts of the backfill mixture must settle in an appropriate timeframe so that the excess fluid can be drained. This drained fluid is collected and pumped back to the ground surface where it is used again to produce more flushing backfill mixture. A significant portion of the transport fluid is thus circulated and only the fluid volume remaining in the backfill body, i.e. which cannot be drained in a relevant timeframe, has to be added or “topped up” into the backfill mixture production process. The process overview for flushing backfill is presented in Figure 2 (“P” denoting a pump).

![Figure 2: Process overview for flushing backfill](image-url)
2.1.3 Description of process, plant and infrastructure for hydraulic backfill

The process, plant and infrastructure required for respectively viscous and flushing backfill are similar but not the same, i.e. an installation built for flushing is unlikely to be suitable for the production of a viscous backfill without some modifications and additional equipment. In the following the process steps for the production of hydraulic backfill are described starting at the delivery of suitable waste materials.

Waste delivery and storage

Dry waste materials can be delivered to the Chandler Facility in pneumatic tanker trucks, big-bags, or other modes of bulk transportation. They will be transferred to silos and/or bunkers by for instance pneumatic transport. In order to minimise the number of silos required, the waste materials are grouped (through laboratory investigations prior to delivery of wastes to the facility) and stored in silos combining certain waste types. From experiences in Germany it can be expected that between 4 and 8 different materials groups, and corresponding silos/bunkers will be necessary to allow most backfill mixtures to be produced. Apart from dry waste materials one or more fluids, such as brines, can be used in the backfill mixture.

Hydraulic backfill production

Both viscous and flushing backfill require a mixing unit, which is fed via dosing units from the silos/bunkers to blend the backfill. A mixing unit can comprise a screw mixer feeding a mixing vessel with a high intensity agitator. Apart from mixing the dry components of a backfill mixture, the mixing unit allows fluid to be added thus forming a suspension. Due to the expected gas-formation potential of the waste materials once mixed with brine, e.g. due to the reaction of aluminium containing wastes with brine, a gas extraction infrastructure should be installed over the mixing unit. To aid further gas extraction and allow other chemical reactions to occur, a second agitated vessels is fed from the mixing unit, the so-called homogenising vessel. Retention time in this vessel can be up to eight hours to sufficiently allow chemical reactions and/or de-gassing to occur which is checked by a combination of sensors and laboratory proofing of samples taken from the mixture.

Pipeline transport of hydraulic backfill

After the backfill mixture has been homogenised and/or degassed it is ready for transport to the mine. The suspension is pumped into a pipeline through the shaft in which gravity is used for transport. The depth of the Chandler Facility (> 800 m bgl) will create a hydraulic head: backfill mixture gradient (approx. 0,16 bar/m) times depth (approx. 850 m) equals 136 bar static head.
Although some dynamic pressure loss will occur in the vertical shaft pipeline, the pipeline infrastructure should be laid out with a sufficient factor of safety and the corresponding pipeline pressure rating will be over 160 bars. This pressure rating largely determines the type and quality of the pipeline system to be used. In addition to the pressure requirements, the pipeline system should be resistant against abrasion and corrosion. In Europe two-layer, steel pipeline systems are often used in which the inner layer provides resistance against abrasion and thickness against corrosion while the outer layer ensures the pressure can be held regardless of the state of the inner layer.

The hydraulic head build up in the shaft pipeline is generally used to “pump”, through its own pressure, the suspension through the mine’s (horizontal) roadways towards its final destination. Pressure reduction of the built-up hydraulic head is performed by the dynamic friction loss within the horizontal pipelines in the mine. Careful design of the horizontal pipeline infrastructure is therefore critical to tune the pipeline diameter to the friction properties of the backfill mixture. Apart from pressure reduction by dynamic friction loss in the pipeline, some form of additional pressure reduction might be necessary which can be a choke station and/or a choke valve. Once most of the hydraulic head is reduced the backfill mixture can be expelled from the pipeline into the mine room to be backfilled. Typical expel pressures should generally not surpass a few bars to minimise sonic emissions from the outflow.

**Backfill emplacement and drainage**

The process layouts for viscous compared to flushing backfill differs significantly from this point onwards as the viscous backfill simply remains completely in the mined rooms whilst the flushing backfill needs to be drained of the excess carrying fluid. The rooms designated for flushing backfill are therefore equipped with a filter at its lowest point comprising e.g. sand and gravel combined with geotextiles or porous bricks. The filter prevents waste materials entering the drainage system and allows a solid free drainage fluid to be collected within a roadway below the lowest point of the rooms to be backfilled (see Figure 2 (p. 8) for details on this layout). The drained fluid is centrally collected underground and pumped back to the ground surface to be re-used in the production of more flushing backfill. This requires a high-pressure pump to be installed underground to overcome the hydraulic head of the drainage fluid: Pressure gradient (approx. 0,12 bar/m) times depth (approx. 850 m) plus dynamic friction loss in vertical shaft pipeline equals > 120 bar required pump head. For this pressure, some type of piston pump will be best suited.
Auxiliary equipment and safety
The production of hydraulic backfill is a batch process but the transport of the backfill mixture to the mine can be a semi-continuous operation when multiple homogenisation vessels are used in the surface plant. Regardless of continuous transport of backfill mixture to the mine the need for a flushing and cleaning system of the overall plant and pipeline infrastructure exists and should be accounted for in the design. This is of particular importance for viscous backfill as binding agents and/or wastes with binding properties might cause blockage/scaling of the vessels and pipelines when flushing is not performed regularly. The flushing system can also comprise so-called “pigging” stations from which a pig (a foam ball or rubber plug) is send through the pipeline system from the surface plant to the mine room. Pigs can either be caught in a receiver station down in the mine or simply be expelled in the mine room to be backfilled and left there. Considering the average lifetime of a foam or rubber pig, the latter method is probably most efficient.

Other auxiliary equipment required for hydraulic backfill comprises the overall monitoring and control of the process. Pressure sensors, flow sensors, gas monitoring in the plant and in the mine rooms to be backfilled will be required to operate an efficient and safe hydraulic backfill process. Concerning gas monitoring in the mine rooms: it cannot be ruled out that some gas formation continues within the emplaced backfill. It is therefore important to allow for this in the design of the mine’s ventilation system and limit the access to rooms being backfilled as gasses can potentially be flammable (hydrogen) and/or toxic (ammonia). In Europe, this is not considered a real challenge as ample experience with ATEX zones, gas monitoring, restricted access, etc. has been gained.

Mine room layout
The general layout of the mine rooms designated to be hydraulically backfilled is shown in Figure 1 and Figure 2. Rooms should be designed, planned and constructed in a way that a gradient is included to ease the filling of the rooms and maximise the emplaced quantity of hydraulic backfill.

The rooms designed for viscous backfill are best constructed using a single entrance from the highest level to avoid the need for a dam at the lower end of the room to hold the backfill in place during emplacement. For flushing backfill the rooms are also best constructed from a single entrance however they should be connected, e.g. through one or more borehole, with a fluid collection system in a second roadway below the lowest level of the rooms. As stated earlier these room are also equipped with a filter to avoid waste materials to enter the drainage system.
2.1.4 Types of wastes suitable for hydraulic backfill

Independently of the type of backfill used, i.e. flushing or viscous backfill, only detailed laboratory work, prior to and during the operation of the Chandler Facility, can determine the suitability of any waste type for hydraulic backfill and the specific backfill mixture recipe. Over the lifetime of the facility, the backfill mixture recipe will change following changes in the supply of waste types for storage. In addition, it is very likely that multiple recipes are used in parallel to maximise the quantities of wastes being backfilled hydraulically.

Both viscous and flushing backfill have similar requirements for the waste materials regarding their particle size, but in a viscous backfill smaller particles can be processed as settlement of the mixture in the mined rooms is not envisaged. Very fine particle sizes cannot be processed in a flushing backfill because the settlement requirements set a limit, i.e. particle sizes must be large enough to allow settlement of particles within a timeframe relevant for the operation of the facility. The maximum waste particle size for both viscous and flushing backfill types is limited due to blockage risks and flow properties in mixing/reaction vessels and pipelines. Furthermore, abrasion should be taken into account during selection of waste types for hydraulic backfill as the backfill mixture transport takes place in pipelines in a turbulent hydraulic regime.

In general, most waste materials which can be collected (at their source), transported, unloaded and stored as a bulk material and fulfil the particle size distribution criteria can be emplaced using the hydraulic backfilling method. Restrictions on the type of waste materials suitable for hydraulic backfill will most likely be chemical, i.e. their reaction behaviour in combination with other waste materials and/or brine. In addition, physical phenomena might exclude a waste from being suitable, e.g. hydrophobic behaviour, which would lead to separation of particles in the mixing and transport infrastructure as well as in the room to be backfilled.

Waste materials which do not fulfil the particle size distribution criteria can be made suitable by particle size reduction. This will however necessitate an additional process step prior to intermediate storage in silos/bunkers. Since particle size reduction is an energy intensive process, a case-by-case weighing of advantages, cost and disadvantages (e.g. dust hazard) must be made for each waste type supplied to the Chandler Facility.

Based on the preliminary inventory of wastes available for long-term storage in the Chandler Facility, K-UTECH has prepared a preliminary assessment of their suitability for hydraulic backfill presented in Table 2. In this table the following colour codes are used:

- **Green**: Principally suited for hydraulic backfill without pre-treatment
- **Orange**: Possibly suited for hydraulic backfill after pre-treatment (e.g. particle size reduction)
<table>
<thead>
<tr>
<th>NEPM code</th>
<th>Waste description</th>
<th>Waste examples</th>
</tr>
</thead>
<tbody>
<tr>
<td>N205</td>
<td>Residues from industrial waste treatment/disposal operations</td>
<td>Spent activated carbon, Ion-exchange column residues, Industrial waste treatment sludges and residues, Residues from pollution control operations, Includes sewerage sludge &amp; residues (including biosolids, where contaminated with substances contained in this list above guideline levels.</td>
</tr>
<tr>
<td>N120</td>
<td>Soils contaminated with a controlled waste</td>
<td>Soils contaminated with residues of substances contained in this list, Dredging spoil similarly contaminated</td>
</tr>
<tr>
<td>N150</td>
<td>Fly ash</td>
<td>Fly ash from coal combustion, Fly ash from incineration or EIW processes</td>
</tr>
<tr>
<td>D220</td>
<td>Lead, lead compound</td>
<td>Leaded glass (CRT glass, small particles &amp; glass dust), Grit blast waste, Lead and zinc refining slags, Mine tailings, Baghouse dust</td>
</tr>
<tr>
<td>C100</td>
<td>Basic solutions or bases in solid form</td>
<td>Wastes with pH &gt; 10, Wastes from cleaning fuels with bases, Ammonium hydroxide, Calcium hydroxide, Sodium hydroxide, potassium hydroxide, Pickling bases, Red mud from alumina refining</td>
</tr>
<tr>
<td>D110</td>
<td>Inorganic fluorine compounds excluding calcium fluoride</td>
<td>Spent Pot Liner (SPL) waste from aluminium smelting, Simple fluoride salts such as sodium fluoride and potassium fluoride</td>
</tr>
<tr>
<td>D230</td>
<td>Zinc compounds</td>
<td>Zinc ash/dust, Galvaniser’s ash, Smelting slag, Spent filter cartridges (from electroplating/ galvanising)</td>
</tr>
<tr>
<td>D300</td>
<td>Non-toxic salts</td>
<td>Coal seam gas industry brine and salt wastes, Aluminium dross, Aluminium industry salt slag, Simple inorganic chlorides</td>
</tr>
<tr>
<td>B100</td>
<td>Acidic solutions or acids in solid form</td>
<td>Waste acids, Pickle liquors (acids)</td>
</tr>
</tbody>
</table>
2.2 Question 2

“Details of environmental (and safety) advantages, possible emissions from reactions of the waste material when mixed with brine, and any risks associated with the backfill mixture not reaching the required composition and being backfilled into a disposal room (e.g. groundwater contamination)”

This question comprises the following parts:

1. Advantages of hydraulic backfill as a waste transport and emplacement mode over dry/containerised waste transport and deposition;
2. Emissions from reactions of the waste material with brine;
3. Risk associated with the hydraulic backfill not reaching the required composition;
4. Considerations associated with groundwater contamination due to backfilling and possible preventive steps.

The question is therefore answered in four parts corresponding the four items listed above:

2.2.1 Transport and emplacement of waste materials

In general, two types of hydraulic backfill are applied for underground waste disposal in salt mines, i.e. flushing backfill (with a recirculation brine flow) and viscous backfill (without a recirculation brine flow). For both types of hydraulic backfill the advantages over dry/containerised wastes are very similar and are mainly connected to the ease of handling, transport and emplacement in the underground mined rooms. Following the path of the waste from the source to the final deposition in the mine the advantages of hydraulic backfill are as follows:

- Waste materials can be collected at the source as bulk material – packing and/or containerising is not necessary and even undesirable (e.g. unpacking of waste materials at the disposal site can be labour intensive, imposes the need for additional process steps and is thereby costly and introduce potential additional worker exposure during chemical waste handling).

- The transport of waste materials as a bulk material can be performed in a clean and contained manner when using the right loading, hauling and unloading equipment. For powder waste materials (ashes, salts, etc.) the loading, hauling and unloading can be done by pneumatic systems whereby interaction with humans and the environment are principally absent. Liquid waste materials can be pumped into tankers and unloaded at the disposal site into tanks, i.e. also fully contained. Coarser materials such as slags and filter cakes can be loaded and hauled in (covered) dump trucks/trains however do require, after unloading and possibly intermediate storage, a size reduction step before application in a hydraulic backfill is possible, see also paragraph 2.1.4.
The different waste materials to be used in a hydraulic backfill mixture can be temporarily stored at the disposal site in tanks, silos/bunkers or (covered) areas until they are mixed into a hydraulic backfill. The size of this temporary storage can differ between a viscous and flushing backfill operation as the viscous backfill is based on a specific and stringent recipe whilst the flushing backfill has a more flexible recipe. This means that the different waste materials can be mixed into a flushing backfill more quickly decreasing the size of intermediate storage at the disposal site. Since the recipe of the viscous backfill is usually rather stringent more intermediate storage is needed to allow for the supply of waste materials to meet the recipe(s). Most wastes can be stored fully contained in silos or tanks thereby eliminating impact on humans and the environment.

Once the waste materials are required in a hydraulic backfill mixture they can be taken from their respective silos/bunkers and/or tanks and transported to the backfill production facility by pneumatic or pipeline transport, again fully contained, thus clean, efficient and safe. In comparison, dry/containerised wastes require many handling steps with a continuous risk of damaging containers, consequent spillage and clean-up. Dry/containerised wastes also require the deployment of heavy handling equipment such as forklift trucks and alike, i.e. equipment which is widely considered to be a main source for workplace injury and accidents. Minimizing or eliminating the necessity for handling equipment/vehicles is therefore a clear advantage of hydraulic backfill over dry/containerised waste.

After production of the backfill mixture, it can be transported through pipelines to the emplacement rooms in the mine:

- For a flushing backfill the shaft pipeline itself acts as a “pump” as the gravitational force on the mixture builds pressure in the vertical shaft pipeline eliminating the need for significant pump effort to transport the mixture from the shaft to the underground rooms. Drainage fluid being re-circulated in this case needs to be pumped to the ground surface requiring energy.

- The consistency of viscous backfill is such that gravity alone most likely will not suffice for transport to the storage rooms and a pump is thus needed. On the other hand, no drainage fluid needs to be pumped to the surface making the total pump effort comparable with the flushing backfill.

- Transport of dry/containerised wastes requires heavy plant to drive down the decline or use the shaft and also drive up the decline again. The energetic efficiency of transport by heavy equipment/vehicles is generally considered to be significantly lower than pipeline transport, compare long distance transport of oil and gas.
2.2.2 Emissions from hydraulic backfill

As described in the previous paragraph, the transport of the wastes used in a hydraulic backfill mixture can be performed in a relatively contained manner and thereby is efficient and clean. Using the proper techniques and equipment, a safe, emission-free and energy efficient transport, storage and production process can be designed. However, considering emissions, the following should be noted for the storage and transport of wastes within the overall process of production, transport and emplacement of hydraulic backfill:

- Storage and transport of dry wastes requires fit for purpose design of (pneumatic) equipment such as compressors, silos and pipelines. Important themes during the design of this equipment are material choice (abrasion), moisture control (compressed air must be dry to avoid clumping) and filters (waste powders should not enter the atmosphere through inadequate solids/air separation). Furthermore, all equipment requires regular maintenance to ensure a sustained emission-free storage and transport process.

- Storage and transport of liquid wastes and/or brines requires fit for purpose design of equipment such as pumps, tanks and pipelines. Important themes for the design of this equipment are material choice (abrasion and corrosion) and pressure class (blockage can lead to high pressures in e.g. pipeline and tanks). Again, a rigorous maintenance schedule should eliminate unplanned and desired emissions.

- Handling of coarse wastes such as slags and filter cakes, if their emplacement in the Chandler Facility via hydraulic backfill is desired, requires size reduction, i.e. crushing and/or milling, as an additional process step before they can be used in hydraulic backfill. This size reduction step can be a source for emissions: in the case of wet crushing/milling (using brine) gas emissions can occur if the wastes contain aluminium and in the case of dry crushing/milling dust control will be necessary. Proper design of the crushing/milling equipment can mitigate emissions and eliminate environmental impact.

Apart from transport, hydraulic backfill is produced in a mixing plant where dry and liquid wastes are mixed (with brine) to a specific recipe and to a predetermined density. Considering emissions during the mixing phase of the process the following should be noted:

- Hydrogen can be formed during mixing of wastes containing aluminium resulting from the reaction of aluminium with water (brine). Hydrogen is not per se a toxic or harmful gas for the environment but is flammable and explosive under the right conditions. The air above the mixing tank should therefore be extracted and the corresponding electric equipment should be ATEX certified.
• During mixing of viscous hydraulic backfill where the pH cannot be kept near 7 (generally recipes for viscous backfills create a pH of around 10 to 11) ammonia gas can form as a result from the reaction of flue-gas-cleansing-salts (cleansing flue gas from in particular NOx). Ammonia is a harmful gas and the concentration of ammonia in the air expelled to the atmosphere should be controlled by either a scrubber (removing the ammonia) or by dilution with large quantities of clean air. Similar reactions can take place when wastes contain for instance phosphorus (phosphine) or arsenic (arsine).

• In order to avoid large quantities of gas being formed underground after the hydraulic backfill has been deposited in the storage rooms in the mine, the backfill mixture should be conditioned in a homogenisation tank for up to 8 hours, see paragraph 2.1.3. During this time, most of the gas forming reactions will have completed and gas formation diminishes.

• It is likely that some gas formation will continue after deposition in the underground mine rooms. The layout of the rooms and the mine ventilation system should therefore be designed to accommodate the proper extraction and dilution of any gases formed underground. Rooms in which hydraulic backfill is deposited should also be classified for some time as ATEX zones and continuous multi-gas monitoring should take place.

• Limited gas formation from the emplaced hydraulic wastes in the storage rooms is normal and is managed safely by:
  1. monitoring of gas formation during backfill preparation;
  2. adjusting retaining time in the homogenisation tank accordingly; and,
  3. ample ventilation of the waste emplacement rooms in the mine.

• The underground waste storage facilities in Germany have shown that gas formation can be managed safely on a routine basis without forming a hazard to workers, the environment, the mine’s stability or jeopardising the long-term isolation of wastes from the biosphere.
2.2.3 Risks associated with backfill composition

The composition of hydraulic backfill is crucially important for viscous backfill but far less critical for flushing backfill. This is explained in the following:

- For flushing backfill, the brine with which the wastes are mixed, is merely used as a transport medium and the actual mixture can constantly change reflecting the actual waste supply. Thus, for flushing backfill the emplacement of the waste materials in the rooms and concurrent drainage of the brine will constitute a semi-solid backfill body in the rooms being backfilled. This means that the strength of the backfill, after emplacement, does not rely on chemical (binding) reactions to occur per-se. Strength is mainly developed by the deposition and subsequent consolidation of particles in the flushing backfill within the storage rooms. Some strength may develop from chemical binding and crystallisation as well, similar to viscous backfill (see next item in this list). Therefore, real risks associated with the backfill mixture not reaching the required composition are not expected. Care must however be taken that the particle size distribution of the backfill mixture is such that sedimentation of the solids in the backfill mixture within the rooms in the mine can take place within a relevant time scale. To illustrate, when all the solid particles in a flushing backfill mixture are fine silt or clay sized, the sedimentation may take years (decades) and the drainage will thus take a very long time. As a result, large quantities of free liquid (brine) may remain in the mine post-closure which is undesirable from a long-term safety point-of-view.

- For viscous backfill the risks associated with the backfill mixture not reaching the required composition are more significant because the fluid, i.e. brine added to the dry waste materials is not merely a transport medium but also a chemical reactant enabling the backfill mixture to set (harden) similar to the setting of a cement mixture. As with the setting of a cement mixture, when the mixture does not have the correct composition, the viscous backfill may either set too quickly, resulting in e.g. clogged pipelines, or not set at all resulting in the mine openings to be filled with a liquid mass instead of a solid mass. This risk might be considerable when thinking of the possible variations of wastes’ compositions. Thorough analysis of incoming wastes is necessary to sufficiently and effectively reduce this risk.
Despite the risks described in the previous two bullet-points the risks associated with the hydraulic backfill mixture not reaching the required composition (e.g. excess fluid in viscous backfill) can be fully mitigated by the overall design of the underground part of the Chandler Facility and the detailed design and construction of the rooms in the mine. To elaborate:

- The rooms of the mine can be designed such that their stability is not dependent on the hydraulic backfill properties after deposition in the rooms. In other words, no load carrying capacity could be assigned to the backfill for at least the operational period of the facility.

- The mine layout and ventilation design can be such that it allows any gas formed in the mine to be properly diluted, extracted and expelled into the atmosphere taking into account gas concentrations and absolute gas quantities. When the latter are considered too great the residence period in the homogenisation tank should be lengthened.

- The rooms can be closed-off after being filled with the backfill mixture in such a manner that no fluids can escape from the rooms during or after the operation of the mine/disposal facility. The room seals can be designed and constructed in such a way that the convergence of the salt is neither hampered by the seal nor the seal integrity deteriorates due to the convergence. In Germany significant experience with seals in deposal mines exists. As examples the extensive research and practical implementation of drift seals in the salt mines of Sondershausen and Teutschenthal can be mentioned here.

- The (vertical) position of the mine within the strata (horizons) can be chosen such that any fluids contained in the rooms post-closure cannot enter the biosphere. Good practice is to allow for sufficient salt roof thickness to contain any fluids being pressed out of the room as a result of creep, i.e. room convergence.
2.2.4 Considerations associated with groundwater contamination due to backfilling and possible preventive steps

The contamination of groundwater, irrespectively in which stratum, should be primarily prevented by the design of the facility, i.e. the position of the mining horizon within the geology. In German legislation to date, only salt rock is considered a suitable host rock for the long-term storage of waste materials. It is stated in German Law\textsuperscript{2,3} that the saline host rock functions as the only barrier rock and the long-term safety documentation in principle has to be provided for the saline rock as a barrier rock. Additional geological barriers may provide extra safety; however, they are not mandatory. The aim of the facility should thus be to completely and permanently seal the wastes from the biosphere and all requirements on wastes, mined voids, geotechnical barriers and all other technical devices and/or operational measures are geared towards that objective.

For the use of hydraulic backfill as a transport and emplacement method for long-term storage of waste materials this means that the facility’s design should fulfil this premise regardless of the composition of the backfill itself while considering the following requirements:

- Hydraulic backfill must not impair the barrier function of the host rock by e.g. dissolution
- Gas formation or other chemical reactions should not diminish the long-term safety of the facility

When the composition of hydraulic backfill fulfils these requirements and in combination with a proper design of the facility that can pass the long-term safety evaluation for dry wastes, this evaluation will also be valid for hydraulically backfilled wastes achieving complete and permanent isolation from the biosphere, i.e. any groundwater.
2.3 Question 3

“How this method ensures a low permeability seal to prevent leakage of liquid waste material from the salt cavern”

The hydraulic transport and emplacement of waste materials itself does not in itself ensure a low permeability seal preventing leakage of liquid waste material. The complete and permanent isolation of waste materials, regardless if they are solid or liquid, must be ensured by the design and construction of the facility. The hydraulic emplacement of wastes and in particular the setting of hydraulically emplaced waste does not necessarily have a negative effects on the facility’s seals, quite contrary, it can even be beneficial to the complete and permanent isolation of waste materials from the biosphere because:

1. Through nearly complete filling of the rooms (better void utilisation than mechanical backfilling), convergence and consequent strain in the host rock mass is reduced. The potential for development of cracks or connected porosity that could form a pathway for fluids, is thereby minimised.

2. The majority of fluid contained in the hydraulic backfill is either largely drained or chemically bound.

3. The permeability of the backfill mass after emplacement in the mined rooms is usually very low thereby physically containing any fluids.

4. The backfill mass can potentially have significant geotechnical strength whereby it can resist the salt’s convergence and thus avoid pressing out of fluids containing contaminations such as heavy metals.

5. Since fluids contained in the backfill should be saturated for a geological repository in a salt host rock, they are unable to dissolve the host rock and therefore the development of hydraulic pathways through the saline host rock, by dissolution, is avoided.

In order for any wastes and/or fluids which have been hydraulically emplaced in the mined rooms to permanently stay in these rooms, the rooms must be closed off from the rest of the facility by dams (seals). The construction and material choice for these dams is instrumental in the isolation of the hydraulically emplaced wastes. Dam design and construction should therefore be well thought through and performed by specialists. After the operational period of the facility the accesses, i.e. shafts and decline, should be properly sealed to further ensure the complete and permanent isolation of wastes from the biosphere.
2.4 Question 4

“A review of lessons learnt from other jurisdictions (e.g. Europe and USA)”

Lessons learnt regarding long-term waste storage in the United States of America have been primarily gained during the development and operation of the Waste Isolation Pilot Plant (WIPP) in New Mexico. The WIPP however has been developed for the storage of mainly radioactive wastes, and whilst the lessons learnt during the development of this facility can be useful for the Tellus project, they will not surpass lessons learnt in the European underground waste storage and disposal industry.

Some general lessons taken from the operation of European underground waste storage facilities as experienced by K-UTEC’s specialists are:

- If possible try to designate a single regulator to oversee and coordinate all other regulators to ensure efficiency, avoid duplication and create a clear and transparent authority and responsibility framework. The most eligible regulator in Europe is usually the mining authority as they will have significant in-house expertise with regards to the critical aspects of underground storage such as geology, geotechnical stability and risk assessment methodologies suitable for assessing and proving long-term safety.

- Gain sufficient real-life experience within the planned facility, through the (initial) development of gateways, drifts and rooms, before actual waste emplacement takes place. Proper exploration followed by analytical calculations and numerical simulations can yield tremendous insights in the mechanisms responsible for impairing the barrier function of the salt rock. Subsequent actual physical development of the facility, combined with in-situ testing, can confirm the assumptions used in the project’s earlier development phases to further improve an already well supported safety case.

- Separate responsibilities such as the facility’s operation, its regulatory oversight and the (scientific) review of safety supporting documentation to sustain a transparent decision-making structure before, during and after operation of the facility.

- Cooperate internationally and exchange information with specialists, operators and regulators in other countries operating underground waste storage facilities such as the United Kingdom, Germany and France.

- Involve the general public in the early stages of a project in order to “educate” and enable incorporation of public feedback in the overall safety case.

The lessons learnt regarding long-term waste storage in underground storage facilities in Europe, has been largely incorporated into European Directives and respective Member State Law.
Especially the German Law contains a very detailed description of all aspects concerning the safe and efficient long-term storage of wastes\textsuperscript{2,3}. In the following paragraphs a summary is presented of the relevant themes from German experiences.

**Site specific safety assessment**

The acceptance criteria for underground storage can only be derived by referring to local conditions, i.e. by assessing the risks related to containment accounting for the overall system of wastes emplaced, engineered structures, mined voids and the host rock for the actual planned site. The risk assessment should identify the following, pertaining to the actual site of the planned facility:

- the hazard, i.e. the emplaced wastes including e.g. their potential behaviour over time, interaction with the host rock and interaction with each other;
- the impact of wastes or their derivatives when they may reach the biosphere;
- the receptors within the biosphere that may be influenced by the wastes or their derivatives;
- the pathways through which the wastes or their derivatives can reach the biosphere.

**Baseline information**

The assessment process should be initiated by collecting the baseline information required in all subsequent phases. In order to properly build the supporting baseline information database its collection should be based on the actual site, including the foreseen mine layout.

Baseline information to be gathered includes the following:

- Geological conditions: barriers, exploration data, resource estimations, host rock structure, tectonic history and strain, historic and present seismic data, subrosion, halokinesis, etc.
- Mine layout details: dimensions, depth, gateway cross-sections, ramps, slopes, (blind-) shafts, levels and sub-levels, cause, origin and composition of expected influxes, presence of hydrocarbons, safety pillars, existing drillings, etc.
- Hydrological conditions: stratigraphy, petrography, storage potential of host rock, neighbouring rocks and overburden, aquifers, aquitards, aquicludes, permeabilities, pore fluid composition, salinity, utilisation of groundwater, surface water, etc.
- Waste emplacement: waste types, emplacement methods, geotechnical behaviour of emplaced wastes, solubility behaviour, gas generation, host rock interaction, etc.
Overall safety concept

Using all the information collected during the baseline information gathering, an overall safety concept should be developed before a final risk assessment is prepared. This concept should yield a first opinion on whether complete and permanent isolation of wastes can be achieved and sustained over the long-term while considering the site-specific conditions. Furthermore, the development of an overall safety concept will show the necessity for additional and/or complementary research into baseline information.

Safety assessment components

Based on the baseline information and the overall safety concept the actual risk assessment should include the following components:

1. geological assessment (local, regional)
2. geotechnical/geomechanical assessments (testing/analytical/numerical/validation)
3. hydrological assessment (numerical/validation/monitoring for groundwater and pore fluids)
4. geochemical assessment (groundwater quality, waste – host rock interaction)
5. biosphere impact assessment (identification and evaluation of receptors)
6. assessment of risks related to or present during the operational phase
7. assessment of long-term risks
8. assessment of risks related to the surface facilities at the planned site
9. assessment of other risks (mining/waste emplacement and their strict separation)

Especially the geomechanical/geotechnical assessment forms the basis for any successful safety concept. To illustrate, the German Law on underground waste disposal/stowage states that if the mechanical stability of the host rock is sufficiently proven, by testing and modelling, under any current or future circumstances, thereby proving complete and permanent isolation of the wastes from the biosphere, further assessments of the eventual dispersing of contaminants through the overburden is not mandatory.
Geomechanical/geotechnical (stability) assessment

The requirements with regards to the facility’s stability which should ensure complete and permanent isolation of wastes from the biosphere are:

1. No deformations of the rooms and ground surface are to be expected, during and after operation of the mine, which could impair the mine’s functional capacity, i.e. the ability to
   a. extract salt and;
   b. seal the wastes from the biosphere.

2. The bearing capacity of the host rock (salt) should sufficiently prevent collapse of the mined rooms that could have a negative effect on the long-term safety of the waste storage facility.

3. The stored wastes should contribute to the mine’s stability in the long-term.

4. After closure of the mine the host rock’s ability to creep, which is a particular property of salt, has to provide full enclosure of the wastes.

During the (continuous) assessment, the following subjects should be sufficiently elaborated over the course of several phases before and during operation of the facility:

- Relevance of geological/tectonic and hydrological information to the expected mechanical situation in the underground facility.
- Dimensioning of the mine voids preferably supported by experiences from initial mine development and/or in-situ testing.
- Comprehensive analysis of expected mechanical behaviour of the rock mass (host rock, overburden) and emplaced waste materials based on laboratory experiments and numerical prognoses. The numerical models to be developed and maintained/improved during the operation of the facility should focus on the stability and convergence of the mined voids, consequent surface subsidence and the long-term effectiveness of the geological barriers, i.e. through a coupled hydro-mechanical assessment.
- Explanation of potential hazards to geomechanical stability arising from numerical prognoses and design of mitigating measures to minimise or eliminate their impact on long-term safety.
• Design of a permanent monitoring system to prove mechanical stability and assess long-term safety and integrity of the host rock. Data yielded by the system can be used for the continuous improvement of the arithmetical proof of long-term safety of the facility.

• In-situ measurements of the stress state during the facility’s development and when considered relevant in-situ measurement of permeabilities

• Development of stability and integrity enhancing measures to be applied during and after operation of the facility.

Proof of long-term safety

Using the baseline information collected, the safety concept and the several different assessments performed, in particular the geomechanical/geotechnical assessment, an overall proof of long-term safety can be established. This comprehensive and all-embracing long-term safety analysis of the complete waste/underground construction/host rock system should comprise the following individual systems and evaluate them on the basis of the multiple barrier system:

1. Assessment of natural barriers

2. Assessment of impacts on natural barriers caused by human intervention (e.g. shafts)

3. Assessment of technical barriers

4. Assessment of events that might impair the complete and permanent isolation of the wastes and cause mobilisation of contaminants (natural events and human induced events)

5. Comprehensive evaluation of the complete system accounting for all safety-relevant aspects

3 Closing remarks

As can be read from the previous chapter, the proof of long-term safety is not just a matter of gathering information and performing a safety assessment once, prior to development and operation of the facility. From the experiences in Europe and in line with the industry practice, the proof of long-term safety is carried out through calculations and modelling before operation and continues during and after actual running of the facility with the validation of the used parameters. By continuously monitoring and adjusting the overall safety concept any (operational) changes or (unexpected) events can be swiftly incorporated in an always up-to-date safety concept by introducing/installing mitigating measures and/or providing additional proof of long-term safety.
K-UTEC feels that, based on the knowledge and information made available by Tellus, the Chandler Facility presents the opportunity to design and plan a purpose-built waste storage facility able to, at least, achieve the level of long-term safety that has been proven for the European facilities. The Chandler Facility has the advantage that its design and planning can, upfront, incorporate measures aiding the aim of long-term isolation of wastes from the biosphere and as such it differs from the European situation where mostly existing mines have been re-purposed for waste storage. The Chandler Facility has thus the unique chance to take in all lessons learnt from the facilities in Europe and potentially improve on them thereby possibly surpassing the level of safety achieved in the existing long-term waste storage facilities worldwide. It is important however, to reiterate the need for a continuously improving safety case by validating assumptions through monitoring, measurements and updating of models during and after the facility’s operational lifetime.

The answers to questions raised by Tellus’ Regulator as presented in this report are based on the combined experience of K-UTEC’s specialists spanning several decades and a multitude of projects and operations. These include, but are not limited to, contributions to the long-term safety cases and ongoing scientific/technical support of backfilling activities in the potash mines of Bleicherode, Sollstedt, Sondershausen, Teutschenthal, Unterbreizbach, in the salt mine of Stetten, in the salt cavern of Staßfurt and in the dolomite mine of Wellen, all Germany;
4 Bibliography


