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Design of Mineralised Waste Disposal Facilities to meet NEMA & NEM:WA requirements

Siyanda Ferrochrome Smelter

SLR Project No.: 710.19057.00003
Report No.: 01
Revision No.: 0

October 2016

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EXECUTIVE SUMMARY

The proposed Siyanda Ferrochrome Smelter Project (SFSP) is located on Portion 3 of the farm Grootkuil 409 KQ located adjacent to the existing Union Section Mine approximately 8 km north-west of Northam in the Thabazimbi Local Municipality, Limpopo Province.

The proposed project will comprise primarily of two new 70 Megawatt DC ferrochrome furnaces, a crushing and screening plant, two mineralised waste disposal facilities (WDFs), a pollution control dam (PCD) and various other related facilities and supporting infrastructure that complete the process.

SLR Consulting (Africa) (Pty) Ltd was appointed by Siyanda Chrome Smelting Company (Pty) Ltd (SCSC) to complete a design for the mineralised WDFs for the SFSP. The design of the mineralised WDFs informs the EIA application process. The mineralised WDFs will consist of two separate storage facilities with the first facility designed to cater for the disposal of molten slag, whilst the second will cater for the baghouse dust (BHD) produced from the furnace.

The proposed WDFs will need to accommodate waste generated over a 20 year life of the smelter which amounts to approximately 7 million dry tonnes of slag and 960 000 dry tonnes of BHD.

This report presents the design of the WDFs for the SFSP and has been prepared as a specialist report in terms of Appendix 6 of the National Environmental Management Act No 107 of 1998. The report has been prepared by Mr Justin Walls Pr.Eng. and Mr David Pillay Pr.Techni.Eng. and reviewed by Mr Alistair James Pr.Eng.

We hereby declare that:

- We have no business, financial, personal or other interest in the Siyanda Chrome Smelting Company (Pty) Ltd for which we have been appointed as a specialist, other than fair remuneration of work performed in connection with this application; and
- There are no circumstances that may compromise our objectivity in performing specialist work.

The terms of reference for the proposed WDFs and associated infrastructure are summarised below:

- Design of the WDFs, PCD and associated infrastructure.
- Generation of engineering drawings for the WDFs, PCD and associated infrastructure and key environmental protection measures to be incorporated into the final design.

For the above-mentioned terms of reference, the following scope of work was undertaken:

- Footprint optimisation to identify the best possible layouts for the WDFs taking into account the limited and confined space available.

- Stage capacity analyses to generate the layout and optimise the available footprint areas in order to maximise the available storage capacity.
- Engineering design of the WDFs and PCD based on the above findings.
- Closure, rehabilitation and aftercare issues associated with the WDFs.

The key assumptions made during this phase of the study are as follows:

- This level of design will be used only to inform the EIA application process, a more comprehensive design will follow in order to support the water use license application (WULA).
- The assumed permeability of the molten slag has conservatively been based on the expectation that the slag will crack significantly and result in a glassy waste rock-type surface.
- The current conservative approach has assumed that all slurry will be placed in bags. SLR is optimistic that the number of bags required can be reduced by “constructing” embankments using the slurry filled bags and then hydraulically depositing the baghouse slurry into the middle of the facility, using the slurry filled bags as an embankment. This optimisation will be investigated further in future design phases. If implemented, this amendment will not materially change the design performance objectives of the facility.
- The exact geosynthetic grading of the bags has been assumed and will need to be confirmed through testing. Any related change will not materially change the design performance objectives of the facility.
- No flocculent is required, although that may change with further test work. Any related change will not materially change the design performance objectives of the facility.
- No geo-grids for stabilising layers within the BHD facility are required. This will need to be verified once the consolidation and shear strength characteristics of the baghouse waste have been determined. Any related change will not materially change the design performance objectives of the facility.

Design objectives

The following design objectives formed part of the SLR design process.

Environmental objectives

- The WDFs must be safe to the environment, immediate communities and other personnel within the vicinity of the facilities.
- Ensure an acceptable risk of failure.
- The WDFs must be as visually unobtrusive as possible.
- Dust emissions must be minimised and satisfy regulatory requirements.
- Leachate must be captured and contained using a barrier and collection system that is in line with the waste geochemical classification as per GN 636.

- Surface water pollution must be minimised and contained.
- Unpolluted surface water must be protected and prevented from entering the waste site.
- Disruption to watercourses must be avoided.

Operational objectives

- Both the Slag Dump and Baghouse Dust Disposal facility must be structurally safe with an acceptable risk of failure.
- Both the facilities need to cater for waste generated over a minimum 20 year life. If Siyanda identifies alternative uses for the waste material then the life of the facilities will be increased.
- The design of the WDFs will need to allow for a simple yet practical deposition process with ease of operation. The option of recovering material from the facilities after deposition for reuse has also been provided for.
- The operation of the WDFs must take into account relevant health and safety risks and regulations.

The design of the WDFs included the designing of the facilities and their associated infrastructure; the following items are excluded from this report's scope of work:

- All mechanical, electrical and instrumentation related items associated with the WDFs, slurry delivery and return water pumping and pipelines.
- Intermediate slag cooling down area to solidify the slag in order to create a protection layer.
- Design and costing of the slurry delivery pipeline, return water pipeline, and return water pump station.

Design summary

The Siyanda Ferrochrome Smelter Project comprises of two separate WDFs and a PCD. The sizing and layout of the facilities were based on the optimum and most practical usage of the project area available. Both the facilities are designed to cater for a minimum 20 year storage life.

The key design features of the WDFs and PCD are summarised in the table below:

Slag Dump	
- Slag dump area	± 21ha
- Maximum slag dump facility height	Approx. 33m
- Slag dump storage capacity	7.04 million tonnes
BHD Disposal Facility	
- BHD disposal area	± 10ha
- Maximum BHD disposal facility height	Approx. 20m
- BHD storage capacity	960 000 tonnes
Total stockpile area	± 6.5ha
PCD area	± 1.8ha

Slag dump

The slag dump will require a compacted earth starter wall in order to contain the molten slag being deposited onto the facility at the start of deposition. Deposition will commence from the inner crest of the embankment wall.

The slag dump outer perimeters wall will progressively be raised using the upstream construction method in lifts using cooled, dry slag in order to allow the molten slag to be contained at all times. These embankment wall raises will be constructed from the cooled slag.

The slag dump will be lined using a *Class C* barrier containment system in the first phase. If testing and assessment results on the actual slag samples produced by the project indicate that the level of barrier system can be reduced, further phases can be designed with the reduced barrier system provided this is authorised by the relevant authorities.

BHD disposal facility

The BHD will be slurried to transport the waste stream to the WDF and pumped at a density of approximately 30% solids and 70% water (by mass).

In order to increase the storage capacity of the available footprint, various options were considered and the option of using large geosynthetic de-watering bags was agreed upon. These de-watering bags have been used to contain dredged material, ash, organic matter and mine waste.

The BHD disposal facility will contain a bund wall around its perimeter constructed from earth. This will ensure the adequate containment of any excess filtrate de-watered from the bags.

This WDF will be built from de-watering bags in an upstream method. The first layer of bags will be placed above a stone leachate collection system. The bags will have sufficient time to de-water, sun dry and partially consolidate prior to the placement of the next layer.

The BHD disposal facility will be lined using a *Class A* barrier containment system in the first phase. If testing and assessment results on the actual slag samples produced by the project indicate that the level of barrier system can be reduced, further phases can be designed with the reduced barrier system provided this is authorised by the relevant authorities.

Pollution Control Dam

The PCD will collect all the polluted run-off from the plant area and underdrainage water from both the WDFs which will pass through a silt trap before being fed into the PCD. Siyanda indicated that it would be preferable to develop the PCD as a single compartment to facilitate the return water pumping.

A leakage detection system under the PCD liner will be provided to assess the integrity of the liner on a regular basis. The protective layer above the plastic liner will negate the need for safety ropes.

A *Class A* liner system will be used to line the basin of the PCD and to tie-in with the containment barrier requirements for storage of leachate generated from a *Type 1* waste material.

Occupational Health and Safety

Given the hazardous nature of the baghouse dust, it is critical to ensure that the construction methods do not result in workers being exposed to unsafe levels of the BHD. A variety of health and safety protection measures are required to be put in place for the slag dump and BHD facilities.

Closure and rehabilitation

Should waste remain on site in the facilities (i.e. it cannot be reused or sold) The rehabilitation of the outer slopes and top surface will be based on a water shedding type capping and cover design following the specifications in the Department of Water Affairs and Forestry Minimum Requirements for Waste Disposal by Landfill, second edition, 1998.

This capping is intended to prevent the ingress of water to the waste as a result of the presence of a low permeability GCL layer equivalent to that of a 450mm clay soil liner.

The slag wall raises and BHD disposal facility outer face will be concurrently clad.

Environmental authorisation conditions

The following conditions should be included in the environmental authorisation:

- Evidence to be provided that the temperature of the liner system beneath the slag dump will be adequately controlled through the provision of the protection layer.
- Concurrent rehabilitation should be enforced as a condition of the license, however this also needs to take into account the reuse and/or resale of the product. If potential buyers are identified during early operational stages or if there is a sudden demand, particularly for slag, this will need to be revisited.
- Monitoring of the construction, operation and closure of the facilities will be required.

DESIGN OF MINERALISED WASTE DISPOSAL FACILITIES TO MEET NEMA & NEM:WA REQUIREMENTS

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ACRONYMS AND ABBREVIATIONS

Below a list of acronyms and abbreviations used in this report.

Acronyms/ Abbreviations	**Definition**
BHD	Baghouse dust
CH	Inorganic clay
DEA	Department of Environmental Affairs
EIA	Environmental Impact Assessment
GCL	Geosynthetic clay liner
GN	Government Notice
HDPE	High density polyethylene
kg/m3	Kilograms per cubic metre
kPa	Kilo Pascal’s
MDD	Maximum dry density
MH	Inorganic silt
MPRDA	Mineral and Petroleum Resources Development Act
m3	Cubic metres
m/s	Metres per second
NEMA	National Environmental Management Act
PCD	Pollution control dam
PPE	Personal protective equipment
PSD	Particle size distribution
SANS	South African National Standards
SC	Clayey sand
SCSC	Siyanda Chrome Smelting Company (Pty) Ltd
SFSP	Siyanda Ferrochrome Smelter Project
SLR	SLR Environmental Consulting (Africa) (Pty) Ltd
tpa	Tonnes per annum
t/m^3	Tonnes per cubic metre
WDF	Waste disposal facility

DESIGN OF MINERALISED WASTE DISPOSAL FACILITIES TO MEET NEMA & NEM:WA REQUIREMENTS

1 INTRODUCTION

The proposed Siyanda Ferrochrome Smelter Project (SFSP) is located on Portion 3 of the farm Grootkuil 409 KQ located adjacent to the existing Union Section Mine approximately 8 km north-west of Northam in the Thabazimbi Local Municipality, Limpopo Province.

The proposed project will comprise primarily of two new 70 Megawatt (MW) DC ferrochrome furnaces, a crushing and screening plant, two mineralised waste disposal facilities (WDFs), a pollution control dam (PCD) and various other related facilities and supporting infrastructure that complete the process.

SLR Consulting (Africa) (Pty) Ltd was appointed by Siyanda Chrome Smelting Company (Pty) Ltd (SCSC) to complete a design for the mineralised WDFs for the SFSP. The design of the mineralised WDFs informs the EIA application process. The mineralised WDFs will consist of two separate storage facilities with the first facility designed to cater for the disposal of molten slag, whilst the second will cater for the baghouse dust (BHD) produced from the furnace.

The proposed WDFs will need to accommodate waste generated over a 20 year life of the smelter which amounts to approximately 7 million dry tonnes of slag and 960 000 dry tonnes of BHD.

This report presents the engineering design of the WDFs for the SFSP.

1.1 DETAILS OF THE SPECIALISTS

This report has been prepared as a specialist report in terms of Appendix 6 of the National Environmental Management Act No 107 of 1998. The report has been prepared by Mr Justin Walls Pr.Eng. and Mr David Pillay Pr.Techni.Eng. and reviewed by Mr Alistair James Pr.Eng.

Curricula Vitae of the specialists and reviewer are attached as Appendix A to this report.

1.2 DECLARATION OF INDEPENDENCE

We hereby declare that:

- We have no business, financial, personal or other interest in the Siyanda Chrome Smelting Company (Pty) Ltd for which we have been appointed as a specialist, other than fair remuneration of work performed in connection with this application; and

- There are no circumstances that may compromise our objectivity in performing specialist work.

Signed:

Justin Walls

David Pillay

Alistair James

2 TERMS OF REFERENCE AND SCOPE OF WORK

2.1 TERMS OF REFERENCE

The terms of reference for the proposed WDF and associated infrastructure are summarised below:

- Engineering design of the WDFs, PCD and associated infrastructure.
- Generation of engineering drawings of the WDFs, PCD and associated infrastructure and key environmental protection measures to be incorporated into the final design.

2.2 SCOPE OF WORK

For the above-mentioned terms of reference, the following scope of work was undertaken:

- Footprint optimisation to identify the best possible layouts for the WDFs taking into account the limited and confined space available.
- Stage capacity analyses to generate the layout and optimise the available footprint areas in order to maximise the available storage capacity.
- Engineering design of the WDFs and PCD based on the above findings.
- Closure, rehabilitation and aftercare issues associated with the WDFs.

3 ASSUMPTIONS AND LIMITATIONS

The key assumptions made during this phase of the study are as follows:

- This design will be used only to inform the EIA application process, a more comprehensive design will follow in order to support the water use license application (WULA).
- The assumed permeability of the molten slag has conservatively been based on the expectation that the slag will crack significantly and result in a glassy waste rock-type surface.
- The current conservative approach has assumed that all slurry will be placed in bags. We feel optimistic that we will be able to reduce the number of bags by "constructing" embankments using the slurry filled bags and then hydraulically depositing the baghouse slurry into the middle of the

facility, using the slurry filled bags as an embankment. This optimisation will be investigated further in future design phases.

- The exact geosynthetic grading of the bags has been assumed and will need to be confirmed through testing.
- No flocculent is required, although that may change with further test work.
- No geo-grids for stabilising layers within the BHD facility are required. This will need to be verified once the consolidation and shear strength characteristics of the baghouse waste have been determined.

3.1 SUPPORTING STUDIES

- The “”Surface Water Study”” done by SLR, Report No. 160926_Siyanda_SW_Study, September 2016;
- “Waste Classification Study” done by SLR, Report No. 2016-09-02_Siyanda_Waste_Assessment, September 2016;
- “Groundwater Impact Study” done by SLR, Report 2016-09-14-SCSC_GW_Report, September 2016.

3.2 DESIGN OBJECTIVES

The following design objectives formed part of the SLR design process.

3.2.1 ENVIRONMENTAL OBJECTIVES

- The WDFs must be safe to the environment, immediate communities and other personnel within the vicinity of the facility.
- Ensure an acceptable risk of failure.
- The WDFs must be as visually unobtrusive as possible.
- Dust emissions must be minimised and satisfy regulatory requirements.
- Leachate must be captured and contained using a barrier and collection system that is in line with the waste geochemical classification as per GN 636.
- Surface water pollution must be minimised and contained.
- Unpolluted surface water must be protected and prevented from entering the waste site.
- Disruption to watercourses must be avoided.

3.2.2 OPERATIONAL OBJECTIVES

- Both the Slag Dump and Baghouse Dust Disposal facility must be structurally safe with an acceptable risk of failure.
- Both the facilities need to cater for waste generated over a 20 year life.
- The design of the WDF will need to allow for a simple yet practical deposition process with ease of operation.
- The operation of the WDF must take into account relevant health and safety risks and regulations.

3.3 BATTERY LIMITS

The design of the WDFs included designing the facilities and their associated infrastructure; the following items are excluded from the scope of work:

- All mechanical, electrical and instrumentation related items associated with the WDFs, slurry delivery and return water pumping and pipelines.
- Intermediate slag cooling down area to solidify the slag in order to create a protection layer.
- Design and costing of the slurry delivery pipeline, return water pipeline, and return water pump station.

4 DESIGN CRITERIA

4.1 SLAG DUMP

4.1.1 PRODUCTION RATES

The total project process tonnages as provided by GLPS for the slag equates to approximately 7.04 million tonnes over the 20 year life of the facility. At the expected in-situ dry density of 1.7 t/m^3 this works out to a total volume of around 4.15 million m^3.

TABLE 4-1: PROPOSED SLAG PRODUCTION TONNAGES

Year	Annual Tonnage (tpa)	Cumulative Tonnage (tonnes)
1	352 000	352 000
2	352 000	704 000
3	352 000	1 056 000
4	352 000	1 408 000
5	352 000	1 760 000
6	352 000	2 112 000
7	352 000	2 464 000
8	352 000	2 816 000
9	352 000	3 168 000

Year	Annual Tonnage (tpa)	Cumulative Tonnage (tonnes)
10	352 000	3 520 000
11	352 000	3 872 000
12	352 000	4 224 000
13	352 000	4 576 000
14	352 000	4 928 000
15	352 000	5 280 000
16	352 000	5 632 000
17	352 000	5 984 000
18	352 000	6 336 000
19	352 000	6 688 000
20	352 000	7 040 000

4.1.2 SLAG CHARACTERISTICS

4.1.2.1 Particle size distribution

The slag will be deposited on the slag dump in molten form. As the slag cools and solidifies it is expected to crack and break down into smaller particle sizes. It has not been possible to ascertain the final particle size distribution (PSD) of the solidified slag but it is expected to breakdown to a poorly graded gravel material (GP) over time through cooling and trafficking. Large boulder sized particles are expected to remain within the slag.

4.1.2.2 Particle specific gravity

The particle specific gravity of the slag as received from GLPS is 2.8.

4.1.2.3 Permeability

The assumed permeability of the cooled slag has conservatively been based on the expectation that the slag will crack significantly on cooling and trafficking and result in a glassy surface with the associated bulk permeability of the slag dump estimated to be in the order of 1 x 10^{-3}m/s.

4.1.2.4 In-situ density of slag

The expected dry density of the slag as received from GLPS is 1.7 t/m³. Based on a particle SG of 2.8 and an in-situ dry density of 1.7 t/m³, the void ratio and porosity of the slag have been calculated as 0.6 and 0.38 respectively.

4.1.3 DEPOSITION METHOD

The slag will be tapped from the furnace via a slag launder into molten pot carriers at a temperature of between 1650 -1700℃. The disposal of slag will be done utilising molten pot haulers which will transport the molten slag in the pots to the slag dump area, where the pots will be emptied and returned to the furnace ready for the next slag tap.

Due to the slag being deposited in molten form, the extremely high temperatures would cause damage to the underlying containment barrier system if not adequately protected from the slag. A thermal protection layer of 2.75m (2.25m slag plus 0.5m sand) has been included to protect the *Class C* barrier system from the high temperatures of the slag. The details of the thermal protection layer can be found under Appendix G.

The slag dump will be progressively raised using the upstream construction method in order to allow the slag to be contained at all times. Deposition will commence along the inner crest of the embankment wall and will gradually progress inwards towards the basin of the facility after the complete perimeter of the embankment has been covered. The deposition method for the molten slag will need to be considered in more detail during future design phases. It has been assumed that the deposition will need to take place over a wider front to prevent the cumulative build-up of heat.

4.2 BAGHOUSE DUST DISPOSAL FACILITY

4.2.1 PRODUCTION RATES

The total project process tonnages as provided by GLPS for the baghouse dust equates to approximately 960 000 tonnes over the 20 year life of the facility. At the assumed in-situ dry density of 1.1 t/m³ this works out to a total volume of around 880 000 m³.

TABLE 4-2: PROPOSED BAGHOUSE DUST PRODUCTION TONNAGES

Year	Annual Tonnage (tpa)	Cumulative Tonnage (tonnes)
1	48 000	48 000
2	48 000	96 000
3	48 000	144 000
4	48 000	192 000
5	48 000	240 000
6	48 000	288 000
7	48 000	336 000
8	48 000	384 000
9	48 000	432 000
10	48 000	480 000
11	48 000	528 000
12	48 000	576 000
13	48 000	624 000

Year	Annual Tonnage (tpa)	Cumulative Tonnage (tonnes)
14	48 000	672 000
15	48 000	720 000
16	48 000	768 000
17	48 000	816 000
18	48 000	864 000
19	48 000	912 000
20	48 000	960 000

4.2.2 BAGHOUSE DUST CHARACTERISTICS

4.2.2.1 Particle size distribution

Baghouse dust is generated as a waste material from the smelting process. A baghouse dust sample was obtained from Mogale Alloys and although the furnace feed material for this operation was not geochemically identical to the furnace feed material to be used at Siyanda, the associated smelting process is expected to be identical and the sample obtained from Mogale Alloys is consequently believed to be geotechnically similar to the BHD expected from Siyanda smelting process. The PSD results are presented below as Table 4-3 and Figure 4-1.

TABLE 4-3: BHD PSD TABLE

Sieve Analysis	
Sieve size (mm)	**% Passing (by Mass)**
75.0 mm	100
63.0 mm	100
53.0 mm	100
37.5 mm	100
26.5 mm	100
19.0 mm	100
13.2 mm	100
4.75 mm	100
2.00 mm	100
0.425 mm	99
0.075 mm	97
Hydrometer Analysis	
0.060 mm	91
0.040 mm	81
0.020 mm	63
0.006 mm	44
0.002 mm	36

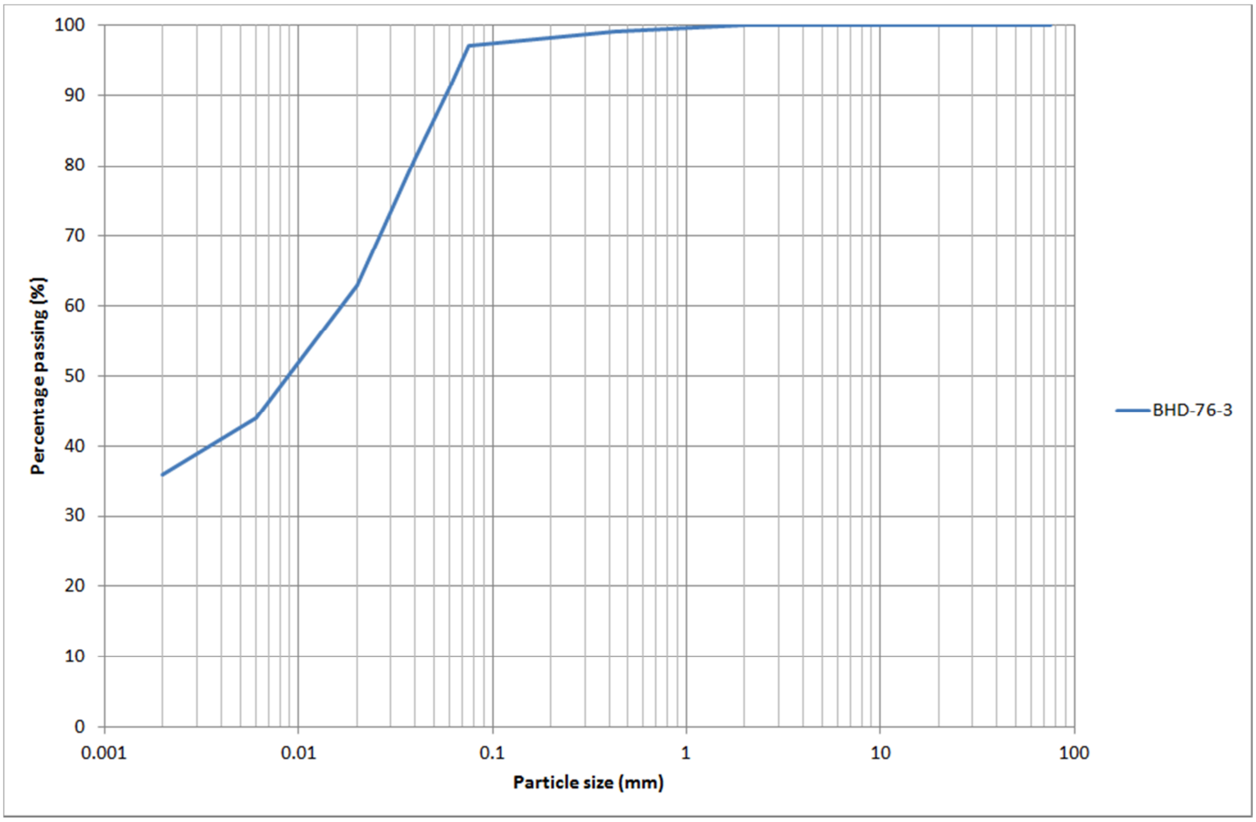


FIGURE 4-1: BHD PSD GRAPH

4.2.2.2 Particle specific gravity and Permeability

The particle specific gravity of the BHD after lab testing was found to be 3.44. The permeability of the material is ~1 x 10^{-8}m/s.

4.2.2.3 In-situ density of BHD

The in-situ dry density of the BHD was found to be in the region of 1.3 t/m³, however a conservative density of 1.1 t/m³ was used to size the facility due to the BHD being deposited in slurry form and the fact that the BHD will never fully consolidate during the operational life of the smelter due to the fine grading of the material.

4.2.2.4 Shear strength characteristics

The Civilab laboratory results determined that the internal friction angle of the BHD is 21.1º and the cohesion is 19kPa.

4.2.3 BAGHOUSE DUST SLURRY CHARACTERISTICS

The BHD will be pumped to the disposal facility in slurry form and at a slurry density of approximately 1.1 t/m³. The percentage solids by mass are estimated between 30% to 35% at a particle specific gravity of 3.44. The estimated water used in slurrying the BHD per month is estimated at 9 200m^3/month.

4.2.4 BAGHOUSE DUST DEPOSITION METHOD

Based on the grading curve of the BHD sample it can be concluded that the material is extremely fine which needed to be taken account of when choosing a suitable deposition method. Due to the nature of the material it was agreed with the client that the material should be slurried to prevent it from drying out and dusting while being transported to, and deposited on, the WDF.

5 AVAILABLE INFORMATION

5.1 PREVIOUS REPORTS

The following information was utilised for the purposes of the WDF design:

- *"Design Base for 70 Megawatt DC Furnace"*, GLPS, Report No. GL-PR003-15-02-000-14028020, April 15;
- *"Scoping report for the proposed development of the Siyanda Ferrochrome Smelter",* SLR Consulting, Report No. 2016-02- 22-Siyanda NEMA Scoping Report for DEA submission, February 2016.

Additional information and data was also received through meetings and/or correspondence and is as follows:

- Environmental information pertaining to the biodiversity priority areas, wetland areas and areas of previous disturbance was provided by the SLR environmental practitioner compiling the EIA for SCSC.
- GLPS provided SLR with the slag and BHD production tonnages, typical densities, slurry characteristics and smelter process operations.

5.2 SURVEY INFORMATION

The terrain elevation contours used in this design were obtained from a LiDAR survey carried out by Southern Mapping who were appointed by SLR. The survey was received in AutoCAD file format.

5.3 CLIMATIC DATA

5.3.1 RAINFALL

No rainfall records were available for the site and as a result rainfall data from the following sources were reviewed to characterise rainfall patterns at the site:

- The Daily Rainfall Extraction Utility programme.
- Water Resources of South Africa 2005 Study (WR2005).

Please refer to *“Surface Water Study”, SLR Consulting, Report No. 160926_Siyanda_SW_Study, September 2016,* for more information.

The rainfall data extracted using the Daily Rainfall Extraction Utility programme includes the Middlekop station (0587139 W) and the Northam station (0587477 W), which is presented in in Table 5-1 alongside monthly average rainfall data obtained from WR2005.

TABLE 5-1: MONTHLY AVERAGE RAINFALL DATA

Month	**Rainfall (mm)**		
	Middlekop (0587139 W)	**Northam (0587477 W)**	**WR2005**
January	119	117	106.4
February	96	82	92.9
March	83	81	79.6
April	48	35	40.7
May	20	8	13.8
June	8	2	6.3
July	6	1	3.6
August	4	2	4.9
September	15	16	13.7
October	48	51	46.2
November	84	81	79.6
December	106	95	104.1
Annual	**639**	**571**	**592**

5.3.2 EVAPORATION

The evaporation data used for the design was obtained from the Water Resources of South Africa manual (WR2005). The project area lies within evaporation Zone 3A. The evaporation obtained is based on Symons Pan evaporation which is then multiplied by a lake evaporation factor to obtain the adopted lake evaporation. A summary of the adopted evaporation for the project is presented in Table 5-2 below.

TABLE 5-2: MONTHLY AVERAGE EVAPORATION DATA

Months	**Symons Pan Evaporation (mm)**	**Lake Evaporation Factor**	**Lake Evaporation (mm)**
January	201.7	0.84	169.4
February	165.7	0.88	145.8
March	153.1	0.88	134.7
April	114.9	0.88	101.1
May	91.3	0.87	79.4
June	71.9	0.85	61.1
July	83.2	0.83	69.1

August	122.1	0.81	98.9
September	168.2	0.81	136.3
October	207.5	0.81	168.1
November	207.8	0.82	170.4
December	213.6	0.83	177.3
Total	**1801**		**1512**

6 COMPLIANCE REQUIREMENTS FOR THE DESIGN

The WDFs have been designed to comply with the following:

- The National Environment Management Act, including Appendix 6 of the 2014 EIA Regulations.
- National Environmental Management: Waste Act, 2008 (Act No. 59 of 2008), GN 632 of 24 July 2015, Regulations Regarding the planning and management of residue stockpiles and residue deposits from a prospecting, mining, exploration or production operation.
- In addition to the above, SLR has carried out further waste characterisation work in accordance with GN 635 of 23 August 2013 (National Environmental Management: Waste Act, 2008 (act No. 59 of 2008)). This characterisation work has been documented in report no. *2016-09-02_Siyanda_Waste_Assessment, September 2016,* prepared by SLR. The Slag was classified as a *Type 3* waste and the BHD was classified as a *Type 1* waste.
- *Type 3* wastes are now required to be disposed of in the equivalent of a *Class C*/ G:L:B+ type landfill facility. The *Class C* design is prescribed in GN 636 of 23 August 2013 and the G:L:B+ in the Second Edition of Minimum Requirements for Waste Disposal by Landfill by the then Department of Water Affairs and Forestry (1998). Similarly *Type 1* wastes are also required to be disposed of in a *Class A*/ H:H landfill facility.

TABLE 6-1: COMPLIANCE SUMMARY TABLE OF APPLICABLE REGULATIONS

Planning and management of residue stockpiles and residue deposits (R.632 of 2015)	
Residue stockpiles and residue deposits must be characterised in terms of its physical characteristics and chemical characteristics.	Section 4.1.2 Section 4.2.2 Chemical characterisation can be found in report no. 2016-09-02 Siyanda_Geochem, September 2016
Residue stockpiles must be classified, have a risk analysis conducted and documented on them, and must be undertaken on the basis of certain criteria mentioned in the regulations.	Section 7.1 Section 7.2 Section 7.3
Design must be done by a registered Professional civil or mining engineer,	Section 1.1

registered under the Engineering Professionals Act of South Africa, 1990.	Appendix A
Design must take into account the entire life cycle of the residue stockpile and residue deposit, from construction to post closure and must include various characteristics, of the residue and receiving environment, the general layout, method for depositing residue, rate of rise of the stockpile or deposit and design of a pollution control barrier system.	Contained in the report as a whole.
Various other design considerations must be included which will vary according to the particular type of the residue.	Contained in the report as a whole.
National Norms and Standards for Disposal of Waste to landfill (R.636 of 2013)	
Depending on the class of landfill (A, B, C or D), the containment barriers of landfills for the disposal of waste must comply with the engineering design requirements for that specific class of landfill. This section also includes requirements of the containment barriers themselves that must be included in the application for a waste management license, relating to the design reports and drawings, material barrier is composed of, drainage layers, alternatives considered, etc.	Section 9.5
Indication of what types of waste can be disposed of at what classes of landfills, also including additional requirements for certain types of waste.	Section 8.3 Section 9.5 Section 9.6 Section 9.7
Construction Quality Assurance (CQA) Plan	See Appendix E
Project Technical Specifications	See Appendix F

7 CLASSIFICATION OF THE WDFS AND PCD

The classification of the WDF in terms of the requirements of the SANS Code of Practice for Mine Residue Deposits (SANS 10286, previously SABS 0286:1998) is documented below.

7.1 CLASSIFICATION OF THE SLAG DUMP

7.1.1 SAFETY CLASSIFICATION OF THE SLAG DUMP

The preliminary safety classification of the proposed Slag Dump has been carried out in accordance with the requirements of SANS 10286 (1998). The safety classification system serves to provide a consistent means of differentiating between high, medium and low hazard deposits on the basis of their potential to cause harm to life or property. The classification system furthermore provides a basis for the implementation of safety management practices for specified stages of the life cycle of a Slag Dump. The code prescribes the aims, principles and minimum requirements that apply to the classification procedure and the classification in turn gives rise to minimum requirements for investigation, design, construction, operation and decommissioning. The information used in the safety classification is presented in Table 7-1 to Table 7-3.

The approximate area that may be affected by a flow slide originating from the proposed Slag Dump is shown in Figure 7-1. The area is based on the guideline values from the SANS 10286 (1998) and the topography of the area.

Based on the safety classification criteria the Slag Dump has been classified as a Medium Hazard Facility. The minimum requirements associated with the design, operation, management and closure of a Medium Hazard Facility are summarised in Table 7-3.

TABLE 7-1: GENERAL INFORMATION FOR THE SAFETY CLASSIFICATION OF THE SLAG DUMP

1	**General Information (Ref SANS 10286)**	
1.1	Name of Smelter	Siyanda Chrome Smelting Company
1.2	Postal Address of the Mine	P.O. Box 62203, Marshalltown 2107
1.3	Telephone No. of the Mine	+27 (0)11 832 2543
1.4	Magisterial District	Thabazimbi Magisterial District
1.5	DME Region	Limpopo Province
1.6	Nearest Towns	Northam
1.7	Direction and distance to town	Northam (approx. 8 km south-east of the site)
1.8	Name of person responsible for residue deposit	Not yet appointed
1.9	Common name of deposit	Siyanda Ferrochrome Slag Dump
1.10	Name of closest river / stream to the deposit	Brakspruit tributary
2	**Safety Classification (Ref SANS 10286)**	
2.1	Description of Residue	Slag
2.2	Is residue deposited hydraulically?	No
2.3	Is deposit still active?	N/A
2.4	Time since decommissioning.	N/A
2.5	Ultimate maximum height of deposit on closure (Crest elevation and lowest toe elevation)	33 m
2.6	Current maximum height of deposit	N/A
2.7	When did deposition start?	Due to start in 2018/9
2.8	What is steepest overall outer slope of the deposit?	Approx. 1V:3H
2.9	Steepest ground slope gradient on downstream perimeter of the deposit over a distance of 200m	1V:80H
2.10	Is deposit located on undermined ground?	No
2.11	What is the shallowest depth to underground excavations?	N/A
2.12	Line diagram of the deposit showing : • Outline of deposit, and ground contours; • Zone of potential influence of a failure of the deposit (ref section 3) • Property / Infrastructure / Services located within	Refer to Figure 7-1

	the zone of influence	
3	**Determination of Zone of Influence**	
Step 1	Deposition is not hydraulic, go to step 5	
Step 2	N/A	
Step 3	N/A	
Step 4	N/A	
Step 5	The zone of influence is a distance of twice the maximum design height at the point of consideration, measured from the toe around the full perimeter.	$2H = 2 \times 33$ m = 66 m

TABLE 7-2: SAFETY CLASSIFICATION CRITERIA (SANS 10286 (1998))

1	2	3	4	5
No. of Residents in Zone of Influence	**No. of Workers in Zone of Influence**[1]	**Value of 3rd party property in zone of influence**[2]	**Depth to underground mine workings**[3]	**Classification**
0	**< 10**	0 – R 2 m	> 200 m	Low Hazard
1 – 10	11 – 100	**R2 m – R 20 m**	50 m – 200 m	**Medium Hazard**
> 10	> 100	> R20 m	< 50 m	High Hazard

1. Not including workers employed solely for the purpose of operating the deposit
2. The value of third party property should be in the replacement value in 1996 terms.
3. The potential for collapse of the residue deposit into the underground workings effectively extends the zone of influence to below ground level.

Source : SABS 0286:1998, Table 2 – Safety Classification Criteria

TABLE 7-3: SAFETY CLASSIFICATION (SANS 10286)

Criteria No.	Criteria	Comment	Safety Classification
1	No. of Residents in Zone of Influence	No persons reside within the zone of influence	**LOW**
2	No. of Workers in Zone of Influence	The zone of influence covers some support facilities such as the service yard, workshops, stores, laboratory, substation and powerline. It is unlikely that there would be more than 10 workers (other than those involved in the operation of the WDFs) within the zone of influence.	**LOW**
3	Value of 3rd party property in zone of influence	The zone of influence extends minimally onto third party property to the north of the WDF*	**MEDIUM***
4	Depth to underground mine workings	N/A	**N/A**

**The value of third party property within the zone of influence results in a "medium hazard" safety classification. However, the area affected by a failure of the waste-rock-type slag dump would be much localised and far smaller than the SANS zone of influence. The safety classification should therefore be lowered to a "low hazard" rating.*

7.1.2 REQUIREMENTS ARISING FROM SAFETY CLASSIFICATION OF THE SLAG DUMP

The Slag Dump is classified as having a medium safety hazard in terms of the requirements of the SANS Code of Practice for Mine Residue Deposits (Table 7-3). A summary of the minimum requirements associated with a medium hazard safety classification is shown in Table 7.4. The design process is currently at the planning stage.

TABLE 7-4: MINIMUM REQUIREMENTS ASSOCIATED WITH A MEDIUM HAZARD SLAG DUMP

Planning Stage	Design Stage	Operation / Commissioning Stage	Decommissioning Stage
1. Conceptualisation by owner 2. Preliminary site selection by owner 3. Geotechnical investigation by owner (assisted by specialist if necessary)	1. Geotechnical report not mandatory 2. Residue characterisation on basis of past experience 3. Design by suitably qualified person. 4. Risk analysis optional 5. Construction supervision by suitably qualified person	1. Risk analysis optional 2. Suitably qualified person responsible for operation 3. Pr Eng appointed to monitor 4. Pr Eng to audit every two years	1. Pr Eng appointed to monitor 2. Pr Eng to audit every two years

7.2 CLASSIFICATION OF THE BHD DISPOSAL FACILITY

7.2.1 SAFETY CLASSIFICATION OF THE BHD DISPOSAL FACILITY

The preliminary safety classification of the proposed BHD disposal facility has been carried out in accordance with the requirements of SANS 10286 (1998). The safety classification system serves to provide a consistent means of differentiating between high, medium and low hazard deposits on the basis of their potential to cause harm to life or property. The classification system furthermore provides a basis for the implementation of safety management practices for specified stages of the life cycle of a BHD disposal facility. The code prescribes the aims, principles and minimum requirements that apply to the classification procedure and the classification in turn gives rise to minimum requirements for investigation, design, construction, operation and decommissioning. The information used in the safety classification is presented in Table 7-5 to Table 7-7.

The approximate area that may be affected by a flow slide originating from the proposed BHD disposal facility is shown in Figure 7-2. The area is based on the guideline values from the SANS 10286 (1998) and the topography of the area.

Based on the safety classification criteria the BHD disposal facility has been classified as a Medium Hazard Facility. The minimum requirements associated with the design, operation, management and closure of a Medium Hazard Facility are summarised in Table 7-8.

TABLE 7-5: GENERAL INFORMATION FOR THE SAFETY CLASSIFICATION OF THE BHD DISPOSAL FACILITY

1	**General Information (Ref SANS 10286)**	
1.1	Name of Smelter	Siyanda Chrome Smelting Company
1.2	Postal Address of the Mine	P.O. Box 62203, Marshalltown 2107
1.3	Telephone No. of the Mine	+27 (0)11 832 2543
1.4	Magisterial District	Thabazimbi Magisterial District
1.5	DME Region	Limpopo Province
1.6	Nearest Towns	Northam
1.7	Direction and distance to town	Northam (approx. 8 km south-east of the site)
1.8	Name of person responsible for residue deposit	Not yet appointed
1.9	Common name of deposit	Siyanda Ferrochrome BHD Disposal Facility
1.10	Name of closest river / stream to the deposit	Brakspruit tributary
2	**Safety Classification (Ref SANS 10286)**	
2.1	Description of Residue	Baghouse dust in slurry form
2.2	Is residue deposited hydraulically?	Yes
2.3	Is deposit still active?	N/A
2.4	Time since decommissioning.	N/A
2.5	Ultimate maximum height of deposit on closure (Crest elevation and lowest toe elevation)	20 m
2.6	Current maximum height of deposit	N/A
2.7	When did deposition start?	Due to start in 2018/9
2.8	What is steepest overall outer slope of the deposit?	Approx. 1V:3H
2.9	Steepest ground slope gradient on downstream perimeter of the deposit over a distance of 200m	1V:80H
2.10	Is deposit located on undermined ground?	No
2.11	What is the shallowest depth to underground excavations?	N/A
2.12	Line diagram of the deposit showing : • Outline of deposit, and ground contours; • Zone of potential influence of a failure of the deposit (ref section 3) • Property / Infrastructure / Services located within the zone of influence	Refer to Figure 7-2.
3	**Determination of Zone of Influence**	
Step 1	Deposition is hydraulic, go to step 2	
Step 2	N/A, go to step 3	
Step 3	N/A, got o step 4	
Step 4	the zone of influence is mainly determined by ground topography and the height of the residue deposit, as follows:	

	a) Upstream – a distance of 5*H* from the toe b) Parallel to slope – a distance of 10*H* from the toe	5*H* = 5 x 20 m = 100 m 10*H* = 10 x 20 m = 200 m
	c) Downstream – a distance of 100*H* from the toe	100*H* = 100 x 20 m = 2 000 m
Step 5	N/A	

TABLE 7-6: SAFETY CLASSIFICATION CRITERIA (SANS 10286 (1998))

1	2	3	4	5
No. of Residents in Zone of Influence	**No. of Workers in Zone of Influence[1]**	**Value of 3rd party property in zone of influence[2]**	**Depth to underground mine workings[3]**	**Classification**
0	**< 10**	0 – R 2 m	> 200 m	Low Hazard
1 – 10	11 – 100	**R2 m – R 20 m**	50 m – 200 m	**Medium Hazard**
> 10	> 100	> R20 m	< 50 m	High Hazard
1. Not including workers employed solely for the purpose of operating the deposit 2. The value of third party property should be in the replacement value in 1996 terms. 3. The potential for collapse of the residue deposit into the underground workings effectively extends the zone of influence to below ground level. *Source : SABS 0286:1998, Table 2 – Safety Classification Criteria*				

TABLE 7-7: SAFETY CLASSIFICATION (SANS 10286)

Criteria No.	Criteria	Comment	Safety Classification
1	No. of Residents in Zone of Influence	No persons reside within the zone of influence	**LOW**
2	No. of Workers in Zone of Influence	The zone of influence extends beyond the PCD. It is unlikely that there would be more than 10 workers (other than those involved in the operation of the WDFs) within the zone of influence.	**LOW**
3	Value of 3rd party Property in zone of influence	The zone of influence extends onto third party property to the north of the WDF.	**MEDIUM**
4	Depth to underground mine workings	N/A	**N/A**

7.2.2 REQUIREMENTS ARISING FROM SAFETY CLASSIFICATION OF THE BHD DISPOSAL FACILITY

The BHD disposal facility is classified as having a medium safety hazard in terms of the requirements of the SANS Code of Practice for Mine Residue Deposits (Table 7-7). A summary of the minimum requirements associated with a medium hazard safety classification is shown in Table 7-8.

TABLE 7-8: MINIMUM REQUIREMENTS ASSOCIATED WITH A MEDIUM HAZARD BHD DISPOSAL FACILITY

Planning Stage	Design Stage	Operation / Commissioning Stage	Decommissioning Stage
4. Conceptualisation by owner 5. Preliminary site	6. Geotechnical report not mandatory 7. Residue	5. Risk analysis optional 6. Suitably qualified person responsible for operation	3. Pr Eng appointed to monitor 4. Pr Eng to audit

selection by owner 6. Geotechnical investigation by owner (assisted by specialist if necessary)	characterisation on basis of past experience 8. Design by suitably qualified person. 9. Risk analysis optional 10. Construction supervision by suitably qualified person	7. Pr Eng appointed to monitor 8. Pr Eng to audit every two years	every two years

7.3 CLASSIFICATION OF THE PCD

7.3.1 SAFETY CLASSIFICATION OF THE PCD

The preliminary safety classification of the proposed PCD for the waste facilities has been carried out in accordance with the requirements of SANS 10286 (1998). The safety classification system serves to provide a consistent means of differentiating between high, medium and low hazard deposits on the basis of their potential to cause harm to life or property. The classification system furthermore provides a basis for the implementation of safety management practices for the PCD. The code prescribes the aims, principles and minimum requirements that apply to the classification procedure and the classification in turn gives rise to minimum requirements for investigation, design, construction, operation and decommissioning. The information used in the safety classification is presented in Table 7-9 to Table 7-11.

The approximate area that may be affected by a flow slide originating from the proposed PCD is shown in Figure 7-3. The area is based on the guideline values from the SANS 10286 (1998) and the topography of the area.

Based on the safety classification criteria the PCD for the waste facilities has been classified as a Low Hazard Facility. The minimum requirements associated with the design, operation, management and closure of a Low Hazard Facility are summarised in Table 7-12.

TABLE 7-9: GENERAL INFORMATION FOR THE SAFETY CLASSIFICATION OF THE PCD

1	**General Information (Ref SANS 10286)**	
1.1	Name of Smelter	Siyanda Chrome Smelting Company
1.2	Postal Address of the Mine	P.O. Box 62203, Marshalltown 2107
1.3	Telephone No. of the Mine	+27 (0)11 832 2543
1.4	Magisterial District	Thabazimbi Magisterial District
1.5	DME Region	Limpopo Province
1.6	Nearest Towns	Northam
1.7	Direction and distance to town	Northam (approx. 8 km south-east of the site)
1.8	Name of person responsible for residue deposit	Not yet appointed
1.9	Common name of deposit	Siyanda Ferrochrome PCD

1.10	Name of closest river / stream to the deposit	Brakspruit tributary
2	**Safety Classification (Ref SANS 10286)**	
2.1	Description of Residue	PCD for waste facilities
2.2	Is residue deposited hydraulically?	Yes
2.3	Is deposit still active?	N/A
2.4	Time since decommissioning.	N/A
2.5	Ultimate maximum height of deposit on closure (Crest elevation and lowest toe elevation)	4 m
2.6	Current maximum height of deposit	N/A
2.7	When did deposition start?	Due to start in 2018/9
2.8	What is steepest overall outer slope of the deposit?	Approx. 1V:2H
2.9	Steepest ground slope gradient on downstream perimeter of the deposit over a distance of 200m	1V:80H
2.10	Is deposit located on undermined ground?	No
2.11	What is the shallowest depth to underground excavations?	N/A
2.12	Line diagram of the deposit showing : • Outline of deposit, and ground contours; • Zone of potential influence of a failure of the deposit (ref section 3) • Property / Infrastructure / Services located within the zone of influence	Refer to Figure 7-3.
3	**Determination of Zone of Influence**	
Step 1	Deposition is hydraulic, go to step 2	
Step 2	N/A, go to step 3	
Step 3	N/A, got o step 4	
Step 4	the zone of influence is mainly determined by ground topography and the height of the residue deposit, as follows: d) Upstream – a distance of 5*H* from the toe e) Parallel to slope – a distance of 10*H* from the toe	5*H* = 5 x 4 m = 20 m 10*H* = 10 x 4 m = 40 m
	f) Downstream – a distance of 100*H* from the toe	100*H* = 100 x 4 m = 400 m
Step 5	N/A	

TABLE 7-10: SAFETY CLASSIFICATION CRITERIA (SANS 10286 (1998))

1	2	3	4	5
No. of Residents in Zone of Influence	**No. of Workers in Zone of Influence[1]**	**Value of 3rd party property in zone of influence[2]**	**Depth to underground mine workings[3]**	**Classification**
0	**< 10**	**0 – R 2 m**	> 200 m	**Low Hazard**
1 – 10	11 – 100	R2 m – R 20 m	50 m – 200 m	Medium Hazard
> 10	> 100	> R20 m	< 50 m	High Hazard

1. Not including workers employed solely for the purpose of operating the deposit
2. The value of third party property should be in the replacement value in 1996 terms.
3. The potential for collapse of the residue deposit into the underground workings effectively extends the zone of influence to below ground level.

Source : SABS 0286:1998, Table 2 – Safety Classification Criteria

TABLE 7-11: SAFETY CLASSIFICATION (SANS 10286)

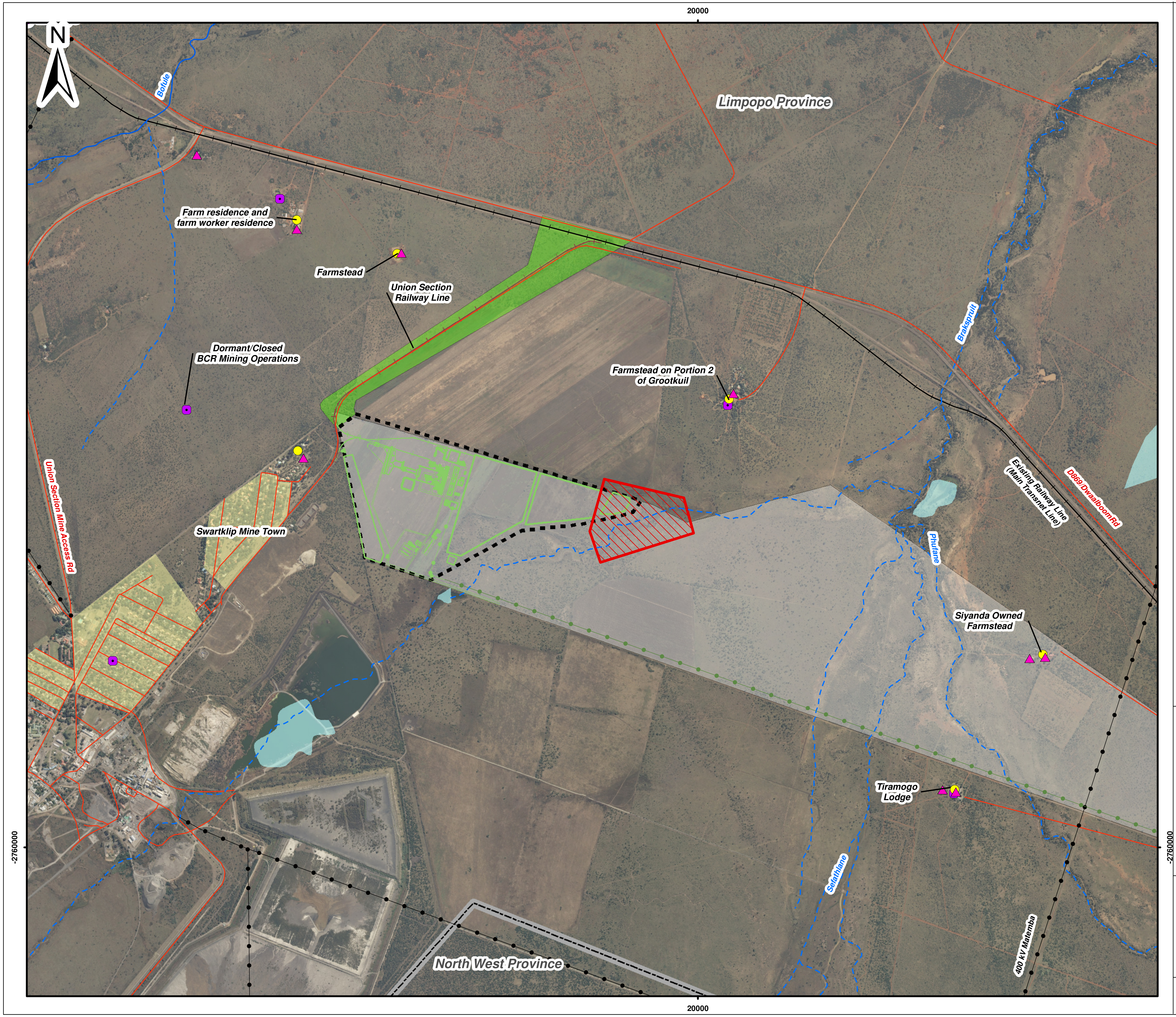
Criteria No.	Criteria	Comment	Safety Classification
1	No. of Residents in Zone of Influence	No persons reside within the zone of influence	**LOW**
2	No. of Workers in Zone of Influence	The zone of influence extends beyond the PCD. It is unlikely that there would be more than 10 workers (other than those involved in the operation of the WDFs) within the zone of influence.	**LOW**
3	Value of 3rd party Property in zone of influence	The zone of influence extends minimally onto third party property to the north of the WDF.	**LOW**
4	Depth to underground mine workings	N/A	**N/A**

7.3.2 REQUIREMENTS ARISING FROM SAFETY CLASSIFICATION OF THE PCD

The PCD is classified as having a low safety hazard in terms of the requirements of the SANS Code of Practice for Mine Residue Deposits (Table 7-11). A summary of the minimum requirements associated with a low hazard safety classification is shown in Table 7-12.

TABLE 7-12: MINIMUM REQUIREMENTS ASSOCIATED WITH A LOW HAZARD PCD

Planning Stage	Design Stage	Operation / Commissioning Stage	Decommissioning Stage
1. Conceptualisation by owner 2. Preliminary site selection by owner 3. Geotechnical investigation by owner (assisted by specialist if necessary)	1. Geotechnical report not mandatory 2. Residue characterisation on basis of past experience 3. Design by suitably qualified person. 4. Risk analysis optional 5. Construction supervision by suitably qualified person	1. Risk analysis optional 2. Suitably qualified person responsible for operation 3. Suitably qualified person to monitor 4. Suitably qualified person to audit every 3 years	N/A



Siyanda Chrome Smelting
Company (Pty) Ltd

Figure 7.3

Zone of Influence - Pollution Control Dam

SLR

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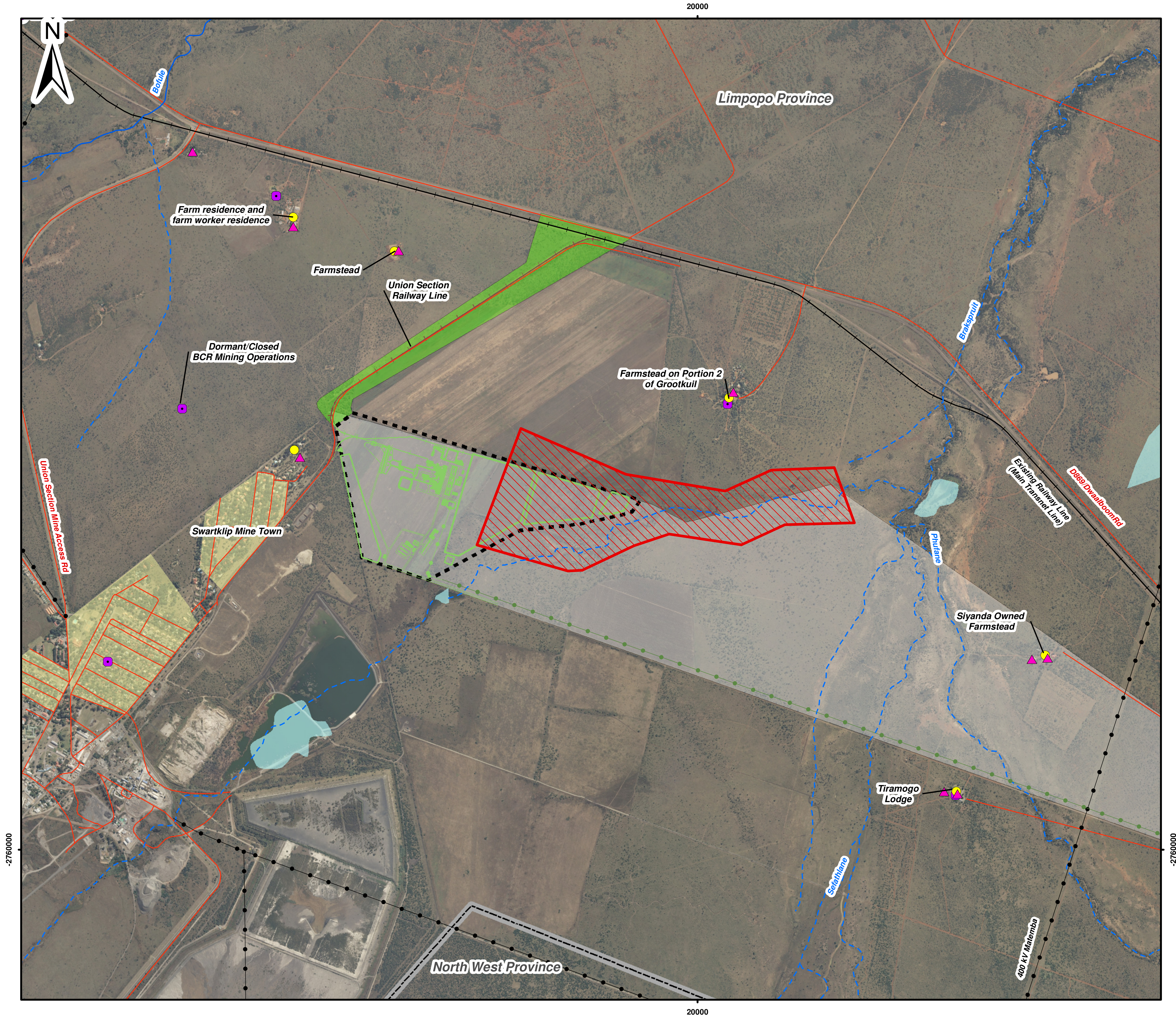
710.19057.00003

September 2016



Legend

- ▨ Zone of Influence - BHD Disposal Facility
- ⬚ Project Infrastructure Area
- 🟩 Road Access Corridor
- ⬜ Farm Portion 3 of Grootkuil 409 KQ
- ●—● Proposed Powerline Route
- — Proposed Infrastructure Layout
- ▭ Provincial Border

Land Use

- ▲ Potential Air Quality Receptors
- ○ Potential Noise Receptors
- ● Communities/Towns/Isolated Farmsteads
- ●—● Powerlines
- — River - Perennial
- - - River - Non-Perennial
- +—+ Railway
- — Roads
- 🟦 Dams
- ▢ Wetlands
- 🟨 High Urban Density

0 0.5 1 Km

Scale: 1:24 000 @ A3

Projection: Transverse Mercator
Datum: Hartebeeshoek, Lo27

Siyanda Chrome Smelting
Company (Pty) Ltd

Figure 7.2

Zone of Influence - BHD Disposal Facility

SLR

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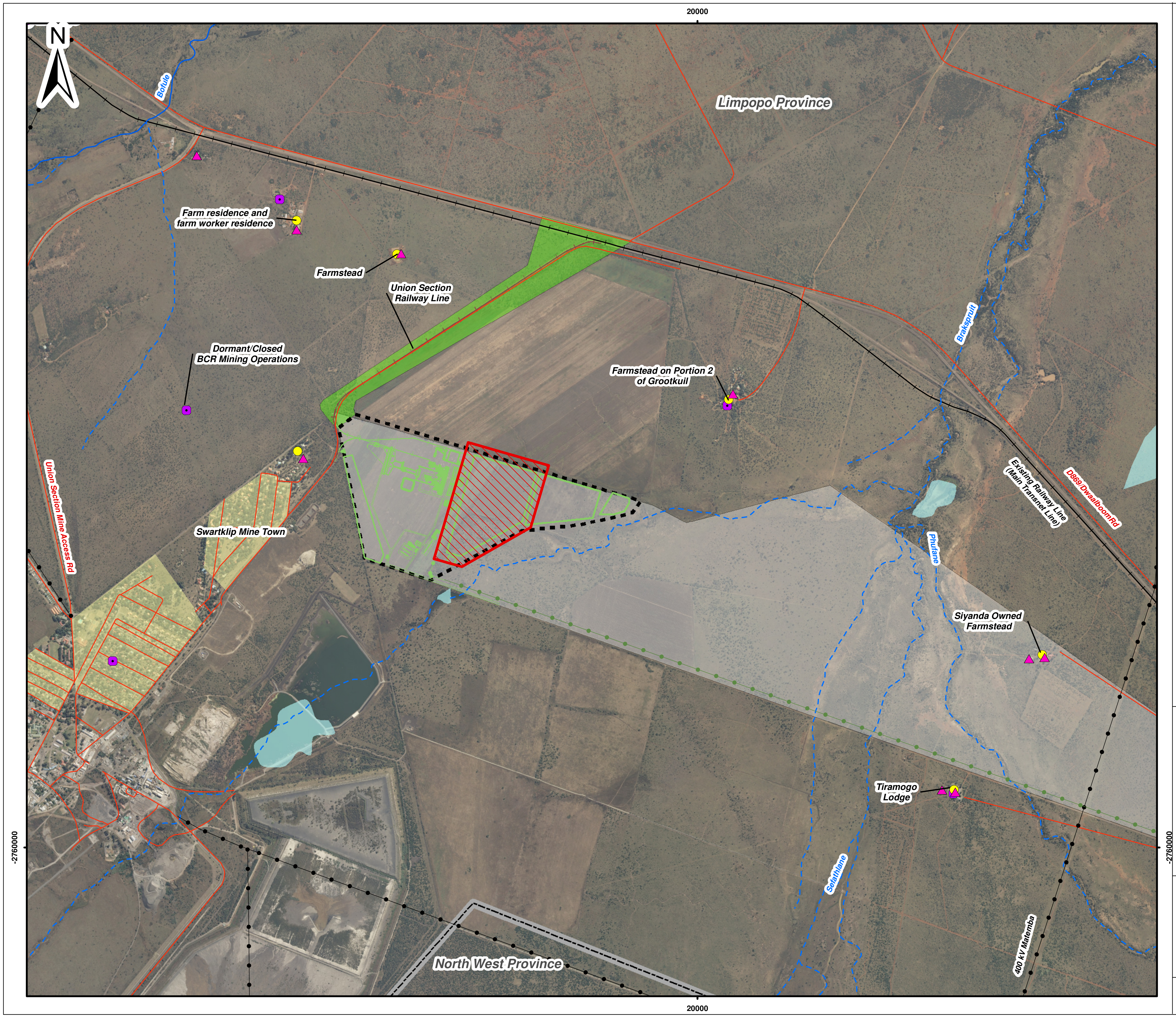

Legend

- ▨ Zone of Influence - Slag Dump
- ⬚ Project Infrastructure Area
- 🟩 Road Access Corridor
- ⬜ Farm Portion 3 of Grootkuil 409 KQ
- •—• Proposed Powerline Route
- — Proposed Infrastructure Layout
- ⬚ Provincial Border

Land Use

- ▲ Potential Air Quality Receptors
- ○ Potential Noise Receptors
- ● Communities/Towns/Isolated Farmsteads
- •—• Powerlines
- — River - Perennial
- - - River - Non-Perennial
- —+— Railway
- — Roads
- 🟦 Dams
- 🟦 Wetlands
- 🟨 High Urban Density

0 0.5 1 Km

Scale: 1:24 000 @ A3

Projection: Transverse Mercator
Datum: Hartebeeshoek, Lo27

Siyanda Chrome Smelting Company (Pty) Ltd

Figure 7.1

Zone of Influence - Slag Dump

SLR

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710.19057.00003	September 2016

8 FACTORS AFFECTING THE DESIGN OF THE WDFS

The design of the WDFs was subject to a number of constraints and limitations based on site specific conditions, geochemical and geotechnical waste classifications as well as hydraulic flood modelling. The following sections highlight these areas and how they impacted the design.

8.1 LAND AVAILABILITY

The Siyanda Ferrochrome Smelter project is proposed to be located in the western area of the farm Grootkuil 409 KQ. The configuration of the smelters and associated infrastructure is fixed given that it is determined by the directional flow of materials (process flow from west to east). In order to reduce the carbon footprint, reduce energy use, limit haulage costs and to optimise efficiency, infrastructure is placed in close proximity to the incoming primary source of chrome concentrate (i.e. Union Section Mine). This proposed site is restricted by property boundaries both to the north and to the south and by the Brakspruit tributary which extends along the south-eastern boundary of the infrastructure area.

Since the configuration of the smelters is fixed given that it is determined by the directional flow of materials (process flow from west to east), this leaves a limited amount of space between the smelters and the Brakspruit tributary for the WDFs and other related support infrastructure. Due to the limited space available, the WDFs had to either extend across the tributary and/or the neighbouring farm to the north, or be kept on one side and designed in such a way as to maximise the storage capacity of the facilities.

Taking into account the risks associated with transporting the waste across the watercourse and the fact that the land to the north is third party land and is therefore not available to Siyanda, it was agreed that the preferred option was to keep the facilities to the west of the watercourse. Hence the design of the WDFs had to be optimised to ensure that the maximum capacity can be accommodated in the limited footprint areas.

8.2 FLOOD-LINES

The Brakspruit tributary flows in a north easterly direction through Portion 3 of the farm Grootkuil 409 KQ and includes several small agricultural dams in the vicinity of the site. In order to comply with Condition 4(a) of Government Notice 704 (Government Gazette 20118 of June 1999), modelling of the flood-lines for tributary flow through the project area was required. It was found that the 1:100 year flood-line was located as shown in Figure 9-1. The 100m offset from the Brakspruit tributary is not shown on the figure as it fell within the 1:100 year flood-line. The flood-line has a significant impact on the geometry of the footprints and has therefore been taken into account in the layout of the facilities. The flood-line modelling is documented in more detail under the “Surface Water Study”, Report No. 160926_Siyanda_SW_Study, September 2016.

8.3 WASTE GEOCHEMICAL CHARACTERISATION AND CLASSIFICATION

The waste classification is documented in Report No. 2016-09-02_Siyanda_Waste_Assessment, September 2016.

The classification of the WDFs and determination of the barrier requirements was carried out in accordance with GN 36784_R 634, 635, 636_Waste Classification and Management Regulations. The option of co-disposal of the baghouse dust with the slag was considered, together with the option of two separate waste disposal facilities, one for BHD and another for the slag. The slag was classified as a *Type 3* waste and the BHD was classified as a *Type 1* waste. This meant that two different containment barrier *Classes* are required for the storage of the different waste types. In line with DWS’ strategy to eliminate waste streams in the longer term, it was recommended (in a meeting held with the DEA Waste Directorate) that waste types be disposed of onto separate waste facilities so as to maximise the opportunity for resale/ reclamation at a later stage.

The separate disposal facility option has the added advantage of being able to allow for the possible future re-working and resale of the waste materials.

8.4 WASTE CHARACTERISTICS

The slag will be deposited in molten form at a temperature of around 1650℃ and the BHD will be made up of particles sizes less than 75 microns. Considering the BHD particle sizes, it will be imperative to ensure that this particular waste product remains moist at all times to prevent it from being blown away and thereby contaminating the environment.

The need to dispose of the different waste products in separates facilities meant that the footprint area had to be split in two, to allow for practical deposition methods to take place.

8.5 FOUNDATION CONDITIONS

A geotechnical site investigation was carried out on the 15th of May, during the winter of 2015. The investigation involved the excavation of 8No. test pits using a TLB. The test pit positions are shown in Figure 8-1.

No groundwater was encountered in any of the test pits. The groundwater level is not expected to rise close enough to the surface to be detected in test pits excavated by a TLB. The season consequently had no bearing on the site investigation.

Geological maps for the area and the information supplied by Geopractica (Geopractica, 2015) indicate that the site is underlain by intrusive rocks of the Pyramid Gabbro-Norite formation, which is overlain by Ferro-Gabbro. Both formations belong to the Bushveld Igneous Complex.

The parent Noritic rock typically has variable weathering depths and is overlain by black clayey silt, often referred to as 'black turf'.

No distinct layer of topsoil was observed on site, although there was some minor evidence of roots in the upper 300mm depth of the black turf.

The summarised soil profiles derived from the geotechnical site investigation are included here as Table 8-1, with the soil profiles included in Appendix B.

TABLE 8-1: SUMMARISED SLR SOIL PROFILES

Depth	Description
0 – 1.6m	Slightly Moist, Black, Firm to Stiff, Slickenslided and Micro-Shattered, Silty CLAY, Black Turf
1.6m – 3.2m	Slightly Moist to Moist, Yellowish Grey to Orangey Brown, Medium Dense increasing to Very Dense with depth, Intact, Gravelly Silty SAND with some presence of calcrete or rock fragments, Residual.
Notes	No machine refusal. No groundwater encountered. Some roots evident (0 – 1.6m).

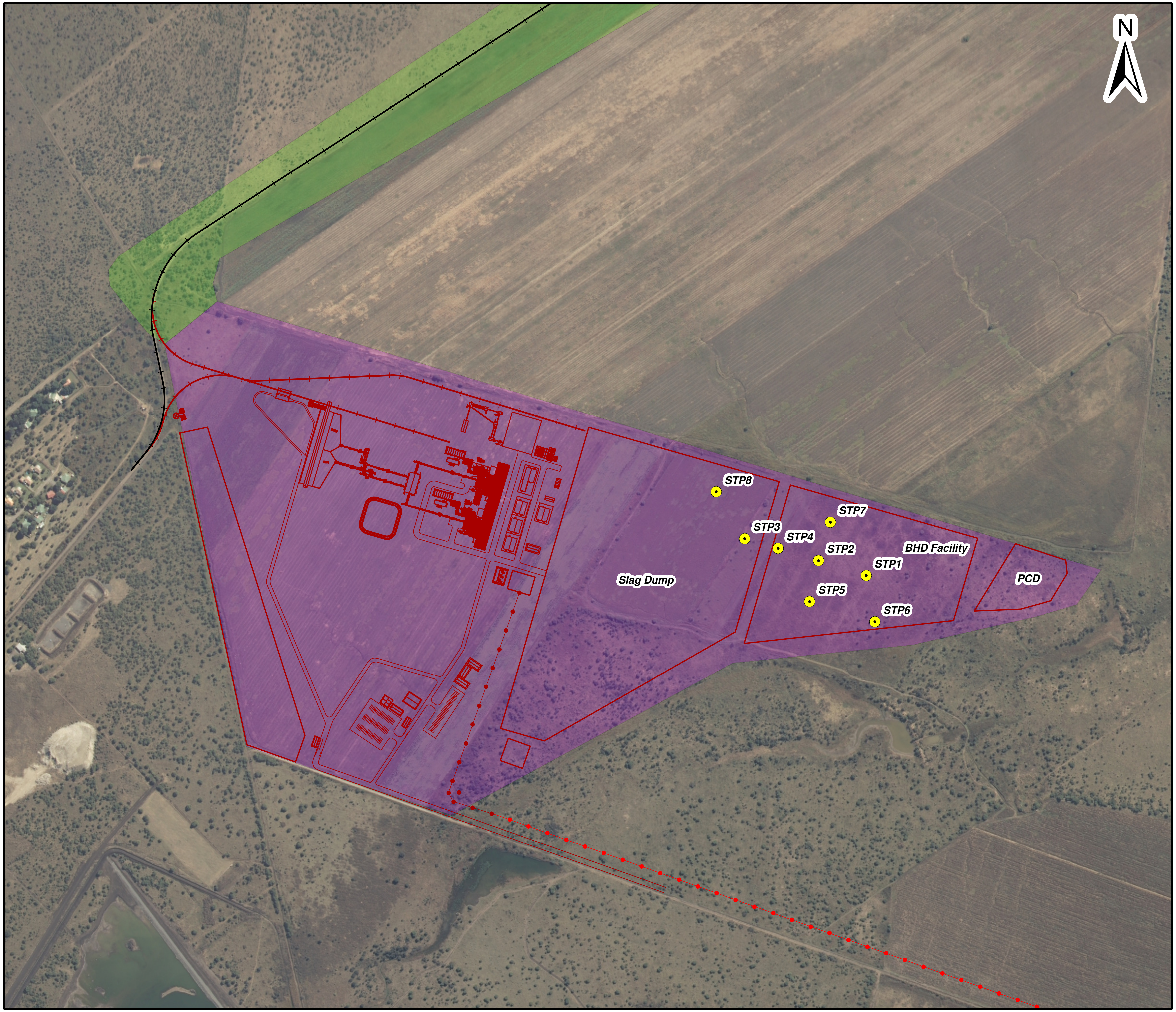
Two soil profiles were provided by Geopractica within the extents of the WDFs, with these profiles summarised here as Table 8-2.

TABLE 8-2: GEOPRACTICA SOIL PROFILES

Depth	TP22	TP23
0 – 1.6m	Moist, black, Stiff to firm, Micro shattered and slickensided, Silty CLAY, Black Turf.	Moist, black, Stiff to firm, Micro shattered and slickensided, Silty CLAY, Black Turf.
1.6 – 2.6m	Slightly moist, Greenish grey, Generally medium dense to dense becoming very dense below 2.4m, intact, Gravelly silty SAND with scattered rock fragments, Residual Norite.	Slightly moist, Orange brown, Dense with minor dense pockets, intact, Gravelly silty SAND with scattered fractured rock fragments and clay along fracture. Residual Norite/ Pyroxenite?
Notes	Refusal of TLB at 2.6m. No groundwater encountered. Some roots evident (0 – 1.6m).	Refusal of TLB at 2.6m. No groundwater encountered. Some roots evident (0 – 1.6m).

The general comments on the site investigation findings are as follows:

- Refusal was only encountered in one of the SLR test pits (STP7) and both of Geopractica test pits. The other test pits were excavated to the limit of the TLB's reach.
- No groundwater was encountered in any of the test pits.
- The soil profiles indicated black turf as the upper layer, underlain by gravelly silty sands to silty clays.
- The underlying soils are generally slightly moist to moist



Legend

- ● Test Pit Locations
- — Proposed Infrastructure Layout
- •—• Proposed Powerline Route
- 🟪 Project Infrastructure Area
- 🟩 Road Access Corridor

0 0.1 0.2 0.3 Kilometers

Scale: 1:8 000 @ A3

Projection: Transverse Mercator
Datum: Hartebeeshoek, LO27

Siyanda Chrome Smelting
Company (Pty) Ltd

Figure 8.1

Layout of Test Pits

SLR Consulting (Africa) (Pty) Ltd
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710.19057.00003

September 2016

Samples were taken from some of the test pits and geotechnically classified by Civilab. The details for the location of the samples tested as well as some selected results are summarised as Table 8-3, with the PSD graph included as Figure 8-2. The full set of test results are provided in Appendix C.

TABLE 8-3: SELECTED TEST RESULTS FOR BULK SAMPLES TESTED

Sample name	JWSS1	JWSS3	JWSS5	JWSS6	JWSS8	JWSS9
Test pit	STP01	STP01	STP03	STP03	STP04	STP07
Depth taken	0 - 1.5m	1.5 - 3m	0 - 1.5m	1.6 - 3.2m	1.6 - 3.2m	1.5 - 3.2m
Overall Plasticity Index	37	23	33	12	8	29
Potential Expansiveness	Medium	Medium/ High	Medium/ High	Low/ Medium	Low	Medium/ High
Material Classification	**CH**	**MH**	**CH**	**SC**	**SC**	**MH**
Permeability (m/s)	7.29E-10	1.15E-09		3.40E-09	7.84E-08	2.71E-10
Maximum Dry Density (kg/m³)	1 350	1 372		1 669	1 956	
Optimum Moisture Content (%)	27.8	24.6		19	14.6	

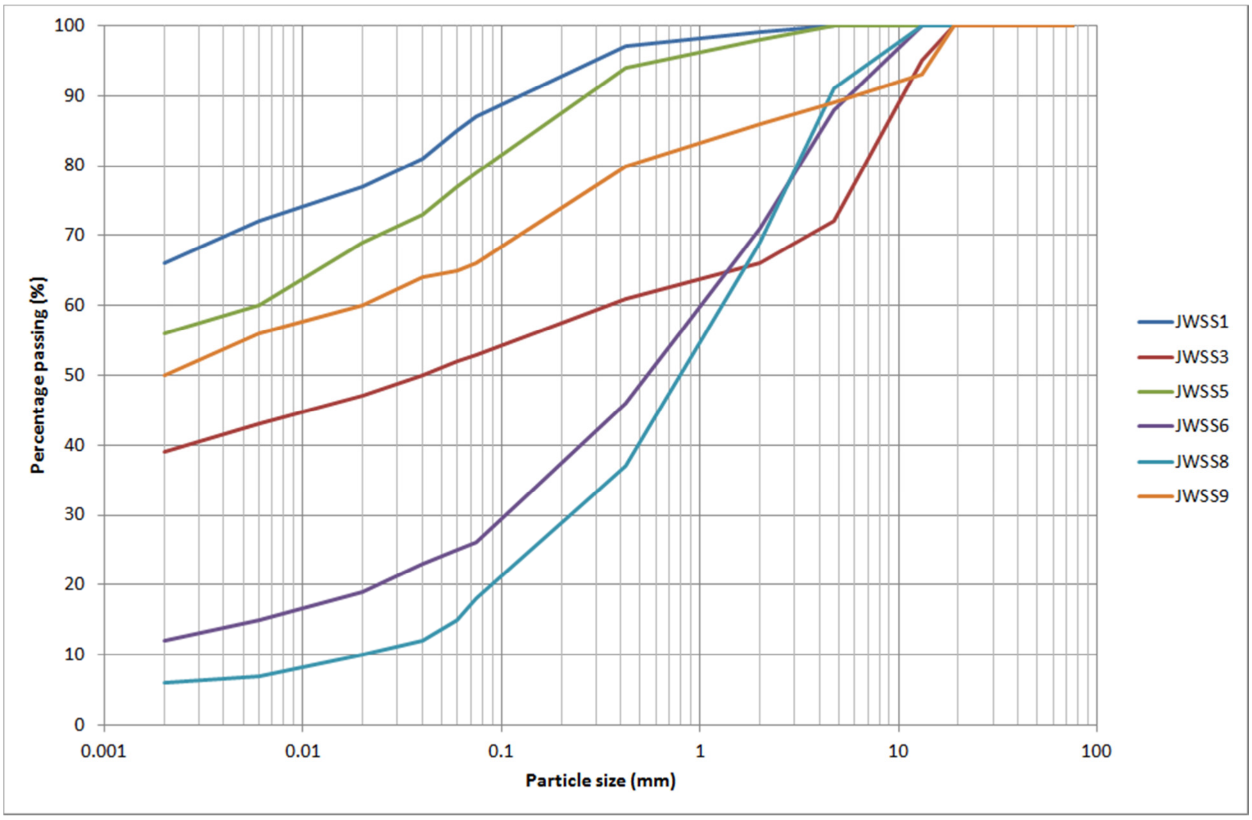


FIGURE 8-2: PSD RESULTS

It can be seen from the test results that:

- The clayey sand (JWSS8) has the greatest maximum dry density (MDD), highest relative permeability and lowest potential expansiveness.

- The other clayey sand tested (JWSS6) has a reasonable MDD, low permeability and low to medium potential expansiveness.
- The inorganic silts (JWSS33 and JWSS9) and inorganic clays (JWSS1 and JWSS5) have lower MDDs and permeabilities and medium to medium/ high potentials for being expansive.

The recommendations from these results are as follows:

- The JWSS6 and JWSS8 clayey sand material would be good for building embankments or used as a lining sub-base, although the small amount of this material lends itself to rather being used where structures sensitive to ground movement are to be constructed.
- The inorganic silts and inorganic clays could be used for embankment construction or as lining sub-bases, provided that more careful construction quality assurance is taken using appropriate construction plant and soil conditioning techniques.
- The inorganic clays (i.e. black turf) should be stripped across the WDF footprints and stockpiled for use as part of the cover material.

The low permeability of the underlying materials could potentially be used as a suitable component of the lining system.

9 WDFS DESIGN SUMMARY

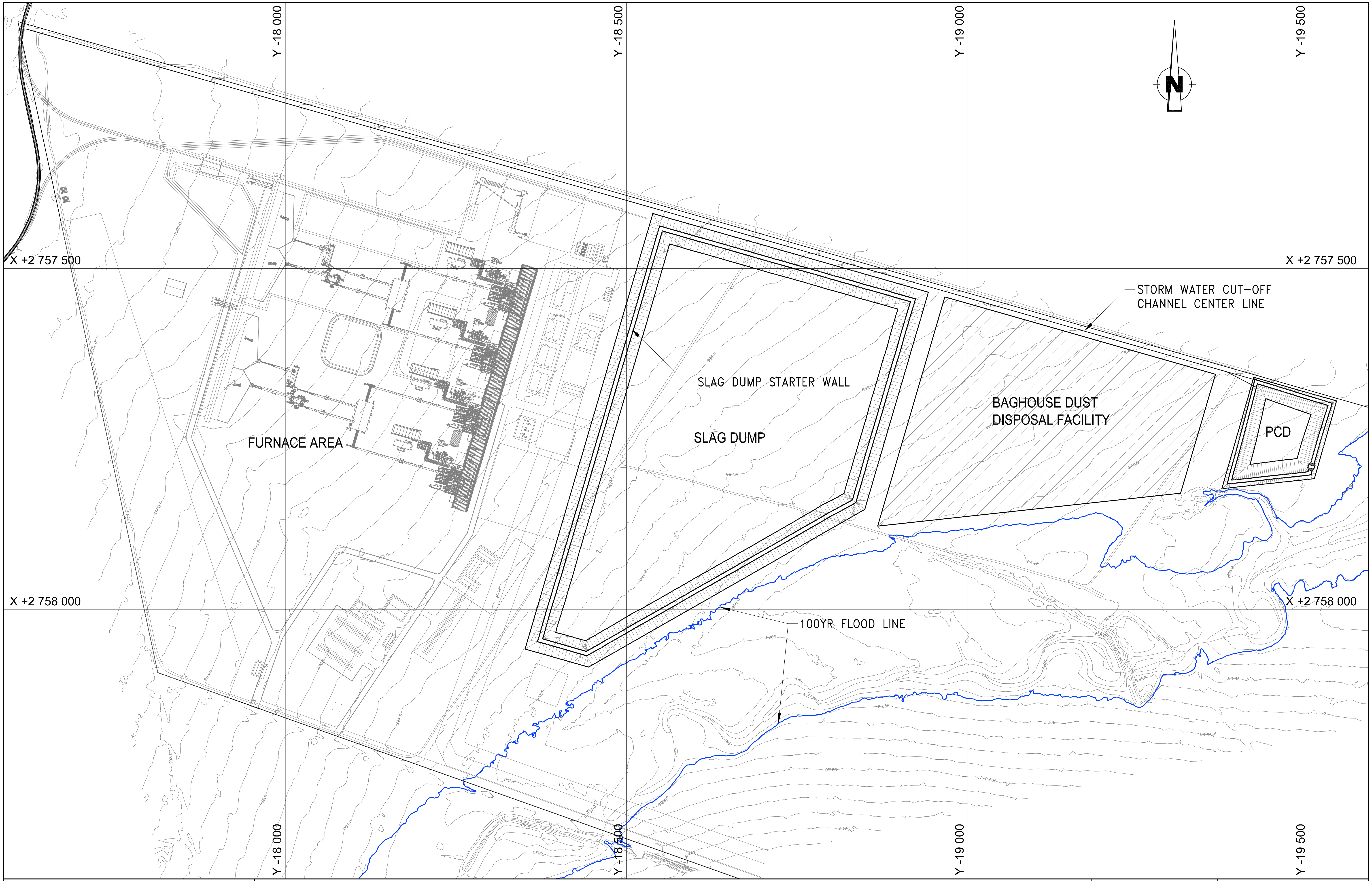
9.1 SIZING AND LAYOUT

The Siyanda Ferrochrome Smelter Project comprises of two separate WDFs and a PCD. The sizing and layout of the facilities were based on the optimum and most practical usage of the project area available. Both the WDFs are designed to cater for a 20 year storage life. The design drawings for the slag dump and BHD disposal facility showing their layout and typical section details are shown in Figure 9-1 below and Drawings 01 and 02 in Appendix D. The key features of the WDFs are summarised in Table 9-1 below.

The next phase of design will go into more detail of the phased construction of the WDFs. The current thinking is to plan to construct the facilities as follows:

- Slag dump: The full footprint will most likely be required upfront, although this will be considered more carefully going forwards.
- BHD disposal facility: It may be possible to defer a portion of the footprint to a later phase of construction by stacking the de-watering bags over a smaller portion of the footprint initially. This has several benefits:
    - The waste classification can be confirmed using actual BHD samples.

  - The containment barrier system could potentially be reduced if an updated waste assessment on actual project samples in the first phase of operations indicates that the waste types and barrier systems could be reduced. This would also have to be authorised by the relevant authorities.
  - The exact de-watering bag details and arrangement can be modified, if required.
  - The deferment of a portion of construction improves the project's cash flow.



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SIYANDA FERROCHROME SMELTER

OVERALL SITE PLAN

Date : SEPT 2016

Scale : 1: 5000

Project No :
710.19057.00003

FIGURE 9.1

TABLE 9-1: KEY SIZING FEATURES OF THE WDFS

Slag Dump	
- Slag dump area	± 21ha
- Maximum slag dump facility height	Approx. 33m
- Slag dump storage capacity	7.04 million tonnes
BHD Disposal Facility	
- BHD disposal area	± 10ha
- Maximum BHD disposal facility height	Approx. 20m
- BHD storage capacity	960 000 tonnes
Total topsoil stockpile area	± 6.5ha
PCD area	± 1.8ha

9.2 BHD SLURRY DELIVERY SYSTEM

The BHD will be slurried to transport the waste stream to the WDF. It is understood that it will be pumped at a density of approximately 30% solids and 70% water (by mass). The details of the BHD delivery system were not provided to SLR during the compilation of this report but will need to be provided and incorporated during the detailed design phase.

9.3 WDFS STARTER AND BUND WALLS

The slag dump will require a compacted earth starter wall in order to contain the molten slag being deposited onto the facility at the start of deposition. Deposition will commence from the inner crest of the embankment wall.

The slag dump outer perimeters wall will progressively be raised using the upstream construction method in lifts using cooled, dry slag in order to allow the molten slag to be contained at all times. These embankment wall raises will be constructed from the cooled slag.

The BHD disposal facility will contain a bund wall around its perimeter constructed from earth. This will ensure the adequate containment of any excess filtrate de-watered from the bags.

The details of the starter and bund walls can be found on Drawing 02 in Appendix D along with the typical sections.

The slag wall raises will concurrently be clad with soil and vegetated, as discussed in Section 11. The outer surface of the BHD disposal facility will similarly be soil clad and vegetated.

9.4 BHD DISPOSAL FACILITY

The first containment design considered for the BHD disposal facility was as follows:

- Construct an initial containment facility for the first phase of operation.
- Construct downstream lifts for the containments to increase the capacity of the WDF as the processing operations continue.

Unfortunately this was not appropriate for the Siyanda BHD facility as the limited footprint could then only store a fraction of the required design capacity. These large embankment volumes resulted in inadequate remaining storage capacity for the slurry. This reduction in volume is schematically illustrated in Figure 9-2.

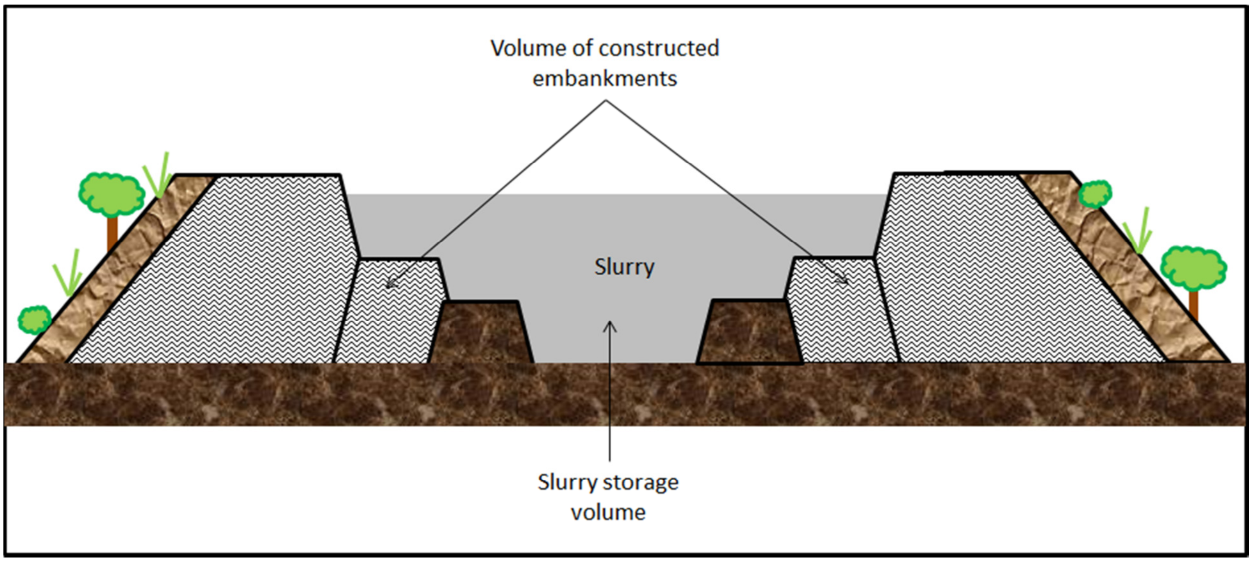


FIGURE 9-2: LARGE EMBANKMENT VOLUME IN COMPARISON TO SLURRY VOLUME

In order to increase the storage capacity of the available footprint, various options were considered and the option of using large geosynthetic de-watering bags was agreed upon. These de-watering bags have been used to contain dredged material, ash, organic matter and mine waste. An example of the use of these de-watering bags for mine is presented below as Figure 9-3.

FIGURE 9-3: DE-WATERING BAGS USED FOR MINE WASTE

In essence, their use can be explained as followed:

1. The bags are designed for the site specific slurry product.
2. The geosynthetic bags are rolled out on top of the liner system.
3. A slurry deposition pipe is connected to the bag.
4. The valve is opened and the bag is filled to capacity in-situ. This initial filling is temporary, as the water immediately starts to bleed out from the bag. The bag is left alone until the bleed water slows down, at which point the bag is again filled to capacity. While the bag is allowed to bleed off the water, other bag(s) are filled in a sequential manner.
5. Once the bleed water has stopped or at least eased off, the slurry pipe will be disconnected from the top of the bag and connected to the next bag.
6. The bags enhance the consolidation of the material as the water is able to squeeze out sideways, unlike a fully contained slurry facility. Flocculent may be required in the bags to clarify the bleed water and enhance the consolidation process, although this will be considered in more detail in further stages of design.
7. The bagged facility is inherently stable due to the relatively rapid consolidation of the slurry and the bags acting as rolls that wedge into the bags below them. It may be necessary to incorporate geo-grid type stabilising layers between the bags in future stages of design, but the preliminary assessments have indicated that this will not be necessary.
8. It is possible to access the material within the bags in the future if a possible reuse scenario is found, by breaking open the bags.

The current conservative approach has assumed that all slurry will be placed in bags. SLR is optimistic that the number of bags can be reduced by “constructing” embankments using the slurry filled bags and then depositing into the middle of the facility like a tailings dam. This will be investigated further in future design phases.

9.5 CONTAINMENT BARRIER SYSTEMS

The containment barrier systems designed in accordance to the norms and standards - GN 636 of 23 August 2013 are indicated below. It is proposed that all compacted clay liner layers be replaced with equivalent geosynthetic clay liners (GCLs) of adequate permeabilites.

The slag dump is to be underlain by a *Class C* containment barrier system, included below as Figure 9-4, while the BHD disposal facility requires a *Class A* containment barrier system based on the current waste assessment results.

Due to the slag being deposited in molten form, the extremely high temperatures would damage the underlying containment barrier system if not adequately protected from the slag. A thermal insulation layer has been included to protect the *Class C* barrier system from the high temperatures. This insulation layer consists of a 0.5m thick layer of sand overlain by a 2.25m thick layer of crushed slag. The details of the thermally modelling undertaken are included as Appendix G.

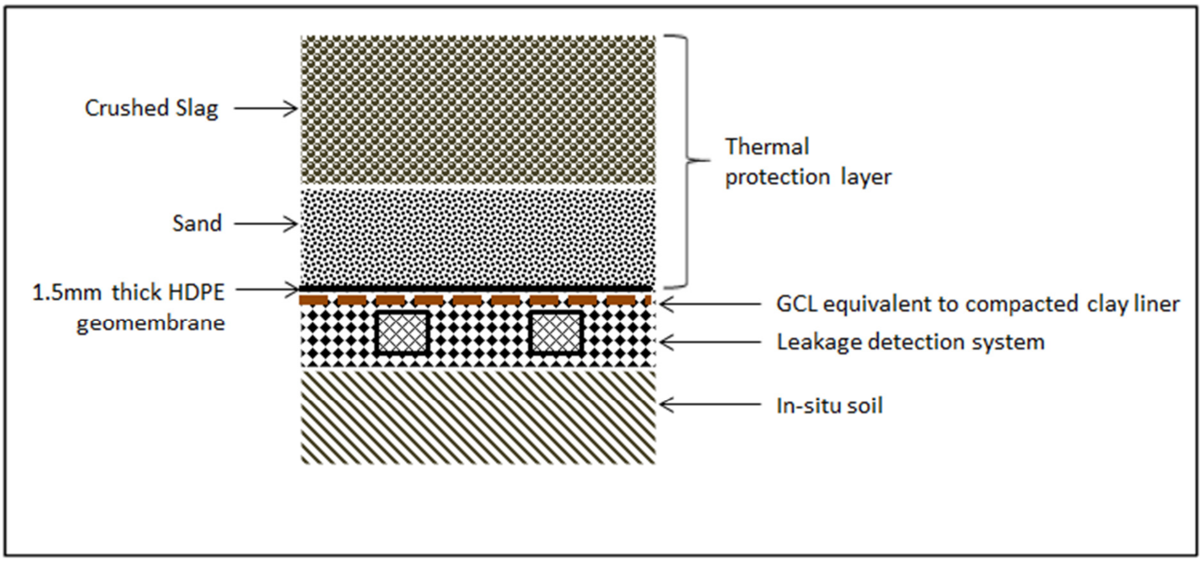


FIGURE 9-4: CLASS C CONTAINMENT BARRIER SYSTEM

In the event that it is possible to construct only the outer embankment portion of the BHD disposal facility using the de-watering bags, then the portion of *Class A* containment barrier system beneath the embankment should include the 200mm stone leachate collection layer. These variations of the *Class A* barrier containment systems for beneath the embankment and central portion are included below as Figure 9-5 and Figure 9-6 respectively.

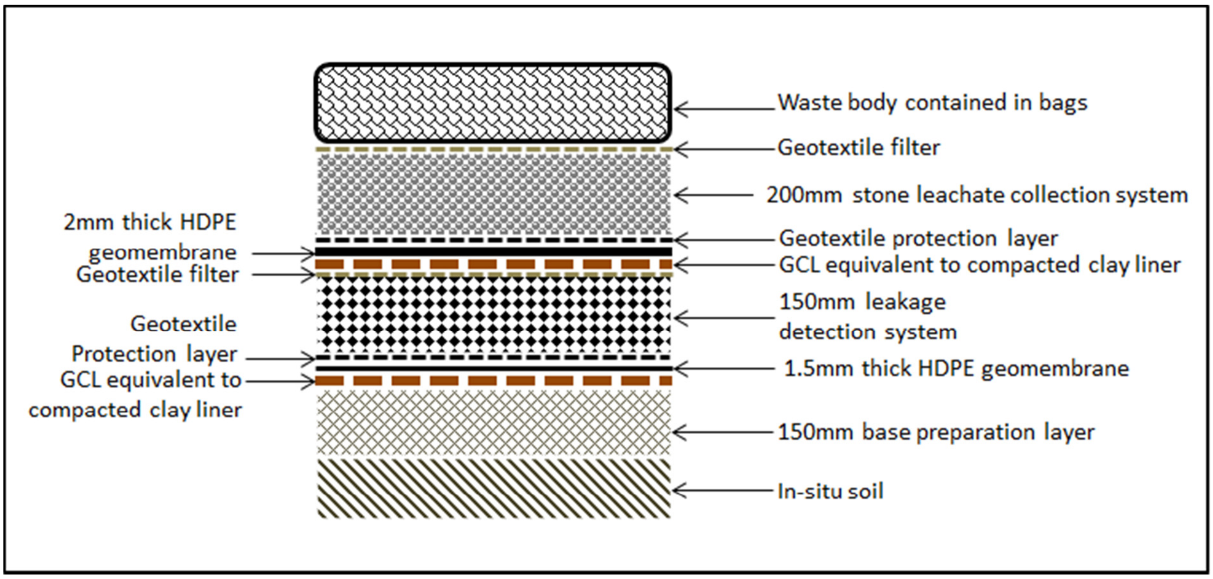


FIGURE 9-5: CLASS A CONTAINMENT BARRIER SYSTEM UNDER DE-WATERING BAGS

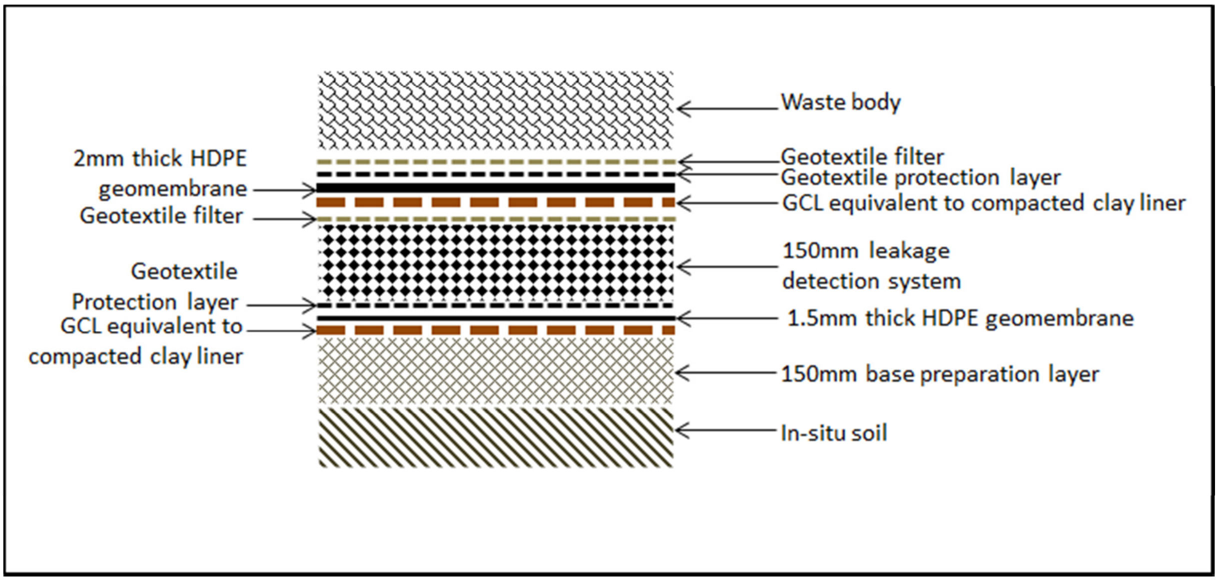


FIGURE 9-6: CLASS A CONTAINMENT BARRIER SYSTEM UNDER CENTRAL SLURRIED WASTE

9.5.1 PHASED DEVELOPMENT AND CONSTRUCTION APPROACH

The geochemical classification of the waste samples has concluded that the BHD is a *Type 1* waste material and the Slag is *Type 3* waste material. As per the waste classification regulations, the containment barrier systems needed to protect the waste had to be designed in accordance to and meet the minimum requirements as set out in the norms and standards - GN 636 of August 2013.

Due to the BHD sample being a proxy, and the fact that the environment surrounding the pilot test plant was not an actual representation of the proposed smelting process, there is fairly good chance that the waste material could actually be downgraded to a *Type 2* waste according to its geochemical properties. The slag sample could also be subjected to a similar classification downgrade. The current containment barrier systems needed to contain the BHD and Slag waste materials are a *Class A* and *Class C* respectively.

In light of the above, a phased construction approach is proposed for the construction of the WDFs. The main focus of the phasing will revolve around the possibility of downgrading the containment barrier systems in addition to deferring start-up construction costs. The initial footprint areas for the WDFs will be constructed using the containment barrier systems as described above but will only cater for limited facility life and therefore not utilise the entire footprint area (refer to Figure 9-7). The limited facility life will take into account the testing of the actual project waste materials deposited, departmental application and approval processes as well as other legal processes and construction scheduling.

If testing of the actual project waste samples prove that the geochemical classification of the waste materials are less hazardous than currently classified, the containment barrier systems will be downgraded and redesigned to meet the new classifications. Two options are presented below to summarise the construction of the WDFs.

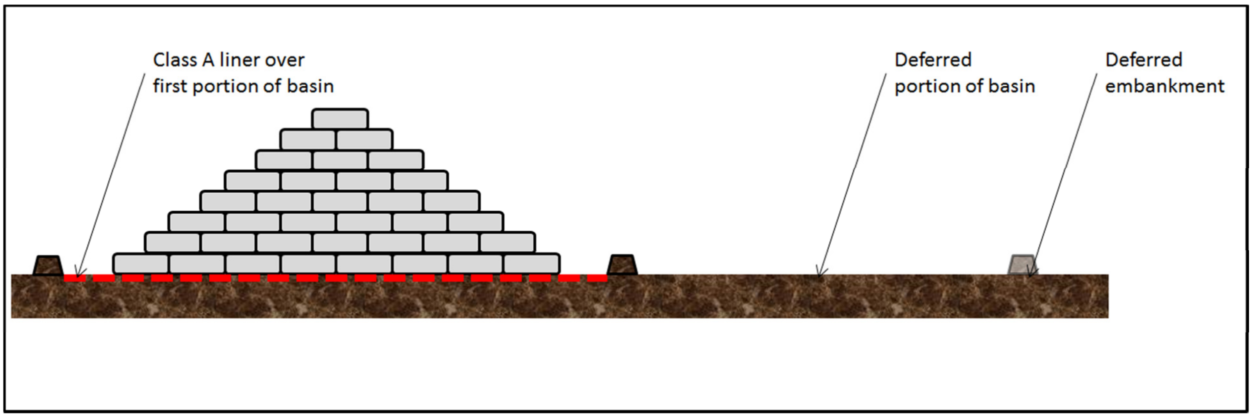


FIGURE 9-7: INITIAL PORTION OF SLAG DUMP CONSTRUCTED

Option 1 – The WDFs will be built to cater for a limited life span. The life duration will be based on obtaining approvals from the relevant authorities and taking into account construction scheduling. During this time the actual project waste samples will be tested. If the actual classifications of the samples are found to be the same as they are currently classified, there will be no need to adjust the design and obtain new approvals and therefore construction will continue as per the original design. Refer to Figure 9-8.

Option 2 – The WDFs will be built to cater for a limited life span. The life duration will be based on obtaining approvals from the relevant authorities and taking into account construction scheduling. During this time the actual project waste samples will be tested. If the actual classifications of the samples are found to be of a lower waste type than currently classified, the containment barrier systems will be downgraded and redesigned accordingly. This design will the need approval and authorisation from the relevant authorities. Once the new design has been accepted, the subsequent phases will be constructed using the downgraded containment barrier systems and tie into the existing system. Refer to Figure 9-9.

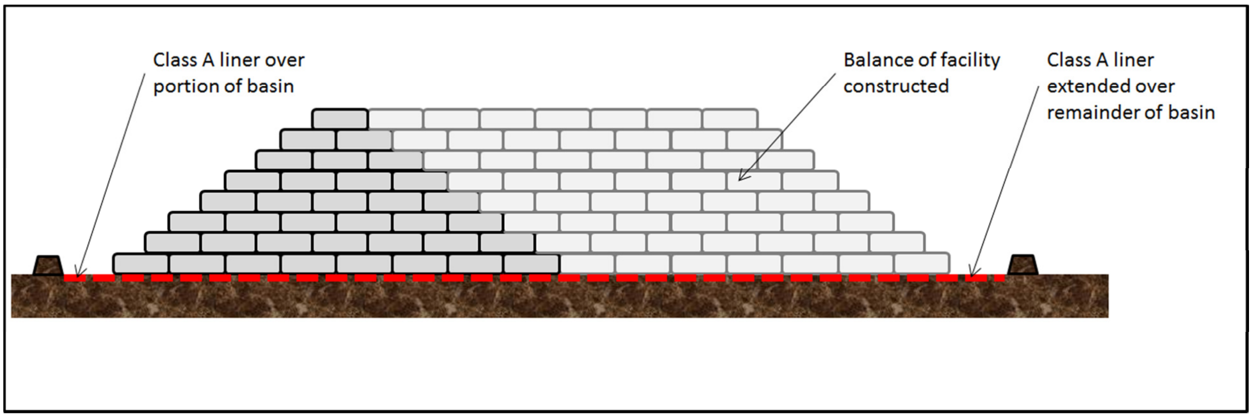


FIGURE 9-8: BALANCE OF SLAG DUMP CONSTRUCTED WITH CLASS A LINER (OPTION 1)

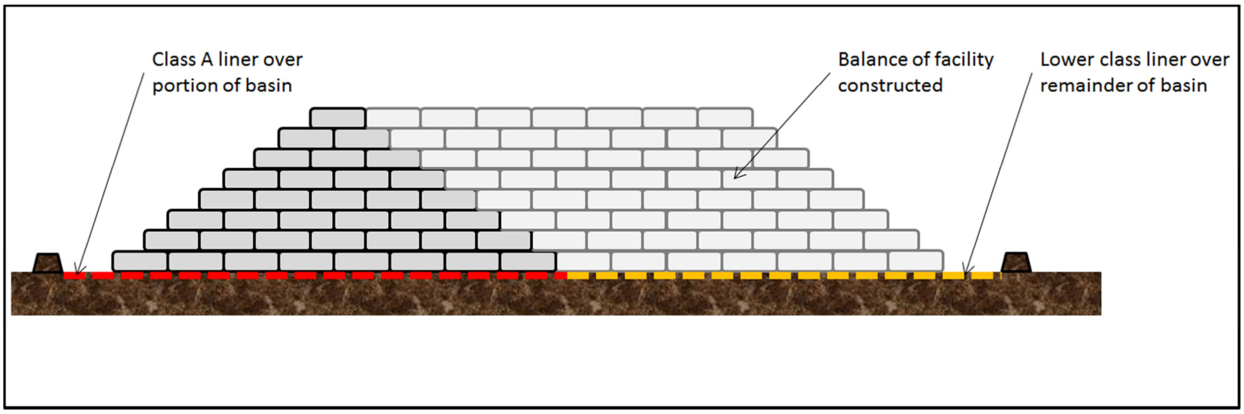


FIGURE 9-9: BALANCE OF SLAG DUMP CONSTRUCTED WITH LOWER CLASS LINER (OPTION 2)

9.5.2 LINER SERVICEABILITY

The serviceability life of the lining system is important in ensuring that the barrier system provides adequate protection to the environment. To this end, the serviceability life of the three lining systems has been assessed in the subsections below.

9.5.2.1 Slag dump

The high deposition temperatures of the molten slag need to be taken account for when determining the service life of the lining system. A thermal insulation layer has been modelled to ensure the desired life of the facility can be accommodated. Computational Fluid dynamics (CFD) has been used to determine the thermal dissipation of the heat given off by the molten slag and its effect on the barrier system. Based on lifetime prediction values provided by the lining manufacturer, a maximum allowable temperature of 25˚C was specified in the thermal modelling in order to provide a minimum lifetime of 265years.

Thermal simulations including multi-phase fluid flow and heat transfer have been carried out utilising advanced Computational Fluid Dynamics (CFD) modelling. Multiple fluid flow, solidification and heat transfer are considered for the molten slag (liquid) and the surrounding cooling air (gas) in this study. Molten slag is assumed to flow for 10 seconds and the Volume of Fluid (VOF) model with a free surface between the molten slag, air and porous insulation layer is used to compute a time dependent solution. Heat transfer via natural convection and conduction is then predicted for up to Time = 806,600 seconds (Sec).

The following insulation layers are proposed:

- 2 m thick crushed slag with a maximum porosity of 34%.
- 0.5 m thick sand with a permeability of 8e-8 m/s.

The following major conclusions are achieved from the results of CFD simulations:

- The molten slag solidifies just below the upper surface of the crushed slag at Time = 10 Sec. The molten slag is assumed to solidify at 1300˚C.
- The slag is completely solidified at time = 250 Sec. This study is considered conservative where a still wind condition with ambient temperature of 27˚C is assumed. This rate of heat transfer from the molten slag will increase with increasing ambient wind speed.
- It takes approximately 30 hours for the heat wave to pass through the liner. The liner temperature is increased by 0.09˚C at Time = 118,820 Sec. The time delay is due to the thermal mass of the insulation material layer (2 m of crushed slag plus 0.5 m of sand). The thicker and more resistive the material, the longer it will take for heat waves to pass through.
- The liner temperature peaks at Time = 635,600 Sec. The peak temperature is 298.82 K (25.82˚C). The reduction in upper surface of the crushed slag is 1,558˚C at the same time. Thus, the liner system will experience a 4.82˚C variation while the slag will experience approximately 1,558˚C variation in external surface temperature at the same time.
- The temperature will fall to 296.39 K (23.39˚C) at 0.25 m below the liner.

If the thickness of the crushed slag is increased to 2.25 m (total insulation layers = 2.25 m crushed slag plus 0.5 m sand) the liner temperature will reduce to below 24˚C.

Based on the fact that the thermal modelling was conducted using various conservative assumptions i.e. considering the worst cases for all external environmental conditions that the liner could possibly be subjected to, it can be said that the geomembrane liner could last for a lifetime of around 400years.

The thickness of the thermal protection layers can be reduced if a water cooling system is presented to reduce the slag temperature. Some of the by-product from heating can be captured by thermal energy storage to operate a combined heating and power system or it can be used in an absorption chiller to produce free cooling. This water cooling system could be conducted during the detailed design stage if this option is desired.

The results from the thermal modelling can be found under Appendix G.

9.5.2.2 BHD disposal facility

The geomembrane portion of the containment barrier system will be protected from physical damage through the inclusion of the filter drainage layer. This will allow the geomembrane to last in accordance with the predicted lifetime of more than 400years as provided by the lining supplier.

9.5.2.3 PCD

The geomembrane included in the PCD containment barrier system will be exposed to UV radiation for the majority of its operational life. The portions of geomembrane which remain out of the water (i.e. above the maximum design level and the anchor trenches) will be subjected to the greatest amount of UV radiation, while the liner covered by water will be subjected to the least UV radiation exposure.

The thickness of the PCD geomembrane has been specified as 2mm. The manufacturer provides a warranty of every 1mm lasting 10years, thereby giving the specified geomembrane a 20year guaranteed life. In the event of the liner failing, either visibly or through deterioration of the groundwater qualities, the geomembrane will need to be repaired and/ or replaced as appropriately required. This shorter liner serviceability life is believed to be suitable as the plastic lining system will be removed post-closure of the waste facilities.

9.6 DRAINAGE SYSTEMS

9.6.1 UNDERDRAINAGE SYSTEM

The purpose of the underdrainage system is to reduce any excess phreatic surface build up within the waste facility in order to achieve adequate structural integrity of the facility.

The slag dump will include a leakage detection monitoring system in order to comply with the requirements of the *Class C* Liner/Containment barrier systems as per GN 636 of 23 August 2013. The underdrainage system will be located in the base preparation layer which will be made up of a slotted drainage pipe with stone surrounds all completely wrapped in a suitable geotextile.

The BHD disposal facility will contain a stone leachate collection system which will be made up of intermediately spaced drainage pipes to help increase the removal of filtrate from the geosynthetic de-watering bags and allow for a faster de-watering and consolidation time.

All the water collected from the underdrainage systems will be conveyed into manholes which will ultimately transport the water to the PCD.

The slag dump underdrainage system will also contain finger drains spaced every 10m, each wrapped in a suitable geotextile.

9.6.2 LEAKAGE DETECTION SYSTEM

The BHD disposal facility will also contain a leakage detection system which will allow for the monitoring of seepage below the liner barrier system. This will aid in determining if there is any damage caused to the overlain lining system and to ensure it functions as designed. Details are shown on Figure 9-5.

9.7 RETURN WATER SYSTEM

The return water system will consist of the following:

- A silt trap.
- A *Class A* lined pollution control dam (PCD) with a capacity of 65 000 m^3 (receives water from the concrete lined silt trap).
- A return water pumping station.
- A return water pipeline, which conveys water from the return water pump station to the processing plant.

A silt trap was incorporated into the overall design to reduce sediment loading in the PCD. The silt trap will be designed to remove particles that are 0.025 mm (or larger) from the decant water, which in turn reduces the chance of damage to the HDPE liner in the PCD as cleaning is less frequent and intensive, as well as to provide return water with a lower concentration of total suspended solids (TSS) to the processing plant.

The silt trap will be required to be cleaned out (de-silted) at regular intervals using mechanical means or a slimes pump, and should be done during dry weather conditions.

The PCD consists of a single compartment into which all water flows. Siyanda indicated that it would be preferable to develop the PCD as a single compartment to facilitate the return water pumping.

A leakage detection system under the PCD liner will be provided to assess the integrity of the liner on a regular basis. The protective layer above the plastic liner will negate the need for safety ropes. Furthermore, the PCD is fenced off to prevent any unauthorised access and to prevent livestock from drinking the water in the dams.

A *Class A* liner system will be used to line the basin of the PCD and to tie-in with the containment barrier requirements for storage of leachate generated from a *Type 1* waste material.

The PCD details are shown on Drawing 03 in Appendix D.

9.8 SURFACE WATER MANAGEMENT

Surface water management for the WDFs entails limiting any pollution caused by the erosion of waste material from the side slopes and top surface of the facilities. Also, any surface dirty water (i.e. water considered to be contaminated) will be kept separate from clean (uncontaminated) surface water run-off as far as possible.

The stormwater management is separated into the following distinct areas:

- The depositional area inside the WDFs.
- The side slopes of the WDFs.
- Areas outside of the complex that drain towards the facilities.

Stormwater that falls onto the depositional area inside the WDFs will be seep through the facility and be captured by either the finger drains on the slag dump or through the stone leachate collection system on the BHD disposal facility.

The catchment paddocks that run around the toe of the slag dump are designed to attenuate stormwater from the side slopes of the WDF, settle the eroded solids and create an area for the establishment of vegetation to assist with the vegetation of the side slope cladding. The water captured in the paddocks will be drained via gabion basket outlets to stormwater channels which will, in turn, convey the water to the PCD.

10 OCCUPATIONAL HEALTH AND SAFETY

Given the hazardous nature of the baghouse dust, it is critical to ensure that the construction methods do not result in workers being exposed to unsafe levels of the BHD. A variety of health and safety protection measures are required to be put in place for the slag dump and BHD facilities.

10.1 SLAG DUMP

The molten deposition of the slag comes with several obvious heat-related risks. These will need to be properly considered in consultation with the operators but the following measures are believed to be required:

- A holistic risk assessment that is reviewed and updated periodically.
- Appropriate heat insulation measures for vehicles.
- Demarcation and restricted access to prevent access to the molten slag.
- Appropriate heat PPE if individuals are likely to get close to the molten material.

Generation of steam within the slag will need to be considered in more detail as there is a possibility of the fresh molten slag superheating the water in the pores of the cooled slag. This will need to be addressed from an Occupational Health and Safety perspective.

10.2 BHD FACILITY

The BHD product is likely to be hazardous to operators which means that all dermal contact, inhalation and consumption contact needs to be carefully managed. The following aspects will need to be managed in consultation with the operator prior to construction:

- A holistic risk assessment that is reviewed and updated periodically.
- Adequate signage and access restriction to the WDF.
- Appropriate personal protective equipment (PPE), most likely including water proof boots, overalls, eye protection, gloves and possibly dust masks.

The risk of dermal contact is reduced by implementing the bag filling procedures documented in Section 9.4. The risk of inhalation will need to be managed by ensure that the baghouse top surface and any exposed side slope surfaces remain sufficiently moist to prevent dusting under windy or trafficked conditions.

11 CLOSURE, REHABILITATION AND AFTERCARE ISSUES

The rehabilitation of the outer slopes and top surface will be based on a water shedding type capping and cover design following the specifications in the Department of Water Affairs and Forestry Minimum Requirements for Waste Disposal by Landfill, second edition, 1998.

This capping is intended to prevent the ingress of water to the waste as a result of the presence of a low permeability GCL layer equivalent to that of a 450mm clay soil liner. The typical cross section through the capping is presented in Figure 11-1 below.

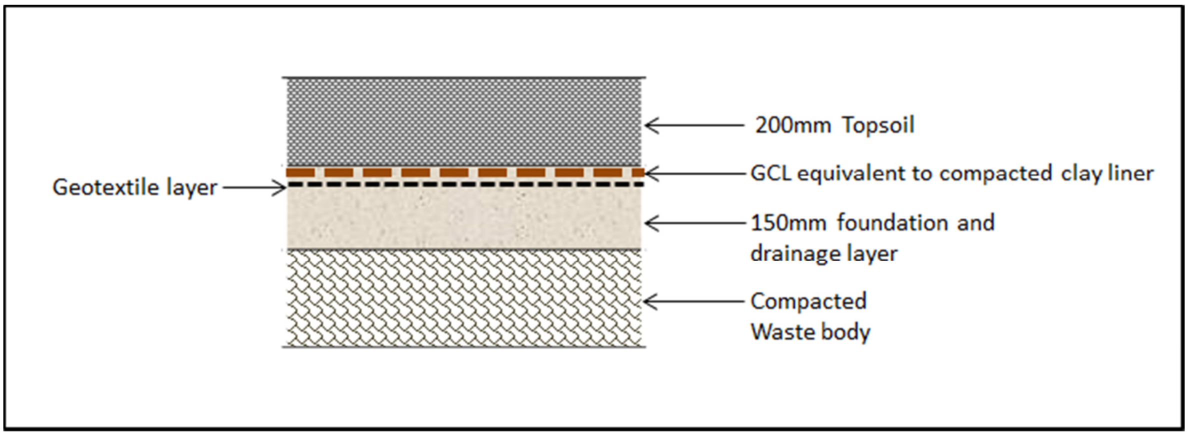


FIGURE 11-1: CAPPING AND COVER DESIGN FOR WDF'S

The exact cover design and composition of the various materials and vegetation mix will form part of future stages of design and ongoing monitoring and modification of the cover, if necessary.

11.1 SIDE SLOPES OF WDFS

If no suitable buyers are identified for the waste materials, particularly for the slag then the WDFs will be concurrently rehabilitated with every raise of the outer walls to fall in line with international best practice. The rehabilitation approach adopted will comprise of the construction of a vegetated final cover to the outer side slopes of the WDFs, as part of the on-going wall raising operations. Cover materials will comprise a combination of materials derived from suitable borrow pits, waste rock (if available) and growth medium. The placement of the cover from the early life of the WDFs will allow the cover design to be tested, and modified if necessary, over the lifetime of the facility to allow a defendable final sign-off of the cover at closure.

The outer side slopes will be constructed to an overall slope of 1V:3H.

The surface water quality discharged from the WDFs will be largely dependent on the integrity and performance of the cover and the ecosystem services that will be provided by catchment paddocks located around the toelines of the WDFs. The function of the cover will be to:

- Enhance the aesthetics of the WDFs.
- Limit the infiltration of water to a relatively low percentage of mean annual precipitation (MAP), but sufficient to maintain the vegetation.
- Provide a substrate for the establishment of a sustainable vegetation cover to the entire surface of the WDFs. The vegetation will serve to enhance the evapo-transpirative flux from the WDFs thereby limiting the migration of salts to the surface of the cover.

- In combination with the vegetation and slope profile, provide a surface that will only erode very slowly to ensure the long term protection of the underlying tailings, and on-going replenishment of nutrients necessary for maintenance of the vegetation cover and long term formation of soils.

Figure 11-2 to Figure 11-5 illustrate the following cover placement stages for the BHD facility:

1. The first couple of layers of bags are de-watering at a rapid rate and no cover is placed. The bags are placed from the outside inwards to encourage the majority of drainage towards the inside of the facility.
2. Once the third layer of bags has been placed, placement of cover around the bottom layer of bags can commence as only minor water will be emanating from the outer bags. A water channel will be constructed at the crest of the cover to convey dirty water and prevent contamination and minimise erosion of the cover.
3. The placement of the cover continues to track the height of the bags, with a channel always established on the crest of the cover.
4. The cover placement continues up the slopes of the facility as a smaller scale, relatively constant rehabilitation activity.

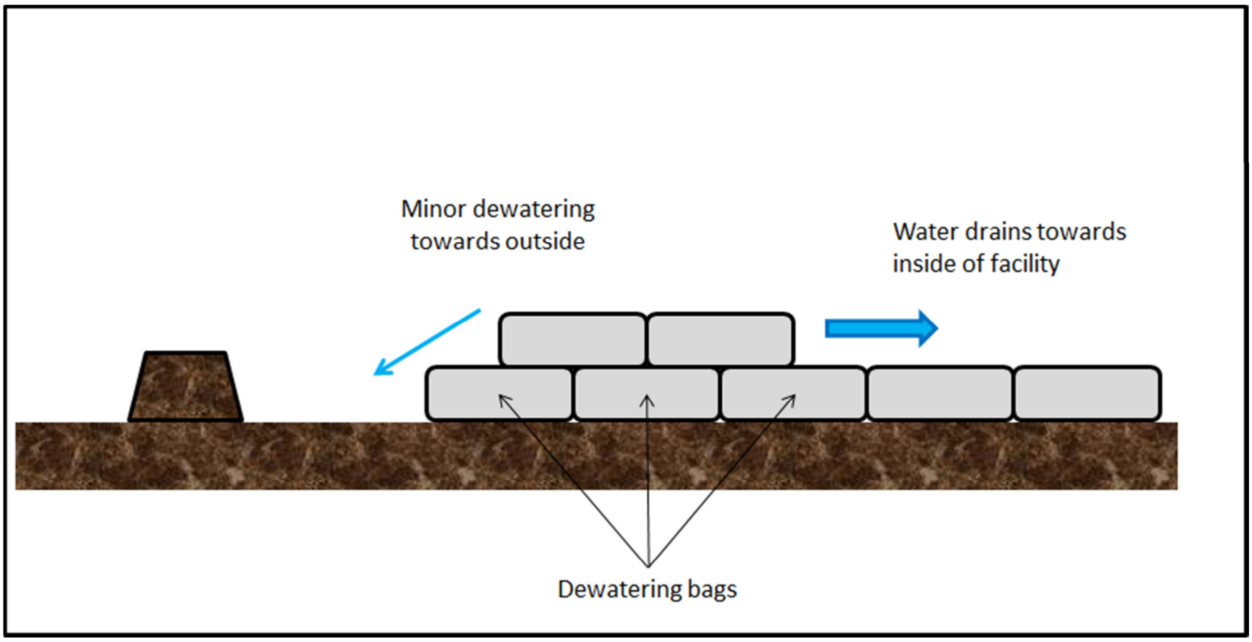


FIGURE 11-2: STAGE 1 - INITIAL LAYERS OF BAG PLACEMENT AND FILLING

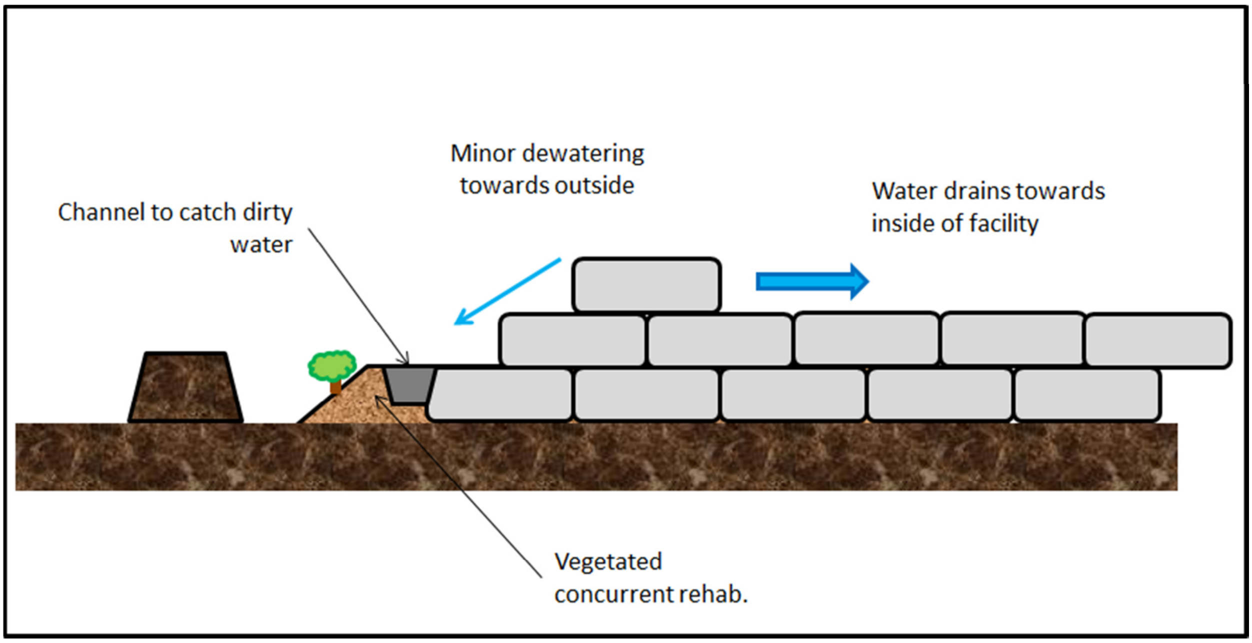


FIGURE 11-3: STAGE 2 - FIRST PLACEMENT OF CONCURRENT COVER

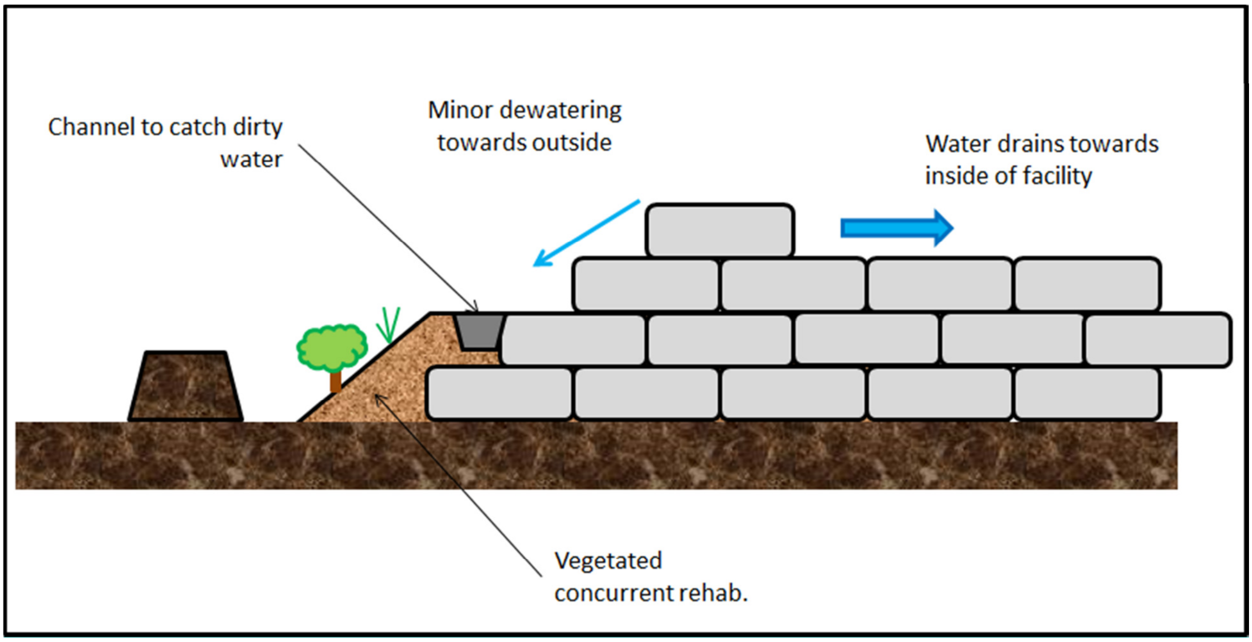


FIGURE 11-4: STAGE 3 - RAISING OF COVER TO TRACK BAG RAISING

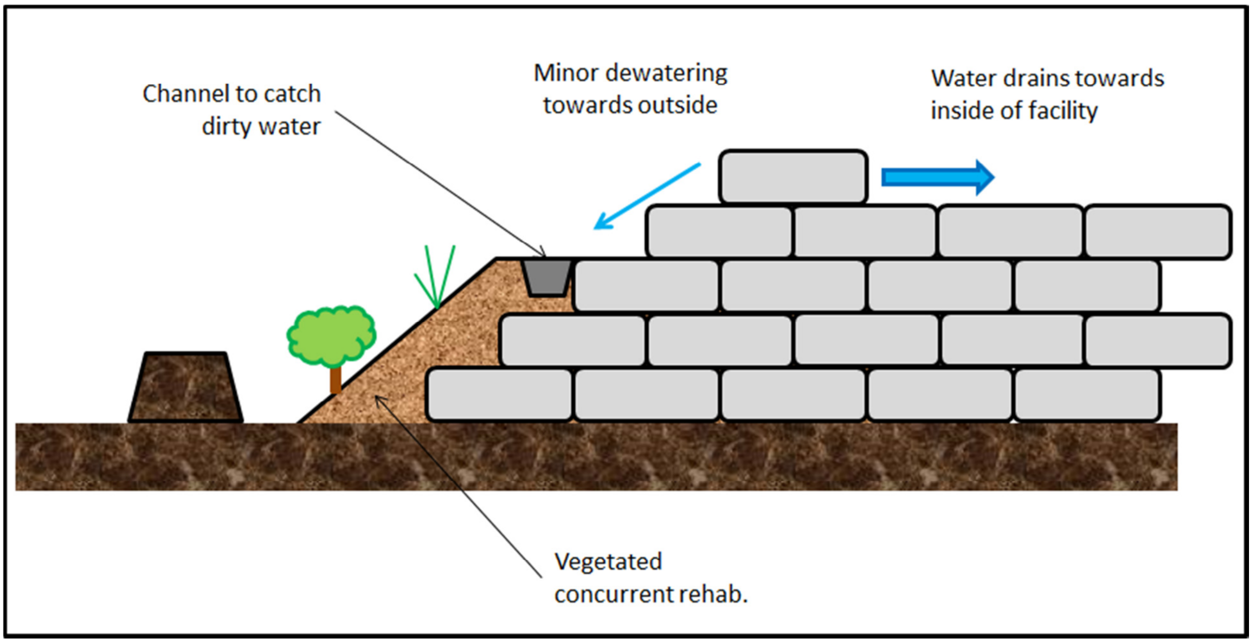


FIGURE 11-5: STAGE 4 - CONTINUED COVER PLACEMENT WITH RAISING OF BHD FACILITY

The concurrent cover placement of the slag dump would follow a very similar approach, with easier maintenance of the cover due to no dirty water emanating from de-watering bags. The only dirty water that the channel will need to capture is the stormwater runoff from the small side slope that is exposed directly ahead of the cover.

The detailed design of the cover may also make use of inclusions such as contouring. Further design will involve consultation with a soil scientist (or similarly experienced person) to assist in determining the soil types required for a sustainable cover.

11.2 TOP SURFACE

As with the rehabilitation of the side slopes, the top surface will receive a cover which consists of a mix of soil, rock and growth medium, which will also be vegetated. The purpose of the top cover will be to limit the ingress of water into the WDFs while providing a substrate for the establishment of vegetation.

The cover design will consider ways to minimise ponding of water on the top surface of the WDFs. Paddocking of the top surface may be incorporated to rather have many smaller and shallower ponds of water than a single deeper pond in the middle.

12 MONITORING

In order to ensure compliance of the facilities with the legal commitments and best practice, the following monitoring activities are envisaged during the life of the facilities:

- Heat sensors above the liner system in the slag dump to monitor predicted vs actual temperatures beneath the thermal insulation layer.
- Dust bucket monitoring around the perimeter of the WDFs.
- Groundwater monitoring through sampling of boreholes.
- Annual leachate quality testing to verify the waste classification.

13 CONCLUSION AND RECOMMENDATIONS

The following conditions should be included in the environmental authorisation:

- Evidence to be provided that the temperature of the liner system beneath the slag dump will be adequately controlled through the provision of the protection layer.
- Concurrent rehabilitation should be enforced and a condition of the license.
- Monitoring of the construction, operation and closure of the facilities will be required.

David Pillay Pr.Techni.Eng.	**Justin Walls Pr.Eng.**	**Alistair James Pr.Eng.**
(Report Author)	**(Project Manager)**	**(Project Reviewer)**

REFERENCES

- SLR EIA Report, 2016-11-01-Siyanda EIA and EMP, November 2016.
- SLR SW Report, 160926_Siyanda_SW_Study, September 2016.
- SLR GEOCHEM Report, 2016-09-02_Siyanda_Geochem, September 2016.
- Geopractica, 2015, Geotechnical Investigation for Northam Ferro-Chrome Project, Job No: 15096
- Government Notices GN 634, 635 and 636
- South African National Standards (SANS) 10286 (previously SABS 0286:1998), Code of Practice for Mine Residue Deposits

APPENDIX A: SPECIALIST CVS

Alistair Robert James
Director

Curriculum Vitae

Qualifications

BSc (Eng Civil)	1985	Witwatersrand
Diploma	1989	Graduate Diploma in Engineering (Wits)
Professional Registration:	1989 2014	Pr Eng (Professional engineer registered in the Republic of South Africa) No. 890393 TCEng No. 090 (Temporary Consulting Engineer registered in The United Republic of Tanzania)
Professional Affiliations:		Member, South African Institute of Civil Engineers
Present:		Director, SLR Consulting (Africa) (Pty) Ltd
		Director, SLR Environmental Consulting (Tanzania) Ltd
		CEO, SLR African Holdings (Pty) Ltd

Key Areas of Expertise

Key areas of Alistair's expertise are summarised below.

Water quality and hydrology	Prediction, prevention and control of contamination of water from tailings dams, spoil piles and other mining and metals processing sources.
Mine and metals processing residue	Feasibility studies, detailed design and construction monitoring. Conventional tailing to thickened tailings. Wide range of experience with a wide range of commodities including gold, uranium, coal, copper, nickel, lead, zinc, kimberlite. Water use efficiency and pollution minimisation.
Ground Water	Ground water and soil contamination remediation. Pit lake studies.
Geotechnical Engineering	Seepage and slope stability analyses, geotechnical characterisation of tailings and foundation materials
Waste Management	Hazardous and non-hazardous waste management. Geochemical characterisation of mining waste materials. Mine drainage quality prediction.
Risk Assessment	Probabilistic modelling in the fields of surface water (floods, dam sizing), closure liability assessment etc.
Sustainability	Development of sustainable mining approaches to mine planning, infrastructure development and closure.

Environmental remediation and control	Environmental remediation and control relating to groundwater, surface water, soils, vegetation and air quality. Mine closure assessments.

Summary of Experience and Capability

Alistair James has worked in the consulting industry throughout his career with most of the work focused on the mining sector. Alistair worked initially as a resident engineer for a large national construction project. After this he worked as a structural/civil engineer involved primarily in the design of commercial office parks and shopping centres.

In 1989 he joined Steffen Robertson and Kirsten in Johannesburg and started work in the mining industry, primarily of mining effluent and mine waste projects.

In 1995 he co-founded Metago which focused largely on the mining sector and became a well known name in the mining sector in terms of mining waste, water and other environmental advisory services, up until March 2011. In March 2011, the shareholders of Metago agreed to merge with SLR Consulting.

Alistair is currently a Director of SLR Consulting (Africa) and SLR Environmental Consulting (Tanzania) and CEO of the African Operations Holding Company. Alistair has 30 years' experience focused primarily on the mining industry in Africa and on mine water and mine waste in particular, including investigations, design, project management, closure, due diligence assessments/audits, liability and risk assessments.

Alistair continues to develop SLR's services within the mining sector internationally.

Alistair also holds the position of Chairman of Metrix Software Solutions, the company that has developed the internationally recognised Isometrix suite of management software products.

Recent Project Experience

Project	**Date**	**Alistair's Role**
Water Related Projects		
Bulbul Drive Landfill: Holistic Beneficiation Plan: Closure design, landfill gas and leachate management	2014	Project manager: Project aimed to find the best balance between capping construction, leachate treatment and gas collection taking capital constraints and other technical constraints into account.
A-Cap Resources – Heap Leach study PFS: Evaporation Rate from saline process water. Geochemical assessment of heap leach material and mine waste rock	2014	Project Director. This project involved the development of a method and laboratory testing to evaluate how the salinity of process water affects the evaporation rate. The geochemical assessment involved the determination of the acid generating and leaching characteristics of the heap leach materials and waste rocks.
Golden Ridge- Tanzania – Pit lake study.	2011	Project Director. This project involved modelling of the pit lakes to ascertain the long term lake levels and seasonal fluctuations likely to arise from planned mining of the pit.
Barrick Gold – Golden Ridge Waste Rock Dump and Pit Lake Study	2011	Prediction of the seepage quality from the waste rock dump. Draw down cone for the pit lakes and final (post closure) pit lake water quality and plume migration. Design of the water management and pollution prevention infrastructure to deal with runoff and seepage. (Project Director)

Project	Date	Alistair's Role
Water Research Commission of South Africa: Decision Support System for Metalliferrous Tailings Disposal Facilities.	2009	Steering Committee member
South Deep Gold Mine- Site wide water balance	2008	Project management and large part of the execution of the project. South Deep Gold Mine has a particularly complex infrastructure network for handling of water. This project involved the development of a water balance to model South Deeps undergroundwater, use of potable water, stormwater, process water and sewage effluent.
Afplats and Xstrata – Hartebeespoort Dam Irrigation Canal Water Loss Investigation. This project involved the assessment of the water losses from the Hartebeespport Dam's East and West Irrigation canals and development of a remedial action plan to reduce the long term losses.	2008	Project Director and reviewer.
Transnet Port Elizabeth Manganese Terminal.	2008	Project Director – the project required the quantification of the impact of the manganese loading terminal on the groundwater and marine environment. The project involved the installation and monitoring of groundwater wells and soils testing. A risk based approach was adopted to provide the client with recommendations concerning the long term land use development and need for and type of remediation necessary to achieve the land use development.
Boehme environmental, health and safety audit. Appointed by URS, Germany.	2007	Environmental audit of the Boehme's Pietermaritzburg factory.
Department of Water Affairs and Forestry of South Africa: Development of Best Practice Guidelines for Resource Protection in the South African Mining Industry. • Pollution Prevention • A4 Pollution Control Dams	2007	Technical Review Committee Member
Avmin Nkomati Opencast Mine: Prediction of the acid generating potential and long term leachate quality from the low grade ore stockpiles and waster rock materials. Recommendations for design and long term monitoring.	2007	Project execution and management
Water Research Commission of South Africa: The assessment of the effect of backfilling of dolomite sinkholes with gold tailings material.	2007	Project development, management and execution.

Project	Date	Alistair's Role
South Deep Gold Mine – seepage interception trench to intercept polluted groundwater seepage emanating from the old South Deep tailings dam and pollution control dam.	2006	Project director and professional engineer responsible for the design and quality control during construction.
Gold Fields - StIves Mine Heap Leach Expansion Project. Australia	2005	Geochemical modelling of the process water quality associated with the heap leach circuit to assess salt accumulations and equilibrium levels. Modelling conducted using PHREEQC. Alistair James conducted the site visit, prepared the model concepts and report.
Kalana- Geochemical characterisation of various wastes for Kalana Gold Mine - Mali – acid rock drainage assessment and leaching potential of various mining wastes including tailings, waste rock and sands.	2005	Project Director and reviewer
Nickel Laterite Deposit – Review of the water supply for a new mining project in Madagascar for Murray and Roberts.	2004	Alistair was required to evaluate and report on: o The risk associated with the proposed water supply from the river, and o The need to gather any additional flow, climatic or other information over the proceeding months to refine and further quantify the draft supply risk. o The need to conduct any additional hydrological study to estimate the risk in the light of the proposed draft.
Tati Nickel Mining Company, Botswana: Prediction of the long term seepage and runoff quality from the proposed Tati tailings dam and design of mitigation measures to manage the environmental impacts.	2003	Project execution including field investigation, modelling and reporting.
Tati Nickel Company: Assessment of the pollution potential associated with the proposed new tailings dam and assessment of alternative pollution control measures including recommendations for the design and operation of the new dam complex.	2003	Geochemical assessment and modelling. Preparation of design recommendations to minimise emissions.
Pering Mine – Prediction of Pit Water quality after Mine Closure	2002	Project Manager and modeller. Pit lake study to determine long term water levels and quality of water in the residual pits at Pering Mine.
Barrick: Bulyanhulu Mine – Tanzania: Review of the design of all mine water management and reticulation systems and the development of a system to optimise water management at each pollution control dam in terms of either minimisation of spill volume, minimisation of	2002	Project management and execution including the development of a probabilistic hydrological model to assess the performance of water management infrastructure under a range of conditions.

Project	Date	Alistair's Role
contaminant load or minimisation of fresh water uptake. Preparation of a water balance.		
RTZ, Argyle Diamond Mine, Northern Territory, and Australia: Assessment of the acid drainage potential associated with the Argyle waste rock dumps.	2001	Project execution including field investigation, modelling and reporting.
Kynoch Fertilisers: Assessment of the soil and groundwater contamination- Potchefstroom Plant.	2000	Project Manager
ETC Water Management Strategy, Mpumalanga, South Africa:	2000	Project management and execution. Preparation of water and salt balances for the entire operational ETC mines including a TDS balance to facilitate the application of integrated water management principles.
SA Chrome and Alloys: Specialist investigation of the leach potential of slag and clarifier slurry including an assessment of the impact of the proposed waste facilities of groundwater quantities in the surrounding area.	1998	Project management and execution including the prediction of the drainage quality but excluding the groundwater modelling.
Tarkwa Mines- Ghana: Review of the heap leach operation with respect to the management of mine water and rainfall runoff and the management of the risk of cyanide contamination in the stream and rivers downstream of the heap leach operation and containment dam.	1998	Project management and execution including field investigation, hydrological cyanide modelling.
Amanzi Joint Venture: Metago were appointed by the project leaders, JCI Projects (Pty) Ltd to conduct the environmental impact assessment for this project	1998	This involved the co-ordination of studies and development of an investigation and modelling technique to predict the impact that the mines will have once the water levels start to recover within the mining basins. The study addresses a number of key issues including the prediction of the mine water quality during and after re-flooding, the effect of the recovery of levels on the development of sinkholes, dolomite aquifers, township services, wetlands and surface water quality as far as the Vaal Barrage. Alistair James is the project director with overall responsibility for the technical and EIA process issues.

Project	Date	Alistair's Role
Eastern Transvaal Consolidated Mines: Water, TDS and Arsenic Balance for New Consort Division (1998)	1998	Project management and execution. This project involved the identification of factors influencing the water balance, salt balance and arsenic balance and their influence of the Noordkaap River. Aspects which had a major impact on the arsenic load to the river were identified and opportunities for reducing the arsenic load identified at conceptual level of detail for various operating scenarios and stages during the mine life cycle.
Eastern Transvaal Consolidated Mines: Assessment of the impact of contaminant loads from the Segalla Tailings dam and the design of environmental protection measures and a contingency plan (1998).	1998	Project execution and authority liaison. This project involved detailed geohydrological investigations to determine aquifer parameters, geoghydrological modelling and detailed seepage analyses to predict the effectiveness of a range of candidate environmental protection measures. The mine were particularly concerned with the impact of the tailings dam on the arsenic loads in the river. Metago recommended plastic lining a portion of the tailings dam in the vicinity of the decant pond and the construction of additional under drains to intercept seepage and draw down the phreatic surface. Contingency plans included the design and installation of a series of scavenger wells and a water treatment facility. The plans were accepted by the relevant authorities.
Anglo Vaal, Nkomati Joint Venture – Main Tailings Dam (MMZ) and Rock Dump Pollution Control.	1997	Alistair James was the consultant responsible for sampling and laboratory testing (acid base accounting tests) for the prediction of the acid generating potential of the waster rock piles and tailings material for the proposed new tailings MMZ tailings dam and rock dump. The project involved the prediction of the acid generating potential of the various waste materials within the waste rock pile and the conceptual design of appropriate measures to deal with potential contamination from the waste facilities.
Durban Navigation Colliery (Durnacol) was threatened with prosecution as a result of continued discharge of contaminated water to neighbouring farm land and a tributary which feeds the Chelmsford Dam.	1997	Alistair conducted the review and advised Durnacol how to bring the operation of the waste facility in line with the current legal requirements and industry standards for similar operations.
Water Research Commission – The development of a method to predict the drainage characteristics from coarse sulphide-containing rock wastes	1996	While employed by Steffen, Roberson and Kirsten CE Inc, (SRK), Alistair James was responsible for the initial development of the model. After leaving SRK, SRK appointed Metago Environmental Engineers to complete the development of the model. Alistair James carried out the major portion of the work associated with this project.
Mining and Mineral Processing Residue Related Projects		
Glencore – Merafe Chrome Smelter – Clarifier Tailings dam Annual review	2014	Tailings dam expert. Annual review of the dam safety, capacity and environmental impact of the Boshoek smelter clarifier tailings storage facility.

Project	Date	Alistair's Role
Sibanye Gold- West Rand tailings retreatment project	2014-2015	Project reviewer for the tailings dams. South Africa
Gamsberg Zinc	2014	Project Director: PFS and DFS level design of the waste rock dump for the Gamsberg Zinc project. South Africa
Swakop Uranium	2013-2015	Detailed design and construction monitoring of the Husab Uranium Tailings dam and Ancillary works. Namibia
Gold One – Tailings Retreatment pre-feasibility Study	2013	Project Reviewer – Tailings disposal – PFS design of a regional tailings dam to store the residue from a gold, sulphur and uranium process plant located on the west Rand, South Africa.
Gold Fields- Tailings Retreatment Feasibility Study for Senet	2012	Project Director – retreatment of the Gold Fields Witwatersrand tailings dams for the recovery of Gold. Involved in the design of a new centralised tailings facility to receive retreated tailings. South Africa
Bulyanhulu Gold Mine – TSF Preliminary Design, detailed design and construction monitoring	2012-2015	Project Director- Preliminary design, detailed design and construction monitoring of a water dam and lined TSF with concurrent rehabilitation of the side slopes. Tanzania
Bulyanhulu Gold Mine – Review of the TSF4 Concept Design	2011	Project Director – Review of the water use, environmental impacts capital and operating costs of the proposed concept design and recommendations for future development. Tanzania
Anglo Gold Ashanti – Dam 4 Stability Review	2012	Project Director -Assessment of the stability of the Compartment 4 stability for Vaal Reefs complex. Design of remediation measures.
Swakop Uranium	2011	Concept design for the Husab Uranium tailings facility
Gold One- Pre Feasibility Study	2013	Project Director for the design of the TSF
Gold Fields Doornpoort TSF Detailed Design and Construction Monitoring	2009-2011	Project Director for the TSF
Golden Ridge - PFS	2011	Design of the waste rock dump for the Golden Ridge Project to mitigate potential environmental impacts. Project Director

Project	Date	Alistair's Role
Anglogold Ashanti- Review of the MWS tailings storage facility.	2011	Project director – the project focused on determining pre-feasibility level costs estimate to upgrade the allowable tonnage and transform the dam into one that would not give rise to long term environmental liability post closure.
Swakop Uranium- Husab Project – Tailings facility and waste rock facility design	2011	Alistair conducted the internal review of the geohydrological modelling, geochemical characterisation, leachate quantity, and quality prediction, and design of the facilities including slurry delivery, liner design and cover concept design.
Gold Fields South Deep Gold Mine – Dormant Tailings facilities – Design of temporary closure measures and plant stormwater management facilities	2011	Project Director
Metorex – Ruashi Sulphide Tailings Dam. Design of a tailings facility to accept sulphide tailings.	2011	Project Director and internal review
Anglogold Ashanti: Compartment 4 sinkhole Investigation and stability assessment	2011	Project Director and internal review
Gold Fields – Feasibility Design for the upgrade of the Doornpoort TSF from 220 ktpm to 330ktpm.	2011	Project Director and Professional Engineer responsible for the design of the tailings dam.
African Barrick Gold- Golden Ridge Feasibility Study- Waste rock Dump Design	2011	Design of the proposed waste rock dumps for the Golden Ridge Project in Tanzania. The waste rock dumps needed to mitigate the potential impact on arsenic on the surrounding environment. Consideration was given to a number of mitigation approaches, acting alone and in combination with each other in an attempt to mitigate the post closure impacts of the proposed waste rock dumps. Mitigation measures that were considered included a blast curtain around the dump, liners, covers, chemical barrier using barium, and a salt sink using the pit lakes. None of the above measures could be proven to work sufficiently and the project was shelved by BArrick due to the risk of As contamination.
Gold Fields – Doornpoort TSF – design and construction of the Doornpoort tailings dam and associated 1 000 000m^3 return water dam for 220ktpm.	2011	Project Director and Professional Engineer responsible for the design of the tailings dam.
Development of a Guideline for the design of mine residue disposal facilities for the Impala Group.	2011	Author of the guideline document. The guideline focused on the process of designing for closure to avoid long term excessive liability and legacy issues typically associated with tailings facilities.
Gold Fields HTO Project. Feasibility study phases 1 and 2.	2010	Project Director and Professional Engineer responsible for the design of a tailings dam to accept reprocessed tailings at a rate of 2200ktpm arising from the re-processing of the Witwatersrand Gold tailings dams. The project focused on designing the tailings dam to minimise Gold Fields post closure liability. The project included a comprehensive site selection study, environmental impact assessment, closure design, slurry delivery, earthworks, storm and

Project	Date	Alistair's Role
		process water management facility design, decant towers and cover design.
South Deep Gold Mine - Doornpoort Tailings Dam Construction.	2010	The project involved the construction monitoring for the construction of the Doornpoort Tailings dam. Alistair James was the Director responsible for the tailings dam aspects of the project. The project also included licensing of the return water dam as a category II dam in terms of the Regulators dam safety regulations.
Gold Fields – Centralised tailings storage facility for Gold Fields Witwatersrand operations. Feasibility study for the design of a new tailings facility and associated infrastructure.	2010	Project Director and Professional Engineer responsible for the design of the tailings dam.
Hernic Bokfontein waste facility investigation and concept design of waste and water management facilities including the slag facility, slurry facilities and pollution control dams.	2009	Project Director – geotechnical and geochemical characterisation of the process wastes, site selection, water balance, geotechnical site investigation, pre-feasibility design, closure cost estimate.
Tharisa Platinum Mine – Conceptual design of water management and mine waste facilities	2008	Project Director
Keaton Energy – Vanggatfontein Coal Project- Preliminary design of water and waste management facilities. Characterisation of mining wastes	2007	Project Director
SA Chrome and Alloys Boskoek Smelter Plant: Design of the clarifier slurry, plant storm water and slag waste facilities.	2007	Project Director and Professional Engineer responsible for the design of the facilities.
Hatch Africa- Nkomati Expansion Project - Waste Rock Dump Concept Design	2007	Project Director- The project has been developed in a pristine area requiring special measures to be incorporated into the design of the waste rock dumps to prevent unacceptable long term visual impacts and impacts on the catchment water quality. Alistair's role was to develop impact mitigation measures that could be achieved in a practical and cost effective manner but that would result in acceptable impact levels.
Cape Gate- Development of an Integrated Waste Management Plan	2006	Project Director- Under the direction of Alistair James the following was achieved: • Compilation of a waste inventory that identified waste streams at the site; • Advise on management methods/disposal options for waste (Integrated Waste Management Plan); • Advise on potential future uses for waste materials in accordance with the principles of reduce, reuse and recycle; • Advise on control measures that could be used to manage contamination entering the

Project	Date	Alistair's Role
		site. through infrastructure that is shared with neighbouring properties (e.g. surface water drainage); • Identify international conventions such as the Kyoto Protocol and Carbon Emission Trading that could be applicable to the site; and • Identify alternative options to specific processes at the site such as the recharging of acids, use of asbestos materials as wiping pads and water recycling
Impala platinum Limited-Development of a Code of Practise for Mine Residue Facilities	2005	Project Director
Camelot Project Tailings Dam and Return Water Dam: Metago Environmental Engineers were appointed by ECMP who in turn were appointed by Eastern Transvaal Mining Company on a turnkey basis to design and construct the tailings dam,	1999	Alistair James was the director responsible for the project. Under Alistair's direction, Metago carried out the geohydrological investigation, hydrological investigation for sizing of the return water dam etc, geotechnical investigation, and seepage and slope stability analyses associated with the project.
ECMP/Eastern Transvaal Consolidated Mines (New Consort Division) Metago were appointed by ECMP to carry out the investigations and design of a tailings dam for 60 000 tonnes per month	1997-1998	Alistair James was the project director responsible for all environmental investigations and the geotechnical and hydrological design and investigation of the dam.
JCI: Ruashi Etoile Feasibility Study (1997/8): Metago were appointed to conduct the environmental and geotechnical aspects of the feasibility study for the development of a copper mine in the Democratic Republic of Congo.	1997-1998	Alistair James gave specialist input of the sitting, design and proposed environmental mitigation for the mine and related infrastructure.
Goldfields Coal Division: New Clydesdale Colliery Discard and Slurry Disposal (1997/8) : Metago were appointed to conduct the site selection, conceptual design, detailed design and EMPR amendment for a new discard dump at New Clydesdale Colliery	1997-1998	Alistair James was the Project Manager and gave specialist input to the technical aspect of the projects and coordination and direction of sub consultants.
Natal Ammonium Colliery Discard Dump Rehabilitation	1997	Responsible for the investigation and design work associated with the rehabilitation of the dump.

Project	Date	Alistair's Role
Iscor, Hlobane Colliery – Contamination due to the main discard dump	1996	Project management and execution. . This project involved an assessment of opportunities for the reduction of contaminant loads to surface waters, and the design of a seepage collection and passive treatment system to neutralise acidic drainage and remove metals from drainage water, to reduce the impact of ongoing seepage from the dump on the water quality and waste load in the Nkongolwana River. The proposed facility included a seepage cut-off and collective system. Alkaline limestone drains, aerobic oxidation ponds and anaerobic ponds. Metago were appointed by SRK to carry out the conceptual design and detailed of the seepage collection system.
Mineral Processing and Mine Waste and Water Management. SA Chrome and Alloys Chrome Mine: Specialist investigation of the water management system at the Chrome mine and review of tailings disposal facilities.	1996	Project management and execution.
Nkomati Joint Venture Project (1996) Massifs Sulphide Problem: Metago Environmental Engineers were appointed by ECMP, who in turn were appointed by AVMIN on a turnkey basis to design and construct the tailings dam.	1996	Alistair James was the director responsible for this project. Under Alistair's direction, Metago were responsible for all investigation work associated with the design and construct the tailings dam and return water including geohydrological investigation work, seepage analyses, slope stability assessment, hydrological and structural design.
Rondebult Colliery – Conceptual and Detailed Design of the Coast Slurry Ponds for Rondebult Mine	1996	Project Director and Professional Engineer responsible for the project.
Gold Fields West Driefontein Gold Mine, detailed stability investigation does dam 3A The stability investigation involved the determination of soil strength parameters using a piezometer probe.	1996	Alistair James was the Director responsible for the project and carried out a major portion of the investigation and design work. A finite element seepage analysis programme was used to determine the location of the phreatic surface; this was calibrated using the piezometer probe results. The programme PCSTABL5M was used to establish the probability of failure of the slope. Remedial measures were designed to reduce the risk of a slope failure to an acceptable level.
Anglo Vaal, Nkomati Joint Venture – Massive Sulphide Body (MSB) tailings dam design	1996	Project management and execution. The MSB tailings dam for the disposal of sulphide-rich tailings posed a significant potential risk to the quality of the pristine surface and ground water in the area. The investigation involved the evaluation of a range of alternative AMD control measures to select the optimal combination of measures on the basis of economics, reliability and effectiveness. Alistair James provided technical input for laboratory and field test work and design of the tailings dam, liner systems, dry cover and water management system for the tailings and return water dam.

Project	**Date**	**Alistair's Role**
Heritage Colliery Discard Dump Failure (1996-Present): In December 1995, a major slope failure developed on the main discard dump at Heritage Colliery. The discard dump was located adjacent to the Richards Bay railway line and therefore posed a significant risk to the railway line. Metago Environmental Engineers were appointed to investigate the cause of failure and proposed suitable remedial measures.	1996	Alistair James was the Director responsible for the project. This project involved a site investigation to ascertain the cause and nature of the slope failure, laboratory testing to estimate peak and seepage analysis using a finite element analysis programme, and detailed design of the proposed remedial measures. The remedial measures included the design of a soil replacement system to replace a portion of the weak clayed soil at the toe of the discard dump with a stronger granular discard material and the construction of a sub-soil drainage system and discard buttress.
Makonjwaan Imperial Mining Company – Heap leach pad geotechnical design. This involved the construction of a heap leach pad in the final void of an opencast mine. The design had to take cognisance of significant differential settlements which were predicted to be in the region of 0,6m.	1995	Alistair James was the Director responsible for the project and carried out the bulk of the analysis work. The differential settlements required that special precautions be taken in the design of the liner system and leachate collection system to maintain the integrity of the heap leach operation system to maintain the integrity of the heap leach operating throughout the mine life and after closure.
Makonjwaan Imperial Mining Company – Makonjwaan tailings dam, preliminary stability investigation	1995	Project Director and professional engineer responsible for the assessment.
Iscor, Hlobane Colliery – acid rock drainage assessment, (1994): Hlobane colliery needed to identify the main contributors to the waste load from the mine and identify the most cost effective method to reduce the waste load to rivers affected by the mining operation, both during the mining operation and after closure. Sources of contamination included several discard dumps underground mining and opencast mining areas, slurry dams, pollution control dams and the plant area.	1994	Alistair James developed a salt balance for the mine based on the current situation and the predicted situation closure. A range of mine drainage control measures were evaluated at a feasibility level, to identify controls or combinations of control measures which could be implemented to assist the mine in reaching the waste load allocation target set by the Department of Water Affairs and Forestry. The salt balance was based on a series of simple drainage prediction models which included factors such as the size or surface area contributing to contamination, the rate of production of contaminants and the rate of flushing of contaminants.
National River Authority (NRA), Wales – acid rock drainage associated with re-flooding of old coal mines, (1994)	1994	Alistair developed a probabilistic risk-based evaluation technique to assist the NRA to select the most appropriate control measures to reduce the level of contamination arising from re-flooded coal mines in Wales. The method incorporated factors such as the benefit, reliability and cost of control measures, and the uncertainty associated with each of these parameters.
Ronneburg Uranium Mine, Wismut, East Germany	1993	Project Engineer. Alistair James was involved in the evaluation of alternative control measures to reduce the impact of acid rock drainage from a number of acid generating sources at the mine.

Project	Date	Alistair's Role
Impala Platinum Refineries Springs – Tailings dam safety and construction of new runoff collection dams	1992	Alistair James was the project leader responsible for the design, preparation of tender documents, tender adjudication and construction contract management for a series of remedial measures to the refineries effluent disposal facilities. This contract involved: The construction of two HDPE lined effluent collection ponds, a series of pipe lines, lined canals cut-off trenches and bund walls. The construction of various remedial measures to improve the safety of tailings dam used as an evaporative surface for the refinery effluent.
Rand Mines, Umgala Colliery – Integrated coal discard and slurry disposal facility	1992	Alistair James was the project manager and provided major technical input for the design of an integrated discard and slurry disposal system at Umgala Colliery. This new method of disposal, developed in conjunction with Rand Mines Limited, was considered advantageous from the point of view of minimising the potential for acid rock drainage and improving the potential for vegetation establishment. Alistair James provided technical input with regard to the geometric and geotechnical design, and the method of operation of the facility.
Trans Natal, Ermelo Coal Mine-Design of a co-disposal system for the disposal of course discards and fine coal slurry	1991	Alistair James was the project manager for the design of waste disposal facility. The project involved: design of rehabilitation measures for the existing coal discard dump to prevent spontaneous combustion and excessive erosion design of a new slurry pond including the slurry delivery system and decant system, embankment and subsoil drainage system design of the return water dam, spillway and decant system
JCI, Arthur Taylor Opencast Mine – Design and construction of a coal slurry disposal facility	1991	Alistair James was the project manager for the design of the tailings dam. This project included the following aspects: Conceptual evaluation of alternative disposal options, sizing, site selection and conceptual design Hydrogeolofical modelling using FLAC to design the under drainage system in such a way that contamination of the groundwater due to the tailings facility would be minimised. Design of the earthworks, slurry delivery system, return water system and seepage collection system.
Tselentis Mining, Heritage Section – Design and construction of Remedial measures to the coal slurry ponds: The slurry ponds had been constructed by dozing a basin and forming an uncompacted embankment. The embankment showed signs of failure.	1990	Alistair James assisted with the design and contract management for a series of subsoil drains and earth buttresses for the existing coal slurry ponds at the mine.
Prevention/ remediation of Chemically Contaminated Groundwater and Soils		

Project	Date	Alistair's Role
South Deep Gold Mine – Blast Curtain Trial	2014	Project Director. This project involved the development and testing of a 30m deep blasted curtain drain designed to capture and intercept polluted groundwater and prevent its long term migration to a nearby stream.
Fairview Mine – Barberton: Preparation of a remediation plan to mitigate the impacts associated with the historic disposal of As_2O_3 in the underground workings of an abandoned gold mine.	2002	Project management and execution.
Rossing Uranium Limited, Modelling of the geochemistry and hydrogeology of the Rossing tailings dam and surround environment: The project involved the integration of various experts including metallurgists; tailings dam experts, hydrogeologist's geochemists, geologists and process engineers	1996	Alistair James was requested by Rossing to act as the lead agent and technical consultant for the development of a systems model to enable factors affecting contamination from the Rossing tailings dam and their relationship to one another to be understood to identify opportunities to reduce losses and contamination of the environment.
Impala Platinum Limited, Mineral Processes, (MinPro), investigation of the nature and extent of ground water, surface water and soil contamination arising from the slag dump, and design of remedial measures. In addition to the slag generated by MinPro, a number of wastes containing acids and heavy metals were deposited on the slag dump over a period of some 15 years. MinPro were concerned that ongoing leaching may result in contamination of both surface and ground water.	1996	Alistair James was the project director and manager responsible for the investigation to assess the significance of contamination and design appropriate remedial measures. The investigation included: Finite elements seepage analyses to assess the temporal changes in the flow regimes within the slag dump. A ground water investigation involving a geophysical survey and the installation and monitoring of boreholes to assess the nature and extent of contamination in the vicinity of slag dump. Detailed design of seepage collection trench on the perimeter of the slag dump.
Bowman, Gilfillan, Hayman and Godfrey (BGHG), Chemrite Coatings Environmental Due Diligence Assessment. Metago were appointed by BGHG to investigate the nature and extent of potential ground water surface water contamination at the Chemrite Coatings factory in Midrand.	1996	Alistair James lead a multi-disciplinary investigation team which included a number of specialist consultants to investigate the site which was potentially contamination by paint raw materials and solvents including a range of hydrocarbons used the factory. The investigation included soil sampling and testing, a soil vapour survey, underground solvent storage tank pressure testing, a geophysical survey, borehole installation and monitoring. A conceptual design and conceptual cost estimate based on a prioritised implementation plan for the remedial measures were prepared. Alistair James was the Metago Member responsible for the investigation.

Project	Date	Alistair's Role
Polifin factory – Ground water and soil contamination investigation, This factory site comprised a number of factory units which have been operational for several decades. The factory was involved primarily with the manufacture of various plastics and cyanide	1994	Alistair James was the project manager for the fist phase of a remediation programme. This phase of the project involved the determination of the extent of contamination of some 20 contaminants including mercury and a variety of organic chemicals. An extensive soil and groundwater sampling and testing programme was implemented to assess the mobility of chemicals with respect to depth and distance from the source of contamination. A geographical information system was used to interrogate the spatial data and identify trends and correlations with respect to the various chemical contaminants.
Impala Platinum Refineries, springs – Ground water remediation Impala Platinum Refineries had disposed of refinery effluents onto the surface of an old disused gold tailings materials and into the underlying aquifers. These contaminants posed a threat to the aquatic environment in the adjacent Cowles dam on the Blesbokspruit.	1992	Project Engineer. This project involved the identification of the contaminant plumes, prediction of the rate and direction of movement, evaluation of a range of possible remedial measures and implementation of selected remedial measures.
Audit, Due Diligence, Competent Persons Reports, Independent Review, expert witness and risk Assessment		
Gold Fields	2013	Annual tailings dam independent review
Tharisa Platinum Mine– Equator Principles Audit	2011	Audit of the waste and water management facilities in terms of their conformance to the Equator Principles
Metorex – Kinsenda Project-Environmental Impact assessment.	2011	Alistair's role was that of internal reviewer with particular emphasis on the equator principles and scientific validity of studies and conclusions.
Anooraq Resources- Annual audit report regarding compliance to Equator Principles for Standard Chartered Bank.	2011	Auditor- Equator Principles compliance.
Coffey Mining- Boteti Mine – review of the Boteti Mine upgrade in terms of the design of the water and waste management facilities and conformance to the Equator Principles.	2011	Project Director/ internal review and provision of the waste facility and water management audit content.
Chemaf – Independent Technical Review – Democratic Republic of Congo	2010	Project reviewer, Equator Principles, Mine waste, other waste, water management, permitting and social impact.
ABSA Capital – Independent review of the design of a gold/uranium tailings dam in the Klerksdorp area prepared for Coffey Mining.	2010	Independent reviewer of the design of the tailings dam with particular focus on the evaluation of the impacts from the tailings dam and the design of impact mitigation measures.
Competent Persons report – Anooraq Resources. Client- Coffey Mining	2009	Prepared the environmental, water management, mine waste, other waste, permitting aspects of the report. .

Project	Date	Alistair's Role
Munali Copper Mine Review for Barclays Capital on behalf of RSG Global	2008	Reviewed the design of the tailings dam, water management facilities, environmental risks, permitting, closure liability, capital and operating costs associated with the above.
Ruashi Mine Equator Principles Audit	2008	Internal review of audit report.
Blue Ridge technical audit for RSG Global of financier.	2008	Reviewed the design of the tailings dam, water management facilities, environmental risks, permitting, closure liability, capital and operating costs associated with the above.
Western Cape Landfill Audits-Department of Environment Affairs and Development Planning. This project involved the audit of 71 landfills, waste transfer stations and waste processing facilities in the Western Cape.	2007	Auditor and overall project internal reviewer
Kamoto Review – appointed by Coffey Mining.	2007	Reviewed the design of the tailings dam, water management facilities, environmental risks, permitting, closure liability, capital and operating costs associated with the above.
Lebowa Platinum Review on behalf of RSG Global for purchaser	2007	Reviewed the design of the tailings dam, water management facilities, environmental risks, permitting, closure liability, capital and operating costs associated with the above.
Ilanga Colliery Review on behalf of RSG Global for purchaser	2006	Conducted a technical review of Ilanga's operations looking at the environmental, waste, water, permitting aspects.
Atomaer Due Diligence. . The project was initiated by Atomaer who sought to re-mine existing slimes dams and sand dumps to recover the residual gold content. The waste was then to be deposited into the redundant West Wits open pit which was to be engineered so as not to give rise to negative environmental impacts. The land beneath the existing waste dumps could then be reclaimed for other purposes.	2005	Project reviewer for the Due Diligence. Under the direction of Alistair, Metago were contracted to carry out a due diligence/ review of the Mogale/Durban Roodepoort Deep (DRD) mining operation based in Krugersdorp, Gauteng, South Africa
Due Diligence on Ocon Brick Manufacturing (Pty) Ltd for Bowman Gilfillan prior to the purchase by Murray and Roberts.	2005	Investigate and document environmental issues that could be financially material to an offer to purchase Ocon as part of a due diligence review conducted by Bowman Gilfillan.
Northern Landfill Review: Koponela Community Association. The Johannesburg Metropolitan Council planned to develop a new landfill near the residential township of Diepsloot north of Johannesburg. Metago was appointed by the Koponela Community Association to conduct an independent review of the site selection, EIA and design of the landfill.	2005	Alistair conducted the independent review and communicated the findings to the public through a series of public meetings.

Project	Date	Alistair's Role
GEM Diamonds- Letseng Diamond Mine – Due Diligence	2005	Alistair James prepared the mine waste, water management, closure liability and permitting aspects of the due diligence.
RSG Global: Bogasu / Prestea / Wassa gold mines – Golden Star Operations in Ghana. Due diligence for credit facility covering geotechnical, hydrological, waste, water and environmental issues.	2005	Alistair conducted the due diligence for the aspects mentioned.
Environmental Due Diligence on a number of GRIEF sites on behalf of Bowman Gilfillan	2004	Safety, health and environmental due diligence conducted under the direction of Alistair James. Alistair James completed the environmental aspects of the DD.
Standard Corporate and Merchant Bank – Review of liabilities associated with the petrochemical contamination of a property development site in Pretoria.	2002	Independent Reviewer to advise the client concerning the work undertaken by the construction contractor and the residual liabilities related to the post construction situation.
SA Ferrochrome Boshoek Smelter EIA: Specialist – waste and water management	2002	Concept design for all the waste and water management facilities including waste geotechnical and geochemical characterisation, water balances and conceptual design of stormwater management and process waste facilities.
Due Diligence Columbus Stainless Steel: Conducted due diligence assessment for Columbus Stainless Steel on beheld of Acerinox of Spain	2001	Due Diligence. Focus area were minerals processing waste, effluent and storm water management.
SAD Operations for Heintz USA: Due diligence assessment of SAD operations in South Africa involving the environmental due diligence of several fruit and fruit product operations.	2001	Due Diligence. Technical aspects of the due diligence including water management, process, hazardous and general waste management, legal compliance, permitting.
Gold Fields : Development of procedures for Mine Closure to satisfy Sarbanes Oxley requirements.	2001	Developed the procedures to meet the requirements of listed companies that are required to adhere to the Sarbanes Oxley requirements.
Environmental Due Diligence of Columbus Stainless Steel's Middelburg Plant for Acerinox on behalf of Bowman Gilfillan Hayman & Godfrey.	2001	Technical aspects of the due diligence including water management, process, hazardous and general waste management, legal compliance, permitting.
Cynergy Global Power – Cottleslow Gas Works: Environmental liability assessment for the Cottesloe gas works which had been contaminated with various hydrocarbon and metal contaminants including BETX, PAH"s and metals such as.	2000	Project management and execution. Alistair was responsible for the preparation of a remedial action plan to form part of the sale and purchase agreement which committed the purchaser to certain remediation activities.
Kahama Mining Corporation: Review of waste disposal operations at Bulyanhulu Gold Project, Tanzania. Preliminary design of landfill.	1999	Project management and execution.

Project	Date	Alistair's Role
Afrikander Leases Environmental Liability Assessment. Metago were appointed by Majestic Resources Limited to conduct an environmental liability assessment on their behalf to identify potential environmental liabilities associated with Afrikander Leases property which they had an option to purchase.	1997	Independent Reviewer
Management Systems		
Development of the quality management system and procedures for Metago	2009	Project Director. Metago was awarded ISO 9000 accrediation in 2009
ETC Fairview and Sheba Gold Mines: Metago was appointed to implement an Environmental Management System for ETC at two of their mines. The system was developed in-house and follows that of ISO 14001.	2000	Alistair James was the Project Director.
Environmental Management Plans: Several mines including Rondebult Colliery, Natal Ammonium, Hlobane Colliery, Tselentis Mine, Barbrook Gold Mine, Chrome Resources, Hernic Chrome and Heritage Colliery.	1998	Alistair James has been involved as a technical specialist in the fields of surface water hydrology, groundwater management, mine drainage water quality and waste disposal for the preparation and assistance with implementation of a number of Environmental Management Plans.
Afrikander Leases Environmental Liability AssessmentMetago were appointed by Majestic Resources Limited to conduct an environmental liability assessment on their behalf to identify potential environmental liabilities associated with Afrikander Leases property which they had an option to purchase.	1997	Independent Reviewer
Anglo Vaal, Prieska Mine Closure costs. Metago were appointed to assess the cost, environmental impacts and reliability of a range of closure strategies for the tailings dam at Prieka Copper Mine. The remote nature of this mine made ongoing maintenance of the tailings dam problematic. Alternative closure strategies to reduce the frequency of ongoing maintenance were investigated and coasted.	1996	Alistair James provided specialist technical input on water quality management and the long term management and maintenance requirements due to contamination arising from infiltration, dusting runoff.

Project	Date	Alistair's Role
Fleurhof Civil Association (FCA), Environmental Management Plan Report (EMPR) and tailings dam design review. Metago were appointed by the FCA to provide an independent professional review of the design of the proposed CMR tailings dams and associated EMPR.	1995	Alistair James provided specialist technical input on aspects hydrology, acid rock drainage and geotechnical engineering.
Gold Fields of South Africa Limited – Evaluation of the environmental liability associated with Tarkwa Mine, Ghana: This project carried out on behalf of Gold fields of South Africa Limited and the World Bank, was concerned with the identification aspects of the Tarkwa Mine operation which fell short of internationally accepted environmental standards, and secondly, the assessment of the costs associated with the remediation of the environmental standards.	1994	Alistair James was involved as a team member in the first phase and as project leader for the second phase. The work involved the evaluation of a broad range of environmental aspects including clean and dirty water management, water supply and sanitation for mine workers, tailings dam safety and operation, refuse disposal, rehabilitation of the tailings dam and opencast mine and the demolition of dis-used infrastructure.
Impala Platinum Limited: Preparation of a closure plan for four old general waste sites previously operated by impala including site investigation and design of closure measures.	1998	Project management and execution.
Risk Assessment		
Alexander Forbes- Evaluation of the environmental liability of a copper mine in the Northern Cape using probabilistic financial modelling	2009	Project management and execution – development of a probabilistic financial liability assessment model.
Cape Gate (Pty) Ltd represented by Deneys Reitz Attorneys. Case concerning manufacture and use of bricks using slag materials derived from Cape Gate.	2004	Advisor to Cape Gate on environmental risks and expert witness in the case against Cape Gate.
CSIR – Assessment of the impacts of the proposed Khan Aquifer Recharge Scheme (KARS) on the environment downstream of Rossing Uranium Mine, Namibia..	1995	Alistair developed a mathematical model to simulate the behaviour of the Swakop and Khan River systems, including flood hydrogeology of the alluvial aquifers, recharge by flood waters, evapotranspiration from the alluvial aquifer and changes in the alluvial aquifer caused by salt and water gains and losses. This study formed part of the environmental impact assessment conducted by the CSIR for the Khan Aquifer Recharge Scheme. The study focused on the impacts of KARS on downstream water users, the effect of the proposed dam on dune movement and the effect of KARS on salinity in the alluvial aquifer.

Project	Date	Alistair's Role
Rossing Uranium Limited – Proposed Khan River Dam and Alluvial Aquifer Recharge Scheme, (1995), desert, Namibia to capture the occasional floodwaters of the Khan River and use this water to recharge the alluvial aquifers of the Khan River gorge, for the later extraction by the mine as a water supply	1995	A probabilistic financial model was developed to ascertain the potential return and financial risk associated with the proposed project. The model included aspects such as the frequency of flooding, magnitude of the flood, infrastructure costs and hydrogeology of the Aquifers in the vicinity of the well fields. Alistair James developed the model.
Gold Fields of South Africa Limited, West Drienfontein Gold Mine Dam 3A, South Africa: A probabilistic risk assessment was carried out for the gold tailings dam in which the risks associated with slope failure; overtopping, a piping failure and liquefaction were quantitatively evaluated. The investigation identified that the greatest risk of a flow slide arose fro the stability of a particular portion of the tailings dam embankment. Actions were identified which needed to be implemented to reduce the risk of slope failure to an acceptable level.	1995	Alistair James was the Metago Member responsible for the project and carried out a major portion of the analysis work.
Cholera Investigation for the Ministry of Local Government and Housing in Zambia. An outbreak of cholera in an urban environment on the Copper belt prompted the Government to appoint a consortium of Consulting Engineers to review status of the water supply and sanitation infrastructure in eighteen towns in Zambia. The project focused on reducing the risk of a cholera outbreak by identifying those aspects of the infrastructure / operation which gave rise to a high risk of an outbreak of water borne disease such as cholera.	1993	Alistair James was the project leader responsible for the development and implementation a unified risk-based approach, which was implemented by the consortium of four consulting engineering firms, to ensure that critical deficiencies in water supply and sanitation infrastructure and management systems were identified and equitably prioritised. A risk-based benefit / cost associated with the recommendations were assessed for each priority level.
Rand mines Limited – Umgala	1992	Alistair James provided the major technical input to

Project	Date	Alistair's Role
Colliery, pollution control dam lining failure investigation, (1991 – 1992, Kwazulu Natal, South Africa) : A fault-event tree approach was used to determine the most likely cause of failure of the lining at the Umgala pollution control dam and thereby apportion responsibility amongst the various parties involved. The dam was line with a 0,5mm HDPE lining which after a number of years had developed holes and tears along the welds, which rendered the lining ineffective from a pollution control point of view.		this investigation. The causes were evaluated using the fault-event tree approach. Using this approach, it was possible to show that the imitating cause of failure was the development of a significant number of burn holes in the liner due to uncontrolled veld burning. These holes enabled water to get behind the liner which resulted in erosion of the embankment due to wave action. . In assessing the liability for failure, a number of possible causes were postulated as the initiating or primary cause of failure. The continual erosion led to the change in the shape of the embankment beneath the liner which in turn placed the liner under excessive bi-directional stress. The excessive bi-directional stress led ultimately to failure along the joint welds.
Mine Closure		
Gold Fields (South Africa) – Assessment of the closure liability associated with Gold Fields Witwatersrand tailings dams.	2010	Development of a probabilistic model to assess the closure liability of all of the Witwatersrand tailings facilities
Karbochem – Industrial Waste Site Closure Liability Assessment	2010	Project management and execution. Probabilistic liability assessment of the closure cost. Identification and quantification of key closure risks.
Navacheb Closure Review	2009	Reviewer. Focus of the review was on the sustainability of the proposed closure measures for the waste rock dunmps, pits and tailings dam.
Xstrata Kroondal Mine Closure	2007	DME closure quantum assessment. Alistair assessed the risks and opportunities associated with the infrastructure and site from a long term land use development and closure perspective. Strategic opportunities to realise long term value after closure were identified.
Everest South Platinum Mine-closure cost estimate	2008	DME closure quantum assessment
Damang Gold Mine: Development of the closure plan and liability assessment for Gold Fields Ghana's Damang Mine	2005, 2008 & 2011	Project Director
Tarkwa Gold Mine: Development of the closure plan and liability assessment for Gold Fields Ghana's Tarkwa Mine	2006 & 2011	Project Director
BHP Billiton, Pering Mine, North West Province, South Africa, Assessment of the magnitude, extent and cost implications of residual environmental risks at the end of the mine. Part of the closure plan development.	2002	Project Director

Project	Date	Alistair's Role
BHP Billiton Limited: Preparation of a Closure Plan for Pering Mine. The decision by BHP Billiton to close Pering Mine resulted in the need to develop a concept closure plan and then a detailed closure plan within approximately 1 year. The detailed closure plan was implemented immediately following preparation of the plan.	2002-2006	Project Director. The closure plan required assessment of the long term impacts associated with the residual infrastructure at Pering Mine with particular focus on the impact of the pits, waste rock dumps and tailings facility on the groundwater and the impact of the fine grained tailings dam on ambient air quality in the surrounding area. Studies included detailed groundwater and contaminant transport modelling, air dispersion modelling and erosion studies using rainfall simulators and the geomorphological evolution model Siberia, all to evaluate the long term performance of the proposed tailings dam cover. Alistair provided overall direction to the project.

Publications:
A number of publications on the following topics:

- Risk-based environmental remediation
- Risk-based selection of lining requirements for waste sites
- Waste management
- Control options for mine drainage
- Prediction of water quality fro sulphide-containing wasters
- Mine closure and re-watering
- Tailings dam rehabilitation

Justin Walls
Technical Discipline Manager:
Mine Waste Engineering

Curriculum Vitae

Qualifications

BSc (Eng)	2006	Civil (Environmental) Engineer
GDE	2012	Graduate Diploma in Engineering (Civil)
Professional Registration	2013	Pr. Eng. (Professional engineer registered in the Republic of South Africa) No. 20130027

Affiliations

LaRSSA	Member of the Land Rehabilitation Society of Southern Africa
GIGSA	Member of the Geosynthetics Interest Group of South Africa

Key Areas of Expertise

Key areas of Justin's expertise are summarised below.

Project management	Mine waste facilities, especially tailings dams, and related components
Design	Tailings dam and related components
Monitoring	Quarterly and ad hoc inspections of mine waste facilities
Review	Review of mine waste facilities at design and operational stages
Erosion modelling	Investigation into the influence of slope geometry and cover design on erosion rates
Hydrological modelling	Water balances and flood line determination
Hydraulic and geotechnical analyses	Modelling and analysis of various hydraulic and geotechnical aspects

Summary of Experience and Capability

Justin is an engineer with SLR (previously known as Metago Environmental Engineers) with some 9 years of experience in mine waste engineering, both in design and project management capacities.

Justin has been involved with several tailing storage facility designs, predominantly in the gold mining sector.

In addition to the design and management aspects, he is involved in various forms of modelling (erosion, hydrological, etc.) as well as closure and rehabilitation.

Recent Project Experience

Key aspects of Justin's recent project experience are summarised below.

Project	Location	Date	Justin's Role
Preliminary design of a centralised tailings storage facility for re-mined historic tailings dams	Secunda, South Africa	2016	Project manager and design engineer
Monitoring of the Bulyanhulu gold tailings dam	Shinyanga, Tanzania	2016	Project manager and site inspections
High level design of a molten slag dump and bag house dust storage facility	Limpopo, South Africa	2016	Project manager
Stability and operational review of Acacia Mining's existing tailings dams	Tanzania	2016	Project manager and reviewer
Review of the existing Sadiola tailings dam as part of an expansion project	Sadiola, Mali	2015	Project manager
Design of a cover system for a large gold tailings dam	Gauteng, South Africa	2015	Design engineer
Design of a cover system for a landfill site	Durban, South Africa	2015	Design engineer
Monitoring of the Baobab platinum tailings dam	Limpopo, South Africa	2013 onwards	Project manager and site inspections
Construction of a lined tailings dam for the new Husab uranium mine	Erongo, Namibia	2013 to 2015	Project manager
Construction of a lined gold tailings dam for a Bulyanhulu gold mine	Shinyanga, Tanzania	2013 onwards	Project manager
Prefeasibility and detailed feasibility studies for the Gamsberg waste rock dump	Northern Cape, South Africa	2014	Project manager
Detailed design of a tailings dam for an existing gold mine	Shinyanga, Tanzania	2013	Project manager and design engineer
Prefeasibility study for a tailings dam at Nyanzaga	Shinyanga, Tanzania	2013	Project manager and design engineer
Prefeasibility study for converting the Ruashi TSF from oxide to sulphide gold tailings	Lumbumbashi DRC	2012	Project manager
Detailed design of a tailings dam and waste rock dump at the new Husab uranium mine	Erongo, Namibia	2012	Project manager and design engineer
Hydraulic design of a stepped energy dissipator for a storm water diversion	Twangiza, Tanzania	2012	Design engineer
Design review of the Bulyanhulu gold tailings dam	Shinyanga, Tanzania	2012	Project manager and reviewer
Monitoring of the South Deep Doornpoort gold tailings dam	Gauteng, South Africa	2011 onwards	Project manager and reviewer
Design of interim closure measures for the South Deep dormant tailings dams	Gauteng, South Africa	2011	Project manager and design engineer

Project	Location	Date	Justin's Role
Prefeasibility design and costing impacts of increasing the deposition rate on the recently constructed South Deep Doornpoort gold tailings dam	Gauteng, South Africa	2011	Project manager and design engineer
Prefeasibility design and costing of a waste rock dump, high hazard tailings facility and surface hydrology study at Golden Ridge	Shinyanga, Tanzania	2011	Project manager, design engineer and Goldsim modeller
Closure costing for a coal mine	Mpumalanga, South Africa	2011	Calculation of required financial provision
Review of a centralised tailings storage facility	Northwest Province, South Africa	2011	Review engineer
Construction of the new South Deep Doornpoort tailings dam	Gauteng, South Africa	2009	Site supervision
Detailed design of the new South Deep Doornpoort tailings dam	Gauteng, South Africa	2008	Design engineer

Publications

Walls, J. and James, A. (2009), 'A relook at the slope geometry of mine residue deposits in terms of erosion, soil formation, vegetation cover and water quality', International Mine Water Conference (IMWA), Pretoria.

Walls, J. (2014), 'Predicting erosion rates from mine waste facilities to assess the effects of sediment yields on downstream catchments', 5th International Mining and Industrial Waste Management Conference (IMIWMC), Rustenburg.

Cole, J., Walls, J. and Collins, R. (2014), 'Husab Tailings Storage Facility Containment Design', Geosynthetics Mining Solutions, Vancouver, Canada.

David Pillay
Technologist

Curriculum Vitae

Qualifications

PrTechniEng	Since 2014	Professionally Registered with ECSA
N.Dip	2009	Civil Engineering
BTech (Cum Laude)	2015	Civil Engineering

Key Areas of Expertise

Key areas of David's expertise are summarised below.

Engineering	Design, Trade-offs, Site Audits, BOQ, Reports.
Tailings – Monitoring, Risk Management, & Operations	Monitoring the risk status of tailings dams using a Hazzard Management system. Managing the risks of the tailings dams. Monitoring and supervising the Operations on a tailings dam.
Project Management	Project planning/scheduling, controlling and costing. Coordinating project staff and activities. Meeting critical project deadlines and milestones.
Drawing Office Management	Making sure the draughtsmen are supplied with all the necessary information in order to complete the drawings. Ensuring that the drawings are produced on time and to a certain level of quality.
Site Management	Providing services as a Civil Resident Engineer.
Quality Management	Ensuring compliance with the company's ISO9001: 2008 QMS system, in terms of the specific responsibilities & requirements in order to fully comply with internal and external QMS audits including Internal Project Closure.

Summary of Experience and Capability

David is a Technologist with SLR and is part of SLR's Mine Waste Engineering Team. David has over 5 years of experience within the Mining industry, involved in both underground and surface engineering projects within the industry. Some of the projects included Concept, Pre-Feasibility & Feasibility studies for clients such as Lonmin, Impala, Petra Diamonds and Anglo Platinum.

Prior to joining SLR in 2015, he worked for Read, Swatman & Voigt (SA) for over 3 years and previous to that, Fraser Alexander Tailings.

Recent Project Experience

Key aspects of David’s recent project experience are summarised below.

Project	**Date**	**David’s Role**
South Deep Doornpoort TSF	2015	Engineer
Newmont Ahafo TSF Wall Raise	2015	Engineer
Petra Diamonds Koffiefontein	2014	Project Engineer
Impala Platinum 1 Shaft	2014	Engineer

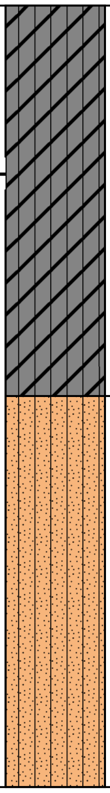
APPENDIX B: SOIL PROFILES

SIYANDA SLAG DUMP
GEOTECHNICAL INVESTIGATION

PROJECT No. 710.19057.00003

TEST PIT (STP 1)

EXCAVATOR	: BELL 315SJ TLB	DATE	: 12/05/1015
OPERATOR	: PIETER BURGER	POSITION	: X:
CONTRACTOR	:		: Y:
PROFILED BY	:	WEATHER	:
HOLE TYPE	:	HOLE NO	: TEST PIT (STP 1)

Depth in Meters	SAMPLE	GRAPHIC	DESCRIPTION
0	JWSS1 & JWSS2		Slightly Moist, Black, Firm to Stiff, Slickeslided and Micro-Shattered, Silty CLAY, Black Turf (0 - 1.5m)
1			
2			Slightly Moist to Moist, Orangey-Brown, Medium Dense increasing to Dense with depth, Intact, Gravelly Silty SAND with Minor Rock Fragments (minute traces of Ferricrete Nodules and increasing traces of Calcrete with increasing depth), Residual (1.5 - 3m)
3			Notes: 1) No machine refusal 2) No water encountered 3) Samples taken at: Bulk Sample (JWSS1 0 - 1.5m), (JWSS2 0 - 1.5m), (JWSS3 1.5 - 3.0m), (JWSS4 1.5 - 3.0m)
4			
5			

07-03-2015 C:\Documents and Settings\bnorman\Desktop\Siyanda\STP1.bor

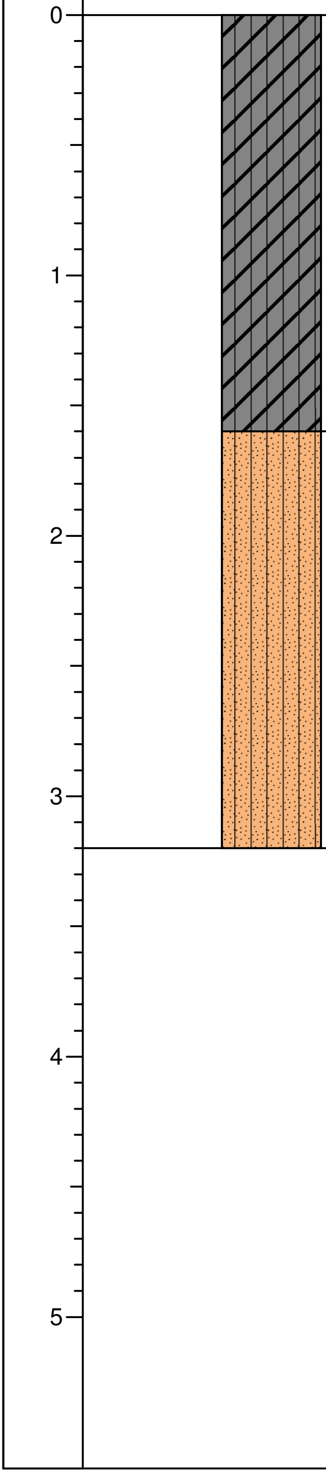
SIYANDA SLAG DUMP
GEOTECHNICAL INVESTIGATION

PROJECT No. 710.19057.00003

TEST PIT (STP 2)

EXCAVATOR	: BELL 315SJ TLB	DATE	: 12/05/1015
OPERATOR	: PIETER BURGER	POSITION	: X:
CONTRACTOR	:		: Y:
PROFILED BY	:	WEATHER	:
HOLE TYPE	:	HOLE NO	: TEST PIT (STP 2)

Depth in Meters	SAMPLE	GRAPHIC	DESCRIPTION



Slightly Moist, Black, Firm to Stiff, Slickeslided, Silty CLAY, Black Turf
(0 - 1.6m)

Slightly Moist to Moist, Orangey-Brown, Medium Dense increasing to Dense with depth, Intact, Gravelly Silty SAND with Rock Fragments and Ferricrete and Calcrete Nodules, Residual
(1.6 - 3.2m)

Notes:
1) No machine refusal
2) No water encountered
3) Some roots encountered (0 - 1.6m)

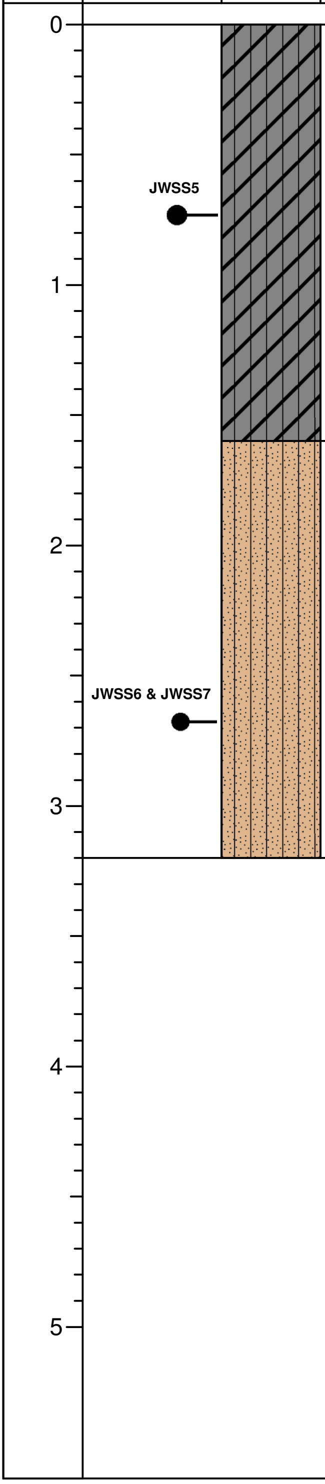
SIYANDA SLAG DUMP
GEOTECHNICAL INVESTIGATION

PROJECT No. 710.19057.00003

TEST PIT (STP 3)

EXCAVATOR	: BELL 315SJ TLB	DATE	: 12/05/1015
OPERATOR	: PIETER BURGER	POSITION	: X:
CONTRACTOR	:		: Y:
PROFILED BY	:	WEATHER	:
HOLE TYPE	:	HOLE NO	: TEST PIT (STP 3)

Depth in Meters | SAMPLE | GRAPHIC | DESCRIPTION



Slightly Moist, Black, Firm to Stiff, Slickeslided and Micro-Shattered, Silty CLAY, Black Turf
(0 - 1.6m)

Slightly Moist to Moist, Yellowish-Grey, Medium Dense increasing to Dense with depth, Intact, Gravelly Silty SAND with Minor Rock Fragments with traces of Ferricrete Nodules and increasing traces of Calcrete with increasing depth, Residual
(1.6 - 3.2m)

Notes:
1) No machine refusal
2) No water encountered
3) Some roots experienced (0 - 1.6m)
4) Samples taken at: Bulk Sample (JWSS5 0 - 1.5m), (JWSS6 1.6 - 3.2m), (JWSS7 1.6 - 3.2m)

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SIYANDA SLAG DUMP
GEOTECHNICAL INVESTIGATION

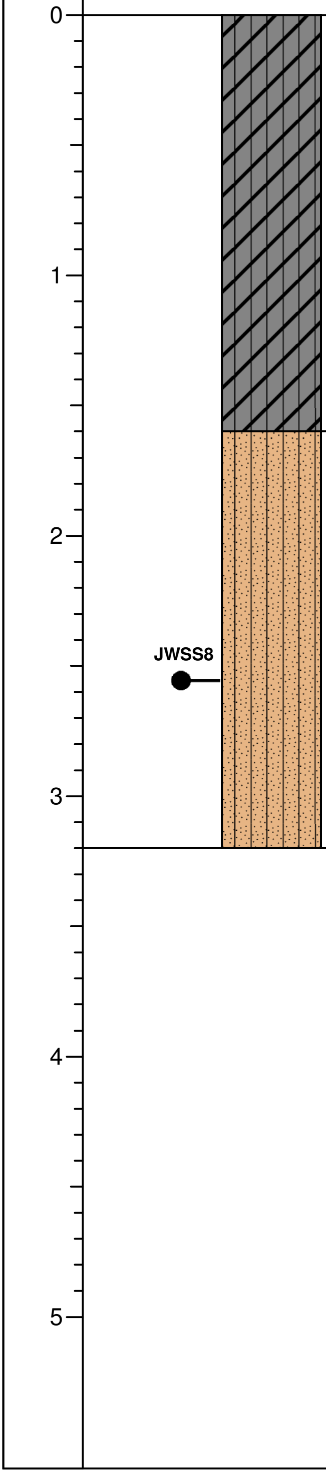
PROJECT No. 710.19057.00003

TEST PIT (STP 4)

EXCAVATOR : BELL 315SJ TLB
OPERATOR : PIETER BURGER
CONTRACTOR :
PROFILED BY :
HOLE TYPE :

DATE : 12/05/1015
POSITION : X:
: Y:
WEATHER :
HOLE NO : TEST PIT (STP 4)

Depth in Meters	SAMPLE	GRAPHIC	DESCRIPTION



Slightly Moist, Black, Firm to Stiff, Slickeslided and Micro-Shattered, Silty CLAY, Black Turf
(0 - 1.6m)

Slightly Moist, Orangey-Grey, Medium Dense increasing to Dense with depth,
Intact, Gravelly Silty SAND with some Rock Fragments Calcrete with minor Ferricrete Staining
and traces of Ferricrete Nodules, Residual
(1.6 - 3.2m)

Notes:
1) No machine refusal
2) No water encountered
3) Some roots experienced (0 - 1.6m)
4) Samples taken at: Bulk Sample (JWSS8 1.6 - 3.2m)

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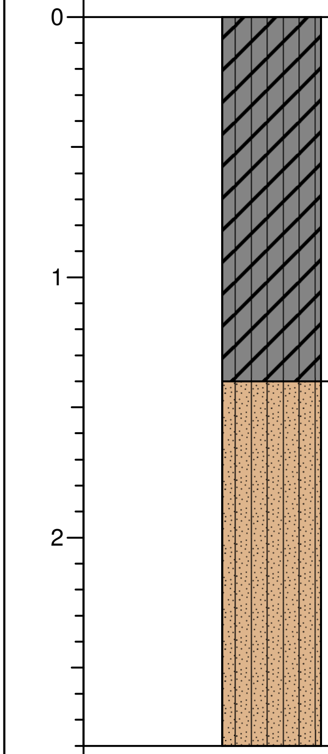
SIYANDA SLAG DUMP
GEOTECHNICAL INVESTIGATION

PROJECT No. 710.19057.00003

TEST PIT (STP 5)

EXCAVATOR	: BELL 315SJ TLB	DATE	: 12/05/1015
OPERATOR	: PIETER BURGER	POSITION	: X:
CONTRACTOR	:		: Y:
PROFILED BY	:	WEATHER	:
HOLE TYPE	:	HOLE NO	: TEST PIT (STP 5)

Depth in Meters	SAMPLE	GRAPHIC	DESCRIPTION
0		▨	Slightly Moist, Black, Firm to Stiff, Slickeslided and Micro-shattered, Silty CLAY, Black Turf (0 - 1.4m)
1.4		▒	Slightly Moist, Yellowish-Brown, Medium Dense increasing to Very Dense with depth, Intact, Gravelly SAND with some Silt containing Rock Fragments and some Calcrete, Residual (1.4 - 2.8m)



Notes:
1) Machine refusal
2) No water encountered
3) Some roots encountered (0 - 1.4m)

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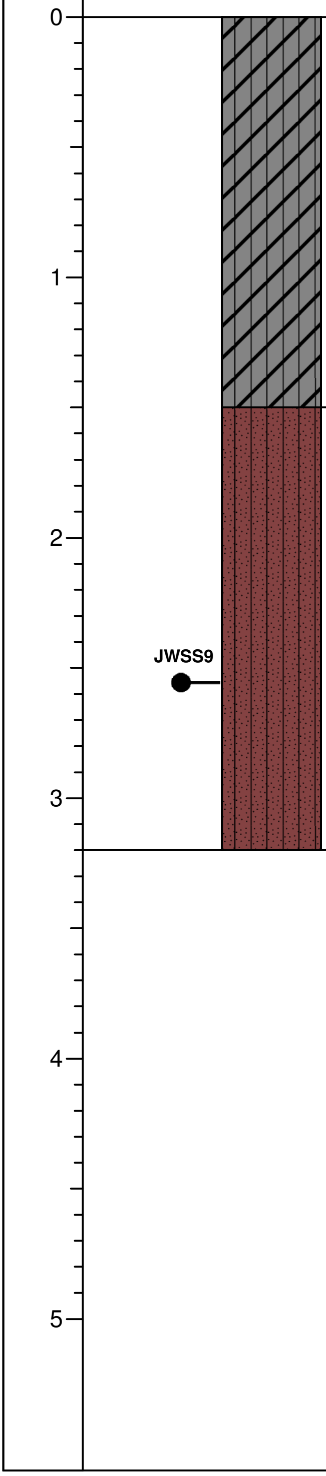
SIYANDA SLAG DUMP
GEOTECHNICAL INVESTIGATION

PROJECT No. 710.19057.00003

TEST PIT (STP 6)

EXCAVATOR	: BELL 315SJ TLB	DATE	: 12/05/1015
OPERATOR	: PIETER BURGER	POSITION	: X:
CONTRACTOR	:		: Y:
PROFILED BY	:	WEATHER	:
HOLE TYPE	:	HOLE NO	: TEST PIT (STP 6)

Depth in Meters	SAMPLE	GRAPHIC	DESCRIPTION



Slightly Moist, Black, Firm to Stiff, Slickeslided and Micro-Shattered, Silty CLAY, Black Turf
(0 - 1.5m)

Moist, Brown, Medium Dense increasing to Very Dense with depth,
ckickensided and Micro-shattered, Silty CLAY with some Gravel and
some Calcrete present, Residual
(1.5 - 3.2m)

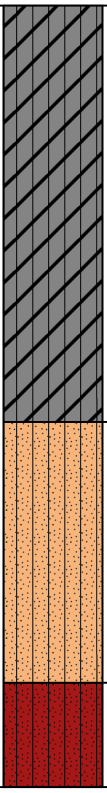
Notes:
1) No machine refusal
2) No water encountered
3) Some roots experienced (0 - 1.5m)
4) Samples taken at: Bulk Sample (JWSS9 1.5 - 3.2m)

SIYANDA SLAG DUMP
GEOTECHNICAL INVESTIGATION

PROJECT No. 710.19057.00003

TEST PIT (STP 7)

EXCAVATOR	: BELL 315SJ TLB	DATE	: 12/05/1015
OPERATOR	: PIETER BURGER	POSITION	: X:
CONTRACTOR	:		: Y:
PROFILED BY	:	WEATHER	:
HOLE TYPE	:	HOLE NO	: TEST PIT (STP 7)



Depth in Meters	SAMPLE	GRAPHIC	DESCRIPTION
0 1			Slightly Moist, Black, Firm to Stiff, Slickeslided and Micro-shattered, Silty CLAY, Black Turf (0 - 1.6m)
2			Slightly Moist to Moist, Orangey-Brown, Medium Dense increasing to Very Dense with depth, Intact, Silty SAND with some Gravel and Rock Fragments (Calcrete), Residual (1.6 - 2.6m)
3			Slightly Moist to Moist, Orange, Very Dense to Refusal, Intact, Silty SAND with some Gravel, Residual (2.6 - 3m)
4 5			Notes: 1) Machine refusal 2) No water encountered 3) Some roots encountered (0 - 1.6m)

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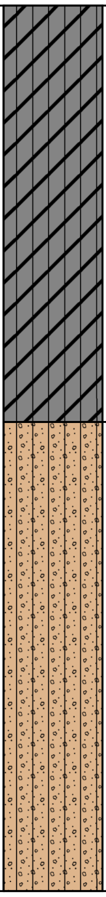
SIYANDA SLAG DUMP
GEOTECHNICAL INVESTIGATION

PROJECT No. 710.19057.00003

TEST PIT (STP 8)

EXCAVATOR	: BELL 315SJ TLB	DATE	: 12/05/1015
OPERATOR	: PIETER BURGER	POSITION	: X:
CONTRACTOR	:		: Y:
PROFILED BY	:	WEATHER	:
HOLE TYPE	:	HOLE NO	: TEST PIT (STP 8)

Depth in Meters	SAMPLE	GRAPHIC	DESCRIPTION
0			Slightly Moist, Black, Firm to Stiff, Slickeslided and Micro-shattered, Silty CLAY, Black Turf (0 - 1.6m)
1			
2			Moist, Yellowish-Grey, Medium Dense increasing to Dense with depth, Intact, Clayey Gravelly SILT with some Rock Fragments (Calcrete and some small Ferricrete), Residual (1.6 - 3.4m)
3			
4			Notes: 1) No machine refusal 2) No water encountered 3) Some roots encountered (0 - 1.6m)
5			

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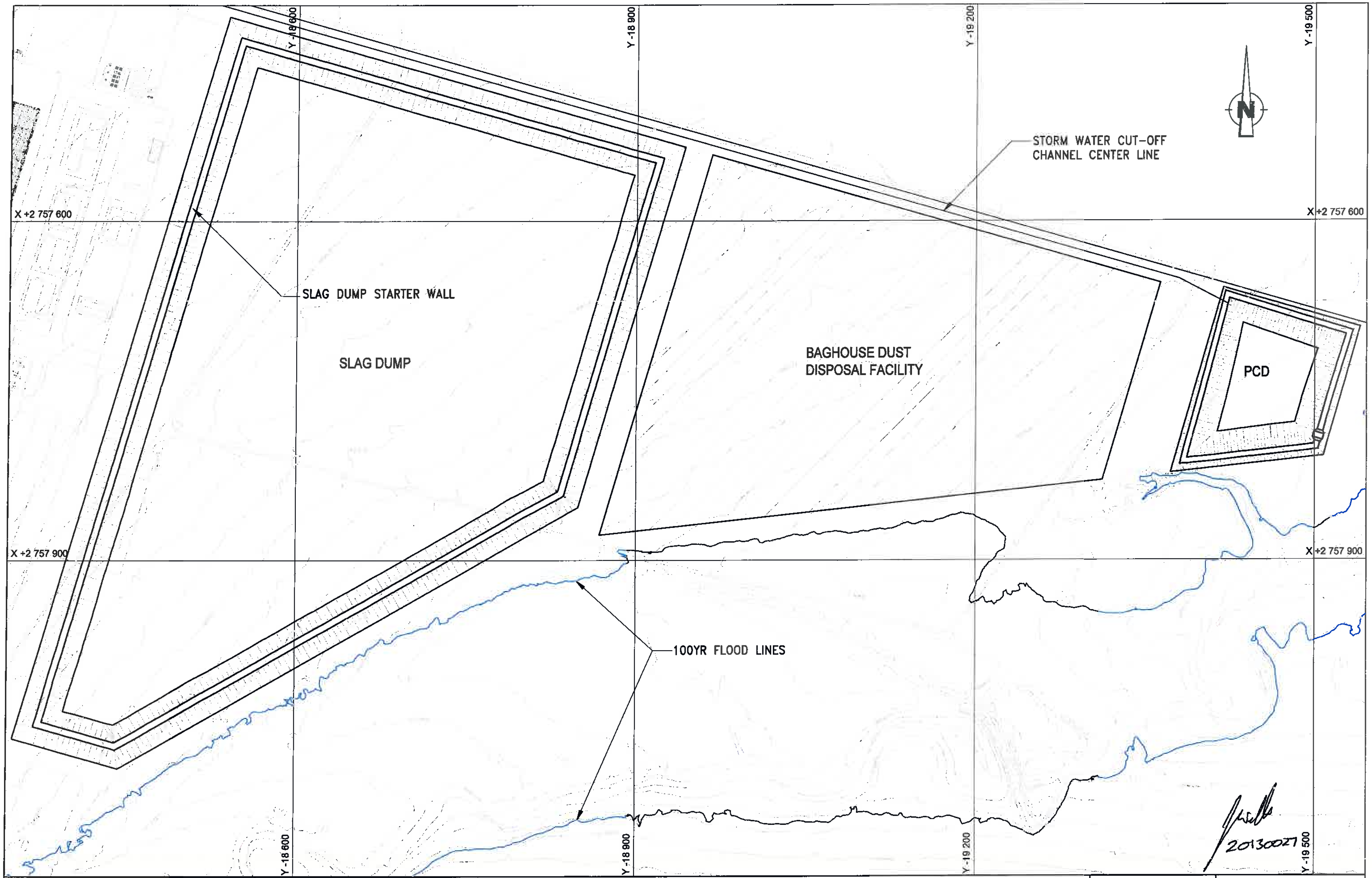
APPENDIX C: SOIL GEOTECHNICAL LAB RESULTS

TP No.	**STP01**	**STP01**	**STP03**	**STP03**	**STP04**	**STP07**
SS No.	**JWSS1**	**JWSS3**	**JWSS5**	**JWSS6**	**JWSS8**	**JWSS9**
Depth (m)	0 - 1.5m	1.5 - 3m	0 - 1.5m	1.6 - 3.2m	1.6 - 3.2m	1.5 - 3.2m
Particle Size (mm)	**% Passing by mass**					
75	100	100	100	100	100	100
63	100	100	100	100	100	100
53	100	100	100	100	100	100
37.5	100	100	100	100	100	100
26.5	100	100	100	100	100	100
19	100	100	100	100	100	100
13.2	100	95	100	100	100	93
4.75	100	72	100	88	91	89
2	99	66	98	71	69	86
0.425	97	61	94	46	37	80
0.075	87	53	79	26	18	66
0.06	85	52	77	25	15	65
0.04	81	50	73	23	12	64
0.02	77	47	69	19	10	60
0.006	72	43	60	15	7	56
0.002	66	39	56	12	6	50
Gravel %	1	34	2	29	31	14
Sand %	14	14	21	46	54	21
Silt %	19	13	21	13	9	15
Clay %	66	39	56	12	6	50
Liquid Limit (%)	69	73	68	48	46	71
Plasticity Index	38	37	35	25	21	36
Linear Shrinkage (%)	20	19.5	18.5	12.5	10.5	18.5
Overall Plasticity Index	37	23	33	12	8	29
Potential Expansiveness	Medium	Medium/ High	Medium/ High	Low/ Medium	Low	Medium/ High
Material Classification	**CH**	**MH**	**CH**	**SC**	**SC**	**MH**
Permeability (m/s)	7.29E-10	1.15E-09		3.40E-09	7.84E-08	2.71E-10
MDD (kg/m³)	1 350	1 372		1 669	1 956	
OMC (%)	27.8	24.6		19	14.6	

APPENDIX D: DRAWINGS



20130027

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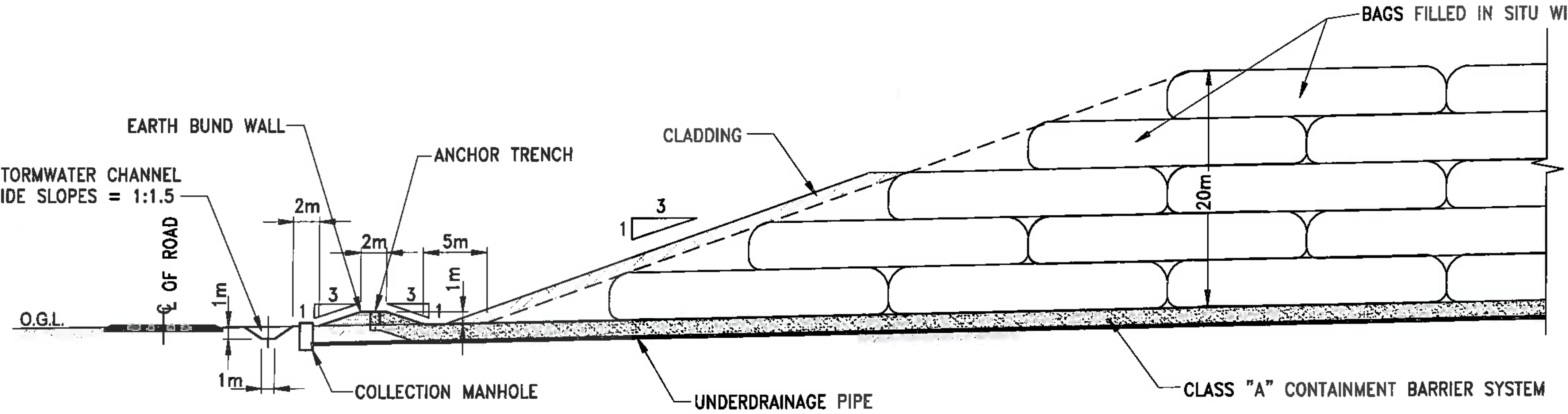
www.slrconsulting.com

SIYANDA FERROCHROME SMELTER

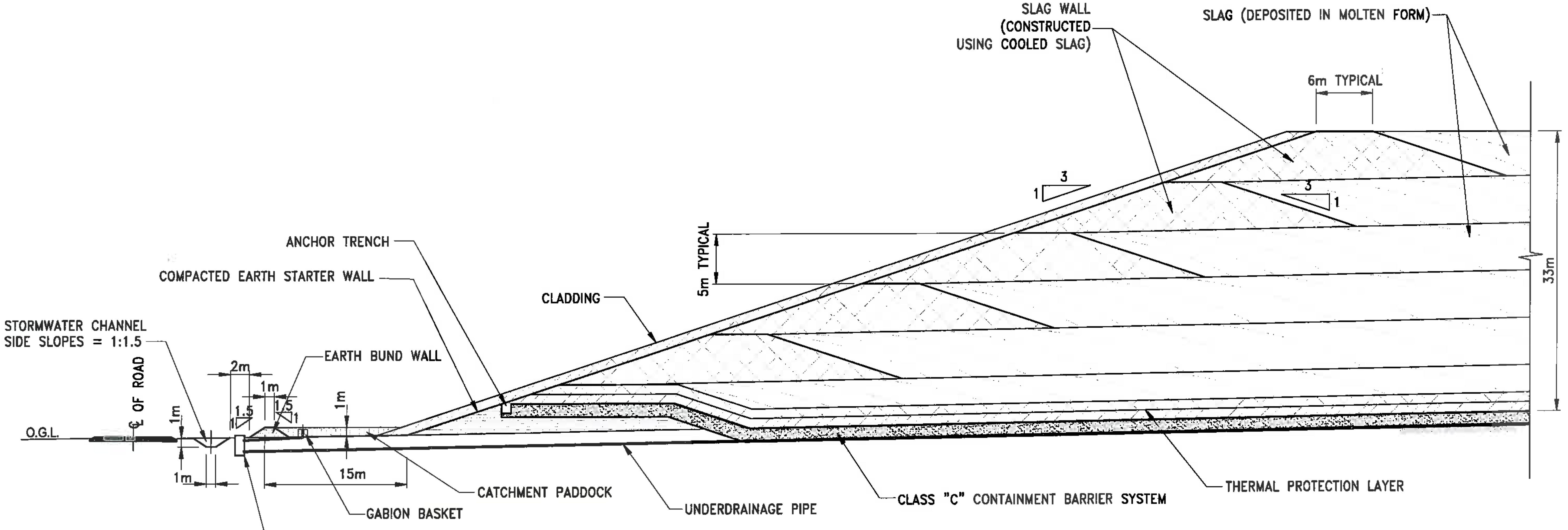
LAYOUT PLAN

Date : SEPT 2016
Scale : 1: 3000
Project No : 710.19057.00003
DRAWING 01



TYPICAL SECTION THROUGH BAGHOUSE DUST DISPOSAL FACILITY

N.T.S



TYPICAL SECTION THROUGH SLAG DUMP

N.T.S

20130027

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SIYANDA FERROCHROME SMELTER

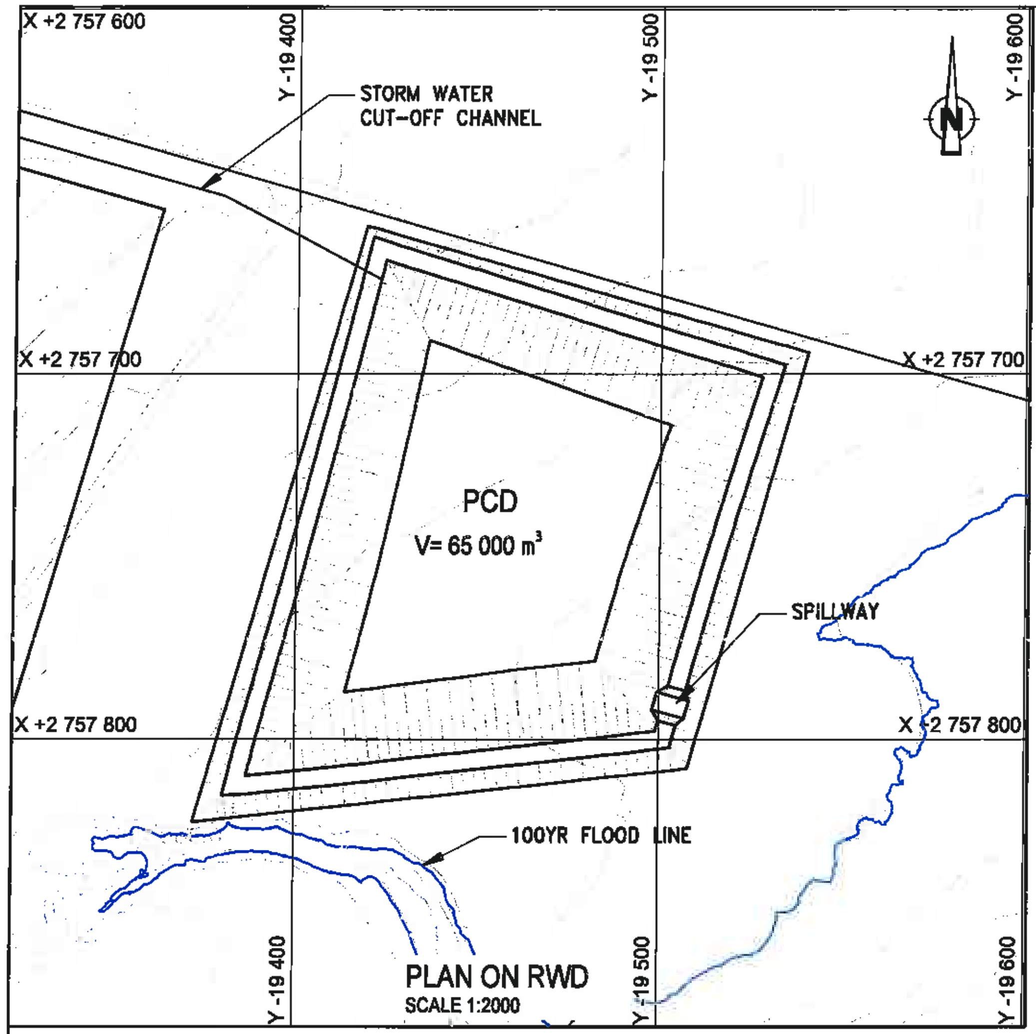
TYPICAL SECTIONS

Date : SEPT 2016

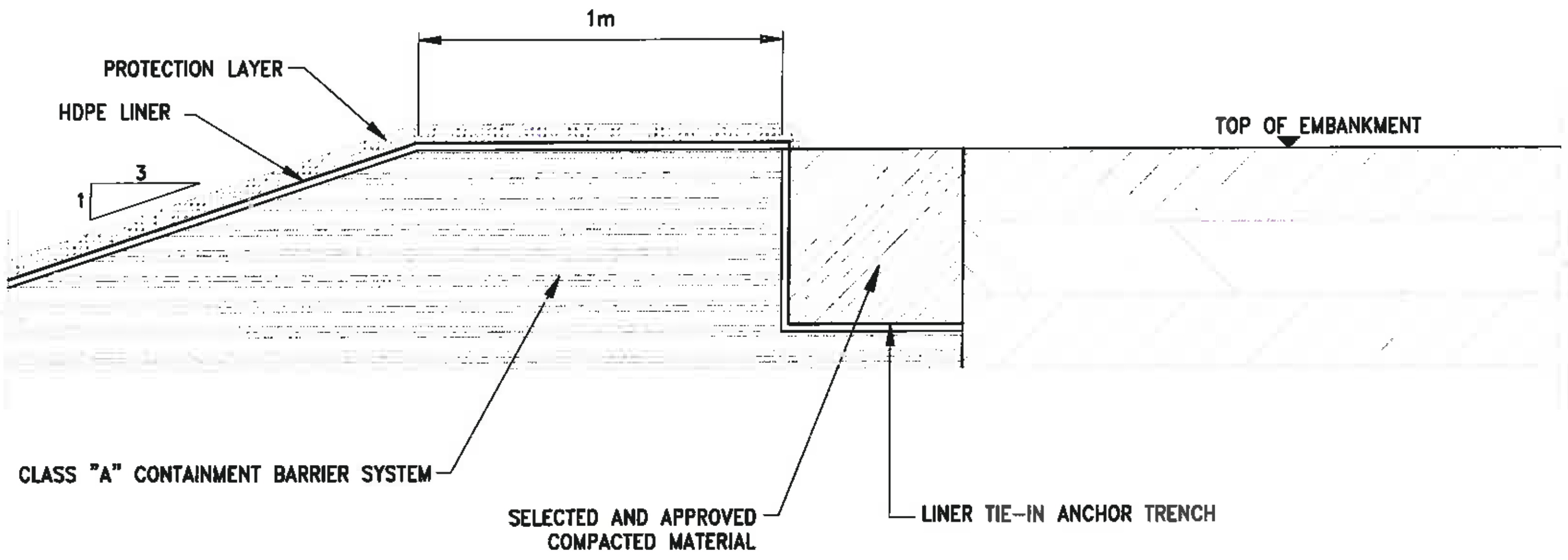
Scale : AS SHOWN

Project No :
710.19057.00003

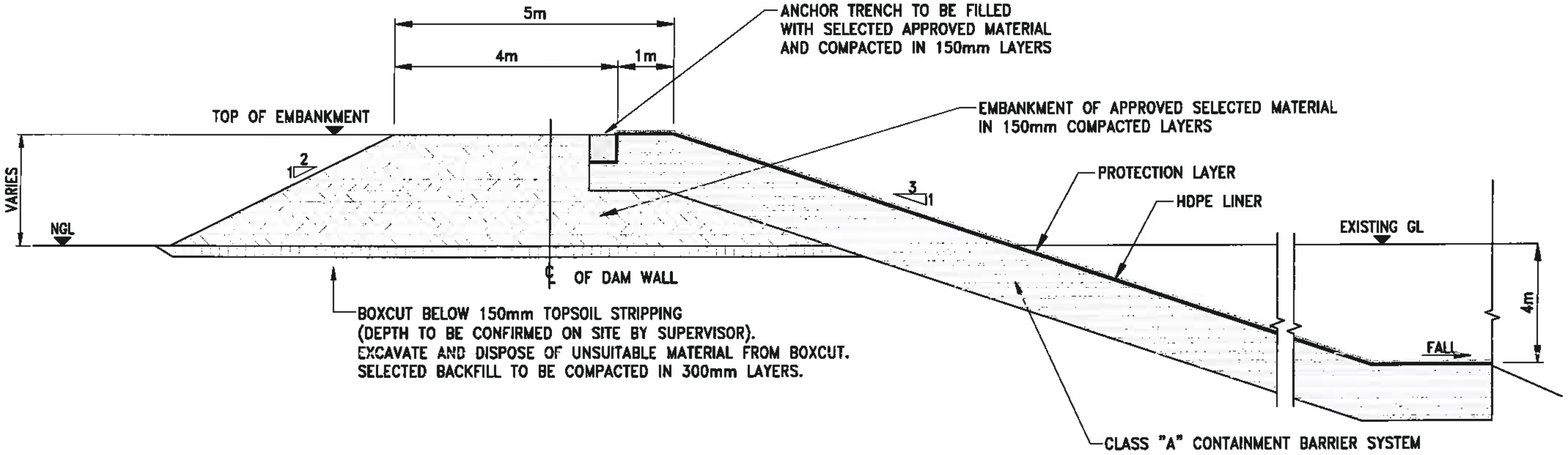
DRAWING 02



PLAN ON RWD
SCALE 1:2000



TYPICAL DETAIL SHOWING ANCHOR TRENCH AND PROTECTION LAYER
SCALE 1:20



TYPICAL SECTION THROUGH PCD
SCALE 1:100

2013002-7

SLR

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SIYANDA FERROCHROME SMELTER

PCD LAYOUT AND DETAILS

Date : SEPT 2016

Scale : AS SHOWN

Project No : 710.19057.00003

DRAWING 03

APPENDIX E: CQA PLAN

Siyanda Ferrochrome

Siyanda Waste Disposal Facilities Construction
Construction Quality Assurance (CQA) Plan for Barrier Systems

SLR Project No.: 710.19057.00003
Report No.: 01 Appendix E
Revision No.: A

October 2016

SLR Consulting (Africa) (Pty) Ltd

SIYANDA WASTE DISPOSAL FACILITIES CONSTRUCTION

CONSTRUCTION QUALITY ASSURANCE (CQA) PLAN FOR BARRIER SYSTEMS

CONTENTS

SIYANDA WASTE DISPOSAL FACILITIES CONSTRUCTION

CONSTRUCTION QUALITY ASSURANCE (CQA) PLAN FOR BARRIER SYSTEMS

1 GENERAL

1.1 INTRODUCTION

This preliminary construction quality assurance (CQA) plan has been prepared by SLR Consulting (Africa) (Pty) Ltd (SLR) for the proposed Mineralised Waste Disposal Facilities at the Siyanda Ferrochrome Smelter Project (SFSP) and outlines the construction, installation and testing procedures and verification methods that will need to be followed during the Works and is specific to the proposed barrier systems for the project. The plan is written for CQA personnel that will be involved during execution of the Works.

Detailed technical specifications for each element of the proposed works will be developed and reviewed during the detailed design phase. This CQA Plan will ultimately be supplemented by the project technical specifications.

SLR has prepared some preliminary design drawings for the Works. Construction drawings will only be produced during the detailed design phase.

1.2 PURPOSE

The ultimate purpose of the CQA Plan is to provide the means for assuring that the barrier systems are constructed in conformance to the project technical specifications, construction drawings, permit conditions and regulatory requirements.

1.3 DEFINITIONS

For the sake of clarification the following definitions are given:

Contractor – defined as the party appointed by the Employer for completing the Works described in the Contract, as required by the Specifications and as detailed on the Drawings. Certain portions of the Works may also be sub-contracted to specialist contractors e.g. a specialist installer for geomembrane liners.

Drawings – defined as the construction plans at or subsequent to Revision 0 that will be issued for the project and any other Drawings provided to the Contractor by the Engineer or others that apply to the Works.

Modifications – defined as changes made to the Specifications or the Drawings that are approved by the Engineer, in writing, after the Specifications and Drawings have been issued for construction. These also refer to changes to design elements in the field to account for unforeseen conditions.

Quality Assurance (QA) – defined as the responsibility of technical direction of the Works to ensure conformity of the Works to the designed intent. CQA services will be the responsibility of the Engineer.

Quality Control (QC) – defined as the testing and inspection necessary to ensure that the Works are constructed in compliance with the Specifications. Quality Control is the responsibility of the Contractor and must be carried out to the satisfaction of the Engineer.

Specifications – refers to the Technical Specifications for the Works which will form part of this CQA Plan, and any other Specifications and Modifications furnished by the Engineer that apply to the Works.

2 SCOPE OF CQA PLAN

This document is intended to provide a complete CQA Plan and Specifications for the two barrier systems forming part of the overall construction project. The two barrier systems are summarised as follows:

- Slag Dump - Class C barrier system:
    - The installation of a basin Thermal Protection layer (specific details to be confirmed).
    - The installation of a 1.5mm thick HDPE geomembrane placed over a prepared subgrade.
    - A geosynthetic clay liner (GCL) of equal or lower permeability to that of a 300mm compacted clay liner.
    - A below-liner Leakage Detection System to intercept leaks through barrier system.
- Baghouse Dust Disposal Facility and Pollution Control Dam – Class A barrier system:
    - The installation of a geotextile filter layer.
    - A 200mm stone leachate collection system.
    - A geotextile filter layer.
    - The installation of a 2.0mm thick HDPE geomembrane placed over a prepared subgrade.
    - A GCL of equal or lower permeability to that of a 600mm compacted clay liner.
    - The installation of a geotextile protection layer.
    - A leakage detection system to intercept leaks through barrier system.
    - The installation of a second geotextile protection layer.
    - The installation of a 1.5mm thick HDPE geomembrane.
    - A GCL of equal or lower permeability to that of a 200mm compacted clay liner.
    - A 150mm base preparation layer.

3 PROJECT TEAM AND ROLE PLAYERS

The following parties all have an influence on the quality of the Works:

1) Employer or Owner: Siyanda Chrome Smelting Company Pty (Ltd).
2) Engineer: responsible for the design of the Works, the preparation of the Specifications and the Drawings.
3) Construction Manager: responsible for managing the construction project.
4) Contractor: appointed by the Employer for the construction of the Works.
5) CQA consultant: responsible for CQA services. The CQA consultant shall be independent from the Employer, Contractor, and geosynthetic manufacturer and installer.
6) CQA laboratory: responsible for CQA laboratory testing services in accordance with the applicable and specified testing standards.
7) Resin Supplier: responsible for the production of the resin used by the manufacturers.
8) Manufacturers: responsible for the production of finished materials in the works (e.g. geosynthetics).
9) Geosynthetic installer: responsible for the installation of geosynthetics.
10) Surveyor.

All parties must be sufficiently qualified to successfully fulfil their respective responsibilities.

3.1 ENGINEER/ CQA CONSULTANT

SLR will be appointed to act as both the Engineer and the CQA Consultant. The Engineer's Representatives will be responsible for CQA activities on site, while the SLR Project Manager will have ultimate CQA accountability. The SLR CQA Team will therefore comprise the following:

- Project Manager (who could be the same person as the "CQA Project Manager"). The Project Manager will be based at the offices of SLR and will be present during the start of the construction works. The Project Manager;
    - attends selected progress or liaison meetings and is the key contact with regulatory officers,
    - reviews all designs, plans and specifications to assess compliance with the CQA Plan,
    - reviews other site-specific documentation, including proposed layouts, and Contractor's qualifications where required,
    - administrates the CQA programme,
    - reviews and approves the Contractor's and Geosynthetic Installer's CQC Program,
    - reviews all changes to the design, plans and specifications where required, and
    - oversees and reviews the CQA Certification Reports.

- Resident Engineer who will also act as the “CQA Engineer” and is located full time at the site. The CQA Engineer;
  - familiarises all CQA Technicians with the site, and the CQA requirements for the project,
  - manages the daily activities of the CQA Technicians,
  - attends all CQA-related meetings (e.g. Pre-construction and Progress),
  - prepares, or oversees the ongoing preparation of the Record Drawings,
  - assigns locations for testing and sampling,
  - reviews all CQA Technicians’ daily reports and logs,
  - reviews MQC documentation,
  - reports to the CQA Project Manager, and logs in his daily report any relevant observations,
  - oversees the collection and shipping of all samples for laboratory testing,
  - reviews results of laboratory testing and makes appropriate recommendations,
  - reports any unresolved deviations from this CQA Plan to the CQA Project Manager,
  - provides all logs and relevant data to the CQA Project Manager for the preparation of final reports,
  - reviews all Certifications and Documentation from the Contractor and makes appropriate recommendations, and
  - notes and brings to the attention of the Contractor any on-site activities that could result in damage to the works.

3.2 CONTRACTOR

The Contractor will be responsible for the complete installation of the Works including the specified barrier system. The Contractor’s scope in relation to the barrier system will include subgrade preparation, anchor trench excavation and backfill, drainage system installation and the coordination of work with the Geosynthetic Installer.

The Contractor shall include with his Tender a statement of which Geosynthetic Manufacturer he proposes to use. The Contractor shall also provide details within his Tender of the proposed accredited independent testing laboratory that will be used for this project and confirmation that this laboratory can undertake the required conformance testing to the standards specified in Section 6. Conformance testing must be performed before the material is shipped from the Geosynthetic Manufacturer’s plant so that it may be used immediately upon arrival at the site. The cost of conformance testing will be borne by the Contractor.

The Contractor shall, upon appointment, provide the Engineer with details of the manufacturing quality control (MQC) and manufacturing quality assurance (MQA) procedures that shall be utilised by the

Geosynthetic Manufacturer. Throughout the barrier system installation, the Contractor shall provide the CQA Engineer with certificates from the Geosynthetic Manufacturer detailing the quality control testing undertaken by the manufacturer for each batch of material delivered to site to demonstrate that the material meets the test values specified.

The Contractor will need to supply a long term service life assurance on similar material that has been installed in similar applications by the Geosynthetic Manufacturer, and on which the aforementioned long term tests have been carried out on exhumed samples or in service samples. This can be demonstrated by historical performance on material produced by that manufacturer. Long term tests results should have been run by an independent laboratory or a laboratory not associated with the manufacturer. Tests result should show material that has been in service for a minimum of 5 years and tested accordingly, with reference to initial test data.

The Contractor shall also include with his Tender a statement of which Geosynthetic Installer he proposes to use, and supply an organogram and CVs for all senior site personnel to be employed in the works including that of the Geosynthetic Installer.

3.3 GEOSYNTHETIC MANUFACTURER

The Geosynthetic Manufacturer shall be able to provide sufficient production capacity and qualified personnel to meet the demands of the project, and shall be approved by the Employer and Engineer.

The Manufacturer shall provide the Contractor with MQC certificates for every roll of geomembrane provided. The MQC certificates shall be signed by the Manufacturer and include roll numbers and identification, and results of MQC tests (as a minimum for thickness, density, tensile properties, stress crack resistance, carbon black content, carbon black dispersion and OIT).

3.4 GEOSYNTHETIC INSTALLER

The Geosynthetic Installer will be required to have a competent, experienced Geosynthetic Installation Superintendent on site full time during the installation who shall have installed a minimum of 1,000,000 m^2 of geosynthetic. The experience of the lead technician (supervisor) for each installation crew must be provided in terms of;

- total m^2 installed, and
- formal training / qualifications.

The Geosynthetic Installer and its Superintendent shall be approved by the Employer and Engineer.

4 PROJECT COORDINATION, CONTROL AND COMMUNICATION

4.1 INTRODUCTION

All formal communications between the Engineer and the Contractor must be in writing.

Meetings of key project personnel are necessary to assure a high degree of quality during construction and to promote clear, open channels of communication. Project coordination meetings are therefore an essential element to the success of the Project. Several types of project coordination meetings are described in the sections below.

The Contractor is to ensure that the Engineer/ CQA Consultant is provided with all information and documentation with respect to the quality control and quality assurance in respect of the manufacture, delivery, storage and installation of the geosynthetics, in a timely manner, in full compliance with the requirements of this CQA Plan and the Specifications.

4.2 PRE-CONSTRUCTION MEETING

Following the award of the Contract and prior to commencement of the Works, a Pre-Construction or Resolution Meeting will be held. This meeting should include all parties involved, and as a minimum include the Construction Manager, Engineer, CQA Consultant, Contractor and the Geosynthetic Installer.

The purpose of this meeting is to present the CQA Plan to all parties involved, to begin planning for coordination of tasks, and to identify any problems which might cause difficulties and delays in construction.

It will be important that all testing and validation procedures and requirements are presented at the meeting and acknowledged and accepted by all parties concerned.

The CQA Plan may be amended by the CQA Consultant following the meeting, if approved to do so in writing by the Engineer.

Specific items for presentation and discussion at the meeting include the following:
i) Confirmation of parties involved and responsibility of each.
ii) A review of the Drawings and Specifications and identification of critical design details.
iii) A review of the CQA Plan.
iv) A review of the Contractor’s, Geosynthetic Manufacturer’s and Installer’s CQC Programs.
v) Confirmation of lines of authority and communication.
vi) Confirm methods for documenting and reporting, and for distributing these.

vii) Reach consensus on CQA and CQC protocols and procedures, especially on methods of determining acceptability of the barrier system.
viii) Identify appropriate modifications necessary to ensure integration and compatibility between the various documents.

The meeting will be chaired by the Construction Manager and will be documented by a person designated by him. The Construction Manager will distribute the meeting minutes to all parties.

4.3 PROGRESS MEETINGS

Weekly progress meetings will be held between the Construction Manager, CQA Engineer, Contractor and other concerned parties participating in the construction of the project. This meeting will include discussions on safety statistics, current progress of the project, planned activities for the following week, revisions to the construction schedule, CQC and CQA activities and incidents. The meeting will be documented and meeting minutes distributed to all parties.

4.4 PROBLEM OR WORK DEFICIENCY MEETING

A special meeting will be held when, and if, a problem or deficiency has occurred or is likely to occur. The meeting will be attended by the Construction Manager, Contractor and the CQA Project Manager and other parties as appropriate. If the problem requires a design modification, the Engineer should either be present at, consulted prior to, or notified immediately upon conclusion of this meeting.

The purpose of the meeting is to define and resolve the problem or work deficiency as follows:
i) Define and discuss the problem or defect.
ii) Review alternative solutions.
iii) Select a suitable solution agreeable to all parties.
iv) Implement an action plan to resolve the problem or defect.

The meeting will be chaired by the Construction Manager and will be documented by the CQA Project Manager or a person designated by him. The CQA Project Manager will distribute the meeting minutes to all parties.

5 DOCUMENTATION

5.1 GENERAL

An effective CQA Plan depends largely on recognition of all construction activities that should be monitored and on assigning responsibilities for the monitoring of each activity. This is most effectively accomplished and verified by the documentation of CQA activities. The CQA Consultant will ensure that all CQA requirements have been addressed and satisfied.

The CQA Engineer will provide the Construction Manager with signed descriptive remarks, data sheets, and logs to verify that monitoring activities have been carried out. The CQA Engineer will also maintain, on site, a complete file of Drawings and Specifications, a CQA Plan, checklists, test procedures, daily logs, and other pertinent documents.

5.2 RECORDKEEPING

The CQA Engineer will be responsible for the following:

i) Daily reports (weather, construction activities, problems and solutions, approvals, observations, changed conditions) – for record purposes i.e. copies will only be provided upon request.
ii) Weekly construction and construction quality progress reports (weather, progress for the week and to date, obstacles to progress and plans for resolution, technical issues, quality control summary) – for regular submission to the Construction Manager.
iii) Monthly construction and construction quality progress reports (weather, progress for the month and to date, obstacles to progress and plans for resolution, technical issues, quality control summary) – for regular submission to the Construction Manager.
iv) A Construction Completion Report including as-built drawings. This report will only be completed after construction completion for submission to the Employer. The report must acknowledge that the Works have been performed in compliance with the Drawings and Specifications and the CQA Plan.
v) Photographic record – for separate submission to the Construction Manager and Employer after construction completion.

The Contractor or the Geosynthetic Installer shall prepare and keep comprehensive CQA logs which shall include the following:

i) Compliance Agreement between the Manufacturer and Installer.
ii) Daily personnel attendance list.
iii) Material inventory.
iv) Conformance testing.
v) Subgrade acceptance.
vi) Material deployment.
vii) Trial seaming.
viii) Production seaming.
ix) Repairs.
x) Non-destructive testing.
xi) Destructive testing.

xii) Daily report.

Design and/or specification modifications may be required during construction. In such cases the CQA Engineer will notify the Engineer. Modifications will only be allowed with the written agreement of the Engineer. Modifications must be captured on revised Drawings and/or addenda to the Specifications.

5.3 AS-BUILT TOPOGRAPHIC SURVEYS

Prior to commencing the construction works and throughout the CQA programme, a number of topographic surveys will be undertaken to confirm that construction is taking place in accordance with the Specifications and Drawings. The Contractor is responsible for setting out the Work and for maintaining on-going grade and alignment control to ensure compliance within construction tolerances. Control and reference survey monuments / benchmarks will be provided by the Employer. The Contractor will establish temporary survey monuments / benchmarks for setting out the Works.

The Contractor shall accurately set out the Works and determine levels from the drawings provided, and shall provide all instruments, pegs, guide rails etc. and attendance necessary for the Engineer and CQA Engineer to check this work. As a minimum detailed survey must be carried out:

1) Prior to topsoil removal.
2) After topsoil removal.
3) After excavations and cuts to the various areas.
4) On completion of fills and embankments.
5) Of each individual geomembrane panel installed along with its panel number.
6) On final completion to provide as-built details, that are submitted to the Engineer for approval. As-built survey shall be sufficiently detailed and complete and shall have separate and appropriately named 'layers' for each works component.

The above survey information shall be incorporated into the as-built drawings and Construction Completion Report.

5.4 CONSTRUCTION COMPLETION REPORT

Upon completion of the Works, the Engineer will prepare a Construction Completion Report summarising the Works undertaken and including all CQA documentation prepared by the CQA Consultant. As a minimum this shall include:

1) Description of Works.
2) Construction progress summary and rainfall records.
3) Summary of design changes and reasons for changes.

4) Signed-off quality control plans.
5) An analysis and summary of all CQC and CQA tests.
6) Confirmation of installed material specifications and warranties where applicable (e.g. geosynthetics, geotextiles and pipes).
7) Instrumentation installation records.
8) Photographic records.
9) As-built drawings.

It is noted that the Contractor's QC documentation will regularly and progressively be submitted to the CQA Engineer (quality control plans, control and record test results etc.) for compilation and filing.

The purpose of the above report will be to confirm that the Works have been carried out in accordance with the design intent, Drawings and Specifications as incorporated in this CQA Plan. The report will only be completed after construction completion.

6 MATERIAL SPECIFICATIONS

The key material specifications related to the two barrier systems relate to the geosynthetic layers. The following geosynthetics are incorporated in the design:

- Slag Dump – Class C barrier system:
  - A 1.5mm thick, black, HDPE geomembrane, conforming to GRI-GM13 as amended in November 2014, and installed to SANS 10409.
  - A geosynthetic clay liner (GCL) of equal or lower permeability conforming to GN 636 of 23 August 2013 and installed to ASTM Standards - D 6102 Guide for Installation of Geosynthetic Clay Liners and to be read in conjunction with manufacturer's guidelines.
- Baghouse Dust Disposal Facility and Pollution Control Dam – Class A barrier system:
  - A 2mm thick, black, HDPE geomembrane, conforming to GRI-GM13 as amended in November 2014, and installed to SANS 10409.
  - A second 1.5mm thick, black, HDPE geomembrane layer, conforming to GRI-GM13 as amended in November 2014, also installed according to SANS 10409.
  - A geosynthetic clay liner (GCL) of equal or lower permeability conforming to GN 636 of 23 August 2013 and installed to ASTM Standards - D 6102 Guide for Installation of Geosynthetic Clay Liners and to be read in conjunction with manufacturer's guidelines.

The Contractor will be responsible for ensuring that suitable quality material is delivered to site and installed in the Works. The Contractor's Geosynthetic Manufacturer will be responsible for confirming full compliance of his material to the above material specifications. Material property data sheets, MQC test procedures and frequency, and MQC certificates must all be reviewed and accepted by the Engineer prior to the shipment of any materials.

In addition, conformance testing will also be specified by the Engineer. The appointment of an independent CQA Geosynthetics Laboratory will need to be agreed between the Contractor, Manufacturer and the Engineer. The CQA Geosynthetic Laboratory shall obtain conformance samples at the manufacturing facility, at the specified frequencies, undertake the specified tests and supply the Engineer with test results.

7 BARRIER INSTALLATION SPECIFICATIONS

A preliminary set of Specifications for the installation of all components of the barrier systems are provided in Appendix F of the Design Report. It is noted that installation of the geomembrane layer shall be to SANS 10409 which shall take precedence to the particular sections under the Specifications.

RECORD OF REPORT DISTRIBUTION

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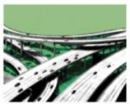
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APPENDIX F: PROJECT TECHNICAL SPECIFICATIONS

Siyanda Ferrochrome

Siyanda Waste Disposal Facilities Construction Project Technical Specifications

SLR Project No.: 710.19057.00003
Report No.: 01 Appendix F
Revision No.: A

October 2016

SIYANDA WASTE DISPOSAL FACILITIES CONSTRUCTION

PROJECT TECHNICAL SPECIFICATIONS

CONTENTS

Note these specifications are to be read in conjunction with the General Earthworks Specifications.

SIYANDA WASTE DISPOSAL FACILITIES CONSTRUCTION

PROJECT TECHNICAL SPECIFICATIONS

SECTION A.1

SITE SPECIFIC SPECIFICATIONS FOR THE INSTALLATION OF THE FLEXIBLE GEOMEMBRANE LINER

A.1.1 GENERAL

The following specification relates to the client's general requirements for a Flexible Geomembrane Lining to the Mineralised Waste Disposal Facilities at the Siyanda Ferrochrome Smelter Project (SFSP). The specified liner system is considered to be the minimum required for the intended purpose of application and whilst alternatives will be considered they should comply in all respects with these minimum requirements.

A.1.2 PURPOSE OF THE LINER

The purpose of the liner is to form the primary barrier against seepage of water into the ground. The physical and chemical characteristics of the liner must be such that the integrity of the liner is maintained during the construction of the Mineralised Waste Disposal Facilities.

A.1.3 EARTHWORKS, SUBSTRATE REQUIREMENTS

The flexible membrane lining that is offered must be considered an integral part of the total system. To ensure the integrity of the system, earthworks should be carried out in accordance with the General Earthworks Specifications (these specifications will be developed and reviewed during the detailed design phase). The following requirements are, however, highlighted:

a) The area to be lined must be free of all protrusions, stones, roots, vegetation and other materials which may be detrimental to the performance of the liner. A maximum particle size of 5-10mm will be allowed, but no sharp edge stones/debris can be tolerated. The material on which the liner will be placed will be a compacted fine grained soil with possible contamination with stones.

"Picking" of the debris/stones etc. will still need to be undertaken to remove unsuitable objects that may exist; this work is to be done by the *Contractor* and is to be included in the tendered price. The "picking" is considered an essential activity in maintaining the integrity the geomembrane and the *Contractor* will be required to submit a method statement to the *Engineer* for approval for this operation. Following the picking operation the surface must be rolled again with a compactor. This is to be done by the Earthworks *Contractor*.

b) A 150mm selected base layer should be compacted to 98% Proctor Density beneath the geomembrane, prior to placement of the geomembrane. The Lining *Contractor* is to sign acceptance of the surface.

c) The base and embankment slopes must be compacted in accordance with the General Earthworks Specifications, and the embankment slopes must be stable.

d) All vegetation must be removed and a suitable weed killer applied, if necessary.

e) The base of the earthworks or structure must be clean and dry. Should ground water be present, a suitable drainage system must be provided for provision for the continuous removal of water from the operation area if necessary. This work will be performed by the Earthworks *Contractor* or would be considered a variation to the contract.

f) Excavation and subsequent backfilling of perimeter lining anchor trenches or mid slope trenches measuring 500mm x 500mm minimum, is to be done by the liner installation Contractor and is to be included in the tendered price. These are minimum anchor trench dimensions and larger dimensions should be considered and approved by the *Engineer*, depending on soil type and liner thickness.

The backfilling must only be carried out once the structure has been filled, air entrapped there under has been vented out and the liner has settled. Suitable backfill material, which must be free of rocks, stones and other sharp objects and have maximum particle size of 10mm must be used. Tolerances for the excavation and backfilling of the lining anchor trenches are:

- The work shall be finished to a permissible deviation from designated levels with reference to the nearest transferred bench mark of ±50mm.
- The flatness of the finished surface (i.e. the maximum deviation of the surface from any straight line of length 3,0m) shall be ±50mm.
- Abrupt changes in a continuous surface are to be limited to a maximum of 3mm.
- Trench to be backfilled and compacted flush with liner surface to 98% standard Proctor Density at OMC –1% to +2%.

A.1.4 MANUFACTURE AND FABRICATION OF MEMBRANES

The name and details of the proposed liner supplier must be supplied with the tender. The name of the liner supplier must also be indicated on each roll of liner supplied to site. There can be no variation to the liner supplier without prior written approval of the *Engineer* and *Employer*.

To ensure its conformance with the requirements of the particular specification, the *Engineer* shall regularly audit the materials used during the geomembrane liner production phase.

Manufacture shall be to the largest possible sheet size to minimise jointing. The minimum seam-free sheet widths shall be 5m. Adequate tests and controls must be performed to ensure a good quality of raw material for sheet production. The sheet production process shall be accurately monitored and shall be such as to ensure homogeneous sheets, free from blisters, bubbles, pinholes and ragged edges.

Each roll of geomembrane liner material should be covered by a certificate of conformance, issued at a frequency of at least once per shift. This shall prove compliance with at least the relevant minimum requirements as specified by GRI-GM13 (as amended in November 2014), or similar internationally accepted and approved specification.

Production data and test reports of all tests done on each batch of material, in accordance with the submitted quality control programme, are to be kept and compiled in a conformance certificate and be submitted to the *Engineer* with each delivery to site.

A.1.4.1 Acceptance of sheets or rolls

The *Contractor* shall carry out a visual inspection of the sheets or rolls on arrival at site for possible transport damage. Sheets or rolls showing damage shall be singled out and clearly labelled as such.

A further inspection by the Lining *Contractor* is required prior to fabrication or installation. Any damaged sheets are to be rejected for installation.

A.1.4.2 Sheet Thickness

The *Contractor* must indicate the proposed thickness tolerances for all types of liner required to be priced for the tender.

Sheet thickness shall be determined in accordance with GRI-GM13 (as amended in November 2014) or similar internationally accepted and approved standards. The average thickness measurement in accordance with this method as determined by the *Engineer* will be taken as actual sheet thickness for site control.

A.1.4.3 Payment for Testing of Materials

The Contractor shall be responsible for all on-site routine testing as called for in this specification and all costs related to these tests shall be included in the rate for the supply and installation of the liner.

A.1.4.4 Conformance Testing

As soon as practicable after the delivery of geomembrane to site the Contractor shall label and cut a sample 1m wide across the entire width of selected rolls under the direction of the Engineer for conformance testing. The Contractor shall submit these samples to the proposed independent, accredited laboratory for conformance testing. All of the parameters listed in the below tables will be tested. The Contractor shall furnish to the Engineer a copy of the laboratory test results immediately on receipt.

If rolls on site from previous projects are being used in the Works at least 1 conformance sample must be taken from these rolls. Rolls on site from previous projects shall only be used if the roll number, batch number and manufacturers details are known.

If testing shows that the geomembrane does not meet any one of the test values listed in the below tables then this may be cause for rejection of the material from that roll. The Contractor's attention is drawn to the need for a rapid turnaround of laboratory results for this purpose. Any repairs or other works occasioned by the failure of the geomembrane to meet the minimum requirements listed in the below tables shall be carried out at the Contractor's expense.

If a conformance sample cut from a roll fails to meet the test values listed in the below tables the Engineer may at his discretion accept material from elsewhere on that roll if the Contractor can demonstrate through further laboratory testing that this material does meet the acceptance criteria contained in the below tables. Any such further testing shall be undertaken at the Contractor's expense.

A.1.5 LINER SPECIFICATION

The geomembrane lining shall be a suitably stabilised pure High Density Polyethylene with a minimum thickness as specified on the drawings, or other liner type and thickness approved by the *Engineer*.

The geomembrane lining shall carry the GRI-GM13 (as amended in November 2014) or similar internationally accepted and approved certification mark and shall be produced in seam-free widths of not less than 5m.

The material and its jointing systems shall be resistant to degradation due to sunlight, ultra violet rays, ozone, airborne pollution, and weathering and have an effective life in excess of twenty years.

The liner shall comply with the requirements tabulated below:

Properties	Test Method	Test Value							Testing Frequency (minimum)
		0.75 mm	1.00 mm	1.25 mm	1.50 mm	2.00 mm	2.50 mm	3.00 mm	
Thickness - mils (min. ave.) • lowest individual of 10 values	D5199	nom. (mil) -10%	nom. (mil) -10%	nom. (mil) -10%	nom. (mil) -10%	nom. (mil) -10%	nom. (mil) -10%	nom. (mil) -10%	per roll
Density (min.)	D 1505/D 792	0.940 g/cc	0.940 g/cc	0.940 g/cc	0.940 g/cc	0.940 g/cc	0.940 g/cc	0.940 g/cc	90,000 kg
Tensile Properties *(1)* (min. ave.) • yield strength • break strength • yield elongation • break elongation	D 6693 Type IV	11 kN/m 20 kN/m 12% 700%	15 kN/m 27 kN/m 12% 700%	18 kN/m 33 kN/m 12% 700%	22 kN/m 40 kN/m 12% 700%	29 kN/m 53 kN/m 12% 700%	37 kN/m 67 kN/m 12% 700%	44 kN/m 80 kN/m 12% 700%	9,000 kg
Tear Resistance (min. ave.)	D 1004	93 N	125 N	156 N	187 N	249 N	311 N	374 N	20,000 kg
Puncture Resistance (min. ave.)	D 4833	240 N	320 N	400 N	480 N	640 N	800 N	960 N	20,000 kg
Stress Crack Resistance *(2)*	D 5397 (App.)	500 hr.	500 hr.	500 hr.	500 hr.	500 hr.	500 hr.	500 hr.	per GRI GM-10
Carbon Black Content - %	D 4218 *(3)*	2.0-3.0%	2.0-3.0%	2.0-3.0%	2.0-3.0%	2.0-3.0%	2.0-3.0%	2.0-3.0%	9,000 kg
Carbon Black Dispersion	D 5596	note *(4)*	note *(4)*	note *(4)*	note *(4)*	note *(4)*	note *(4)*	note *(4)*	20,000 kg
Oxidative Induction Time (OIT) (min. ave.) *(5)* (a) Standard OIT — or — (b) High Pressure OIT	D 3895 D 5885	100 min. 400 min.	100 min. 400 min.	100 min. 400 min.	100 min. 400 min.	100 min. 400 min.	100 min. 400 min.	100 min. 400 min.	90,000 kg
Oven Aging at 85°C *(5), (6)* (a) Standard OIT (min. ave.) - % retained after 90 days — or — (b) High Pressure OIT (min. ave.) - % retained after 90 days	D 5721 D 3895 D 5885	55% 80%	55% 80%	55% 80%	55% 80%	55% 80%	55% 80%	55% 80%	per each formulation
UV Resistance *(7)* (a) Standard OIT (min. ave.) — or — (b) High Pressure OIT (min. ave.) - % retained after 1600 hrs *(9)*	D 7238 D 3895 D 5885	N. R. *(8)* 50%	N.R. *(8)* 50%	N.R. *(8)* 50%	N.R. *(8)* 50%	N.R. *(8)* 50%	N.R. *(8)* 50%	N.R. *(8)* 50%	per each formulation

(1) Machine direction (MD) and cross machine direction (XMD) average values should be on the basis of 5 test specimens each direction
Yield elongation is calculated using a gage length of 33 mm
Break elongation is calculated using a gage length of 50 mm

(2) The yield stress used to calculate the applied load for the SP-NCTL test should be the manufacturer's mean value via MQC testing.

(3) Other methods such as D 1603 (tube furnace) or D 6370 (TGA) are acceptable if an appropriate correlation to D 4218 (muffle furnace) can be established.

(4) Carbon black dispersion (only near spherical agglomerates) for 10 different views:
9 in Categories 1 or 2 and 1 in Category 3

(5) The manufacturer has the option to select either one of the OIT methods listed to evaluate the antioxidant content in the geomembrane.

(6) It is also recommended to evaluate samples at 30 and 60 days to compare with the 90 day response.

(7) The condition of the test should be 20 hr. UV cycle at 75°C followed by 4 hr. condensation at 60°C.

(8) Not recommended since the high temperature of the Std-OIT test produces an unrealistic result for some of the antioxidants in the UV exposed samples.

(9) UV resistance is based on percent retained value regardless of the original HP-OIT value.

Properties	Test Method	Test Value							Testing Frequency (minimum)
		0.75 mm	1.00 mm	1.25 mm	1.50 mm	2.00 mm	2.50 mm	3.00 mm	
Thickness mils (min. ave.) • lowest individual for 8 out of 10 values • lowest individual for any of the 10 values	D 5994	nom. (-5%) -10% -15%	nom. (-5%) -10% -15%	nom. (-5%) -10% -15%	nom. (-5%) -10% -15%	nom. (-5%) -10% -15%	nom. (-5%) -10% -15%	nom. (-5%) -10% -15%	per roll
Asperity Height mils (min. ave.) *(1)*	D 7466	0.40 mm	0.40 mm	0.40 mm	0.40 mm	0.40 mm	0.40 mm	0.40 mm	every 2nd roll *(2)*
Density (min. ave.)	D 1505/D 792	0.940 g/cc	0.940 g/cc	0.940 g/cc	0.940 g/cc	0.940 g/cc	0.940 g/cc	0.940 g/cc	90,000 kg
Tensile Properties (min. ave.) *(3)* • yield strength • break strength • yield elongation • break elongation	D 6693 Type IV	11 kN/m 8 kN/m 12% 100%	15 kN/m 10 kN/m 12% 100%	18 kN/m 13 kN/m 12% 100%	22 kN/m 16 kN/m 12% 100%	29 kN/m 21 kN/m 12% 100%	37 kN/m 26 kN/m 12% 100%	44 kN/m 32 kN/m 12% 100%	9,000 kg
Tear Resistance (min. ave.)	D 1004	93 N	125 N	156 N	187 N	249 N	311 N	374 N	20,000 kg
Puncture Resistance (min. ave.)	D 4833	200N	267 N	333 N	400 N	534 N	667 N	800 N	20,000 kg
Stress Crack Resistance *(4)*	D 5397 (App.)	500 hr.	500 hr.	500 hr.	500 hr.	500 hr.	500 hr.	500 hr.	per GRI GM10
Carbon Black Content (range)	D 4218 *(5)*	2.0-3.0 %	2.0-3.0 %	2.0-3.0 %	2.0-3.0 %	2.0-3.0 %	2.0-3.0 %	2.0-3.0 %	9,000 kg
Carbon Black Dispersion	D 5596	note *(6)*	note *(6)*	note *(6)*	note *(6)*	note *(6)*	note *(6)*	note *(6)*	20,000 kg
Oxidative Induction Time (OIT) (min. ave.) *(7)* (a) Standard OIT — or — (b) High Pressure OIT	D 3895 D 5885	100 min. 400 min.	100 min. 400 min.	100 min. 400 min.	100 min. 400 min.	100 min. 400 min.	100 min. 400 min.	100 min. 400 min.	90,000 kg
Oven Aging at 85°C *(7)*, *(8)* (a) Standard OIT (min. ave.) - % retained after 90 days — or — (b) High Pressure OIT (min. ave.) - % retained after 90 days	D 5721 D 3895 D 5885	55% 80%	55% 80%	55% 80%	55% 80%	55% 80%	55% 80%	55% 80%	per each formulation
UV Resistance *(9)* (a) Standard OIT (min. ave.) — or — (b) High Pressure OIT (min. ave.) - % retained after 1600 hrs *(11)*	D 7238 D 3895 D 5885	N.R. *(10)* 50%	N.R. *(10)* 50%	N.R. *(10)* 50%	N.R. *(10)* 50%	N.R. *(10)* 50%	N.R. *(10)* 50%	N.R. *(10)* 50%	per each formulation

(1) Of 10 readings; 8 out of 10 must be ≥ 0.35 mm, and lowest individual reading must be ≥ 0.30 mm; also see Note 6.

(2) Alternate the measurement side for double sided textured sheet

(3) Machine direction (MD) and cross machine direction (XMD) average values should be on the basis of 5 test specimens each direction.
Yield elongation is calculated using a gage length of 33 mm
Break elongation is calculated using a gage length of 50 mm

(4) The SP-NCTL test is not appropriate for testing geomembranes with textured or irregular rough surfaces. Test should be conducted on smooth edges of textured rolls or on smooth sheets made from the same formulation as being used for the textured sheet materials.
The yield stress used to calculate the applied load for the SP-NCTL test should be the manufacturer's mean value via MQC testing.

(5) Other methods such as D 1603 (tube furnace) or D 6370 (TGA) are acceptable if an appropriate correlation to D 4218 (muffle furnace) can be established.

(6) Carbon black dispersion (only near spherical agglomerates) for 10 different views:
9 in Categories 1 or 2 and 1 in Category 3

(7) The manufacturer has the option to select either one of the OIT methods listed to evaluate the antioxidant content in the geomembrane.

(8) It is also recommended to evaluate samples at 30 and 60 days to compare with the 90 day response.

(9) The condition of the test should be 20 hr. UV cycle at 75°C followed by 4 hr. condensation at 60°C.

(10) Not recommended since the high temperature of the Std-OIT test produces an unrealistic result for some of the antioxidants in the UV exposed samples.

(11) UV resistance is based on percent retained value regardless of the original HP-OIT value.

A.1.6 LINER DURABILITY

If required, the Lining *Contractor* shall conduct tests to confirm that the geomembrane liner offered is resistant for the duration of the guarantee period to the effects of the liquids intended for storage. The *Engineer* may, at his discretion, request that immersion tests be undertaken for a period of 28 days minimum for the proposed lining in a liquid sample provided by the client. These samples will be tested for changes in physical and mechanical properties and compared with those immersed in water over the same period of time.

Where the liner system is to be partially or fully exposed to the full blown effects of the sun, the Lining *Contractor* shall provide satisfactory evidence of successful liner use of a period of at least 20 years in South African conditions or in conditions worldwide where the ultra-violet radiation levels meet or exceed those in South Africa, for approval by the *Engineer*.

A.1.7 WARRANTY

The Lining *Contractor* shall provide a written guarantee for a period of 1 year against defects due to poor workmanship as well as a guarantee against the effects of weathering degradation for a period of 20 years.

A.1.8 PLANT

The *Contractor* shall make available at all times a suitable log book, per item of equipment, detailing, as a minimum

a) maintenance history, and

b) compliance with the calibration of all relevant parameters.

All equipment pertinent for the lining of the facilities shall at all times be in fit working order and available on site.

The equipment used shall be demonstrated to be state-of-the-art in terms of exceeding compliance with best (current) environmental control practices and shall after each designated interval, e.g. shift, be subject to compliance testing, which results shall be logged.

A.1.9 HANDLING

A.1.9.1 To Site

The *Contractor* shall ensure that the supplier:

a) Demonstrates competence to be an expert,

b) Details and ensures compliance by itself and the transporter of all of the critical handling procedures pertinent to the material(s) being delivered, and

c) Ensures and demonstrates delivery of all the necessary knowledge and procedures pertinent to the handling, storage and care, on site, of the material(s) specified and delivered.

A.1.9.2 On Site

The *Contractor* shall ensure:

a) The provision of storage facilities,

b) The provision of handling equipment, and

c) The deployment of all the specified materials, in a manner which will at least comply with all the best practices as specified by the supplier.

A.1.10 INSTALLATION OF GEOMEMBRANE SYSTEM

A.1.10.1 General

The Lining *Contractor* is to undergo and abide to all the environmental requirements as set out by the mine.

Installation of the geomembrane shall conform to SANS 10409 which shall take precedence over any specifications provided below.

Before the commencement of a contract, during the planning stage, a sheet layout will be prepared by the Lining *Contractor* on a plan of the Return Water Dam for approval by the *Engineer* and the main *Contractor*.

The Lining *Contractor* will submit a method statement for the placing of the plastic lining, given the effect of weather (rain, wind) and the shape and fall of the surfaces to be lined (effect of run off on plastic laying). The final accepted method will be determined after award of the contract and will be a combined *Contractor*/ Lining *Contractor* responsibility.

The geomembrane sheets shall be laid and welded down the slope and adequate arrangements must be made for anchoring at the top and bottom of the embankment as well as cognisance taken for prevailing wind directions, and the possibility of inclement weather and dust storms.

There shall be no smoking on or around any of the specified materials.

All cutting knives shall be of the retractable (or sheathed) type and except during actual use by an authorised person, shall be sheathed. A knife shall not be irresponsibly passed, other than by hand to hand.

Cutting of material shall be on or over a protective sacrificial layer.

There shall be no casual walking on laid material. All access to and from the working areas shall be along paths designated on a daily basis. The use of rope ladders on the slopes is mandatory. All “completed” areas shall be demarcated as out of bounds, with barrier tape.

No equipment, pallets or any other article shall be stored on or carried over laid material. Service cables or hoses, which may be required to be laid upon laid material, shall be free from any appendages which may be judged to cause injury to that material. If portable power generation is used, it shall be so sited and protected that leakage of hydrocarbons cannot impact upon the integrity of the liner.

The surface of the facilities walls and floors to be lined shall be free from any material, e.g. stones or protrusions which will in any way give rise to deformation of the lining material. All such deformations which may occur, be they from protrusions or deployment, shall be clearly marked, recorded and adjudicated for repair.

No operator (or operation) shall be required to perform in any manner, which may be deemed to be deleterious to the material, e.g. the deploying of material by hand whilst imposing strains not designed for.

Equipment or tools that will inflict damage to the geomembrane by handling, traffic or other means shall not be used. Clamps and metal tools shall be padded or have rounded corners and shall never be tossed or thrown above the geomembrane.

No personnel working on the geomembrane shall wear shoes that could cause damage or engage in other activities that could damage the geomembrane.

The (ad hoc) level and frequency of destructive testing and non-destructive testing shall be at the prerogative of the *Engineer* or *Employer*.

A.1.10.2 Delivery, transportation and handling

The geomembrane panels shall be packaged and shipped by appropriate means in order that damage is eliminated or minimised.

Materials shall be shipped in either a closed trailer or on a flatbed trailer covered from the ingress of moisture, and delivered to the site only after the required submittals have been approved and received by the *Contractor* from the *Engineer*.

The *Contractor* shall repair or replace any material damaged during shipment at his own cost.

Geomembrane, when off-loaded, shall be placed on a smooth well drained surface, free from rocks or any other protrusions which may damage the material. Stones, bricks or rocks shall not be used to secure the rolls of geomembrane. Custom-made restraining items (e.g. “socks” of geomembrane filled with soil) shall only be used.

The following shall be verified prior to off-loading the geomembrane:

a) Handling equipment used on the site is adequate and does not pose any risk of damage to the geomembrane; and

b) Site personnel are conversant with safe handling techniques and will handle the geomembrane with care.

The *Contractor* shall document any damage during off-loading. Any other damage (vandalism, accident, etc.) to the material shall be reported by the *Contractor* within 24 hours.

If a forklift is not available, slings shall be used to lift pallets off the trailer with a cradle style lift (“spreader bar”) in a way that will not damage the geomembrane material.

Any welding rod delivered to site shall be kept covered and dry and placed in a storage facility.

Upon arrival at the site, the *Contractor* shall conduct a surface observation of all rolls for defects and for damage. This inspection shall be conducted without unrolling rolls unless defects or damages are found or suspected.

A.1.10.3 Storage

The *Contractor* shall provide storage space in a location (or several locations) such that on-site transportation and handling are minimised. Storage space shall be protected from theft, vandalism, passage of vehicles, and be adjacent to the area to be lined. The geomembrane shall be stored so as to be protected from puncture, dirt, grease, water, moisture, mud, mechanical abrasions, excessive heat, extreme cold or other damage.

The various components of the total installation (geonet, geotextile, etc.) shall be separated by type at the storage facility or area.

If pallets are to be used, they shall be stored on a prepared level surface as close to the work area as possible. The pallets shall not be stacked.

A.1.10.4 Supervision and Manning

As detailed in Section C.1.14, the Lining *Contractor* must supply an Organogram and CV's for all site personnel to be employed in the works. As indicated in the *Tender* Document the Lining *Contractor* must also supply a schedule of personnel that it proposes to utilize on site during the carrying out of the works.

The *Engineer* must approve any proposed changes to the schedule of personnel in writing. The Lining *Contractor* shall allow in its manning levels for adequate coverage of leave requirements, to allow continuous operation at maximum production levels.

The Lining *Contractor* will be required to have a competent, experienced Lining Installation Supervisor on site full time during the lining installation. Both the *Contractor* and the *Engineer* must approve in writing, the proposed lining installation supervisor.

A.1.10.5 Preparation before Laying

The Lining *Contractor* will be required to thoroughly check the finished earthworks surface ahead of installing the liner and to remove particles which remain that could damage the liner. No protruding sharp objects will be allowed. Checking and picking of the final earthworks layer will be the responsibility of the *Contractor*.

The surface may require rolling just prior to laying of the geomembrane due typically to erosion runnels caused by rain storms and damage due to picking. This rolling is to be done by the *Contractor*.

The surface must be inspected in the presence of the *Engineer* before the sheets are installed. If the *Engineer* is satisfied with the finished earthworks, he will sign the Substrate Clearance Certificate to allow the Lining *Contractor* to commence installation of the plastic liner. Any subsequent repairs required to finished earthworks shall be the responsibility of the *Contractor*.

The Lining *Contractor* shall perform the works as expeditiously as possible to minimise the possibility of damage to the completed earthworks due to rain. The *Contractor* shall make all reasonable efforts to prevent any occurrences that may cause damage to the finished earthworks.

A.1.10.6 Procedure

The liner must be installed in accordance with the sheet layout as agreed with the *Engineer*.

The pattern of sheets laid must be such that no more than three sheets shall lap at any place. This can be achieved by staggering adjacent strips of sheet forming T-joints instead of “+” joints. A full record of work done with respect to date and position must be kept and forwarded on a weekly basis to the *Engineer*.

Individual sheets must be rolled out to ensure that the possibility of damage is kept to a minimum and the geomembrane is exposed to subsequent construction activities for the shortest possible time.

The sheets/panels shall be placed in such a manner as to minimise wrinkles (especially differential wrinkles between adjacent panels). Minimum wrinkles will be allowed to insure the lining is installed in a relaxed condition. There shall not be excessive wrinkles, i.e. wrinkles which overlap themselves. The geomembrane shall not be stretched. Wrinkles shall not be walked on nor scuffed. If a permanent crease occurs this shall be repaired by patching or over welding.

Adequate ballast (e.g. cover soil or similar measures that will not damage the geomembrane) shall be placed to prevent uplift by wind (Refer to Clause C.1.12.2). In the case of high winds, continuous ballasting is recommended along the edges of panels to minimise the risk of wind flow under the panels.

Direct contact with the geomembrane by equipment shall be minimised, i.e. geotextile, extra geomembrane, or other suitable cover materials or soil shall be used to protect the geomembrane in traffic areas.

No vehicles, other than those approved shall be allowed on the geomembrane. Only small rubber (pneumatic) tyred equipment with a ground pressure not exceeding 35 kPa, and a total weight not exceeding 330 kg shall be allowed, i.e. air compressors, generators, etc. that would be required during installation and testing.

The programme of construction shall be such as to minimise exposure of the sheets before the filling of the lined facility is commenced.

All joints must be prepared for welding by grinding - (Extrusion Fusion welding only) - the surface of the membrane over the full width and length of the joint.

A.1.10.7 Membrane Placement

In placing the membrane, protection precautionary measures shall be taken by the *Contractor* to minimise the risk of any damage to the liner.

Each compartment must be covered with plastic liner according to the program submitted to the *Engineer*. The *Contractor’s* QC activities and correction of defects must follow directly behind the laying of the plastic.

The *Contractor* shall inspect each geotextile after placement and geomembrane prior to seaming for damage. The *Engineer* will indicate which lining or portions of lining shall be repaired.

Damaged lining or portions of damaged lining, which have been rejected, shall be marked and their removal from the work area recorded by the *Contractor*. Repairs to geomembrane shall be made according to procedures described herein.

A.1.10.8 Seaming of Adjacent Liner Sheets on Site

The seaming of adjacent liner sheets on site will be carried out in such a way and by such means that the strength of the seams are at least as strong as the adjacent sheets when tested in the peel mode of testing at ambient temperatures.

The seaming methods should produce totally homogeneously bonded areas which will be at least as resistant to the effects of the stored liquid and at least as resistant to the effects of climatic degradation of the adjacent geomembrane sheets.

In general, seams shall be oriented parallel to the line of maximum slope, i.e. oriented along, not across the slope. In corners and odd-shaped geometric locations, the number of seams shall be minimised.

No horizontal seam shall be less than 1.5 m from the toe of the slope or areas of potential stress concentrations unless otherwise authorised.

Normal seaming shall occur when the ambient temperature is between 2 and 38 degrees C. Do not seam if the ambient temperature is above 38 degrees C.

Automatic or manually operated equipment may be used in the welding process. All welding shall be undertaken and controlled by competent operators and the *Contractor* must arrange to demonstrate the ability of his operators to weld the geomembrane to comply with this specification. Field start-up samples will be produced for each machine in the morning and afternoon before on-site welding commences and when no welding has been done by a machine for more than 1 hour.

Either or both of the following seaming methods will be employed on site:

a) Electric Double Wedge Weld

Adjacent sheets of geomembrane lining are joined together on site based on continuous fusion by automatic electrically heated double wedges which create parallel homogeneously bonded areas either side of a central and continuous air void.

b) Extrusion Fusion Welding

Adjacent sheets of geomembrane lining are joined together on site, using equipment based on a continuous fusion welding system that applies extrudate along the prepared overlap to provide a totally integrated and homogeneous weld which will not fail when tested in shear and peel configuration, at ambient temperatures.

All joints must be prepared for welding by grinding the surface of the membrane over the full width and length of the joint. The weld area and the heating head must be clean and care must be taken that no air bubbles or foreign matter is trapped in the weld.

A.1.10.9 Seaming Equipment and Products

The approved processes for field seaming are extrusion fusion welding and hot wedge welding. Extrusion fusion welding shall be used at overlapping corners. Normal seams shall be welded using the wedge welding method. Proposed alternate processes may be documented and submitted to the *Engineer* for consideration.

The extrusion fusion welding apparatus shall be equipped with calibrated gauges giving the temperature of the apparatus at the nozzle and extruder barrel, speeds and input voltage. It shall be an automated vehicular mounted device, which produces a double seam with an enclosed space.

The *Contractor* shall verify that:

a) All the necessary safety equipment (earth leakage apparatus, PPE, temporary fencing, etc.) is available and functional.

b) Equipment used for seaming is not likely to damage the geomembrane.

c) The extrusion fusion welder is purged prior to beginning a seam until all heat-degraded extrudate has been removed from the barrel.

d) The electric generator, if required, is equipped such that no damage occurs to the geomembrane and is able to provide sufficient power to the complete suite of equipment employed at any one time.

e) Buffing shall be completed no more than one (1) hour prior to extrusion fusion welding (buffing is not necessary for hot wedge welding) and shall not remove more than 10% of the total sheet thickness.

f) The geomembrane is protected from damage by the use of sacrificial material, in heavily trafficked areas.

The critical parameters of welding polyethylene with a hot wedge welder are:

i) temperature of the wedge;

ii) the speed of the welder;

iii) the temperature of the panels to be welded, and

iv) the compressive force exerted by the drive wheels.

The *Contractor* shall provide gauges/tools in order to measure and control the critical variables.

Liner temperatures can vary by up to 30˚C or more between the lining on a slope and the lining on the bottom of a cell. When clouds interrupt sunshine, similar changes occur. If any circumstance causes the lining temperature to move outside the ideal welding parameters, a change in the speed or the wedge temperature is required, this shall be recorded.

The attributes of a good seam made by a hot wedge welder are:

i) Both areas of fused material shall be void of any seam lines.

ii) The edge of the tracks shall not cut the lining.

iii) The air channel shall be clear.

iv) The widths of the tracts should be equal.

v) The squeeze out should be barely visible.

The operator shall keep a constant check on the temperature controls, as well as on the completed seam coming out of the machine. Occasional adjustments of temperature or speed as the result of changing ambient conditions will be necessary to maintain a consistent seam. Constant visual and hands-on inspection is also required.

A 1.5 metre long test strip shall be fabricated and test specimens manually tested prior to constructing each seam, or at any time the seaming procedure (e.g. speed, wedge temperature) has changed. A minimum of one test strip shall be made each morning and afternoon prior to commencement of welding.

On butt welds across ends of panels, it may be necessary to trim any loose edges of the field seams.

On some soils, the hot wedge welder may tend to “bulldoze” into the ground as it travels. This causes soil to enter the seam area, making the seam unacceptable. To overcome this, it is recommended that strips of geomembrane be placed under the liner to be welded. This has proven to be effective in preventing this bulldozing effect and provide a hard flat surface for the welder to travel on. It is usually necessary that at least two people work together in making hot wedge seams; the Tenderer’s certified operators and one assistant.

The extrusion fusion welder provides heat and an extrudate of molten plastic made from the same raw material as the sheet. The molten plastic is deposited over the edge of (fillet welding) or in between the two surfaces (flat welding) to be welded. Extrusion fusion welding is considered much more cumbersome than hot wedge welding and subsequently much slower to operate than the hot wedge welder. However, it is the only method that can be used for patching. Like the hot wedge welder, the extrusion fusion welder shall be calibrated to the temperature of the panel and the extrudate.

Since patches, penetration repairs and detail work are always necessary, this type of welding shall be performed by the extrusion fusion welder. The surfaces to be welded shall be tacked together at overlap to form a temporary bond prior to welding. The surface area to be used for welding shall then be buffed to provide a roughened surface for the extrudate to better adhere and cause melt flow. Care shall be taken to not remove too much from the panel when grinding (no more than 10% of the total sheet thickness). The profile of the shoe shall be checked regularly for correctness.

The speed of traverse and the angle of contact of the extruder head to the joint area affects the efficacy of the weld. Regular destructive tests shall be carried out to ensure integrity of the weld. The resultant extrusion seam shall be flat and without ribs or corrugations, which will cause doubt as to the weld integrity and inhibit vacuum testing of the weld.

A.1.10.10 Seam Preparation

The Contractor shall verify that:

a) prior to seaming the seam area is clean and free of moisture, dust, dirt, debris of any kind, and foreign material, and

b) seams are aligned with the fewest possible number of wrinkles and “fishmouths”.

A.1.10.11 Weather Conditions for Seaming

The high temperature limit for welding is the temperature at which one or all of the following takes place:

a) the well-being of the crew becomes uncertain,

b) air pressure channels begin to close,

c) passing welds are unobtainable,

d) unless authorised in writing by the *Engineer*, no seaming shall be attempted at ambient temperatures below 10˚C. This decision is based upon the ability of the crew to obtain passing trial and field welds.

In all cases, the geomembrane shall be dry and protected from wind.

A.1.11 TESTING REQUIREMENTS FOR LINER WELDING

The sections below outline the minimum requirements for testing of the liner welds. The methods proposed by the Lining *Contractor* are to be outlined in greater detail in the method statements and QC procedures submitted with the tender. The methods and procedures used in the works will be subject to the approval of the *Engineer*.

A.1.11.1 Welding tests

The *Engineer* may, at his discretion, call for welding tests to be conducted prior to contract award and must include the following on the geomembrane liner:

(i) A single weld at least 10m long performed in the open;

(ii) Patching of a 400mm x 300mm hole by hand welding;

(iii) The welding of three sheets to form a T-joint.

The *Engineer* reserves the right to take as many samples as and where it is considered necessary after the demonstration.

A.1.11.2 Testing of Completed Seams

Whether the Double Electric Wedge or the Extrusion-Fusion welding systems are employed on site, the seams should all be confirmed as continuous and fully integrated by undertaking non-destructive and destructive tests.

A.1.11.3 Non-destructive Testing

The following methods shall be employed:

a) Vacuum Testing

This test creates a vacuum on one side of the joint. If a vacuum of –75 kPa can be maintained for 3 minutes, the joint shall be considered to be effective. This test must be done where the sheets are lapped or where patching is done and on straight runs at a rate of one test per 50 linear metres of weld.

b) Electric Spark Testing

This method shall be used over 100% of all the extrusion-fusion welds on site and which method shall be subject to the approval of the *Engineer*.

c) Air Pressure Testing of Double-Wedge Welded Seams

Preparation

Ensure that all testing equipment is clean and dust-free. Make a straight cut 90°C across the weld, as close as possible after the beginning of the weld but not further than 100mm from the edge of the sheet.

Testing

Force open the void between the welds at the cut end, using a screw driver or similar blunt object. Insert the pressure gauge/needle assembly into the void, clamp, secure and tighten the gasket hard up against the cut face over the void, allowing it to flow freely out of the opposite end.

Immediately after completing a seam, commence the testing procedure. Seal the one end of the seam by applying heat with a hot air gun until a seal is achieved. While hot, clamp off the seam end, using the vice grip.

Pump air into the void to a pressure of 3 Bar. Maintain this pressure for a minimum of 2 minutes.

Repairs

If the pressure of 3 Bar cannot be attained or the pressure drop is greater than specified, check both ends of the seam to ensure a proper seal and retest.

Should the test still be unsuccessful and no visible leak could be detected, repair the failed seam by extrusion welding the outside edge of the wedge- welded seam.

d) Identification of Tested Areas

The Tester shall mark each seam tested individually, by signing his name and date tested with an indelible pen on the plastic sheet. This position should also be transferred on to the sheet layout drawing. Once non-destructive tests have been carried out to the satisfaction of the *Engineer*, further destructive tests shall be carried out to confirm the integrity of the weld.

A.1.11.4 Destructive peel testing

The destructive peel tests will be carried out on all seams at 150m intervals or one per hour per machine minimum. The Lining *Contractor* must be capable of performing the peel test on site.

This test determines the effectiveness of the weld by peeling the weld apart at a rate of 50mm/min on a strip 25mm wide cut perpendicular to the joint direction at both ends of all samples. An increasing force is applied to the two strips of membrane forming the joint. If one of the strips breaks prior to full separation across the weld, it is considered acceptable. If the weld separates, the weld is considered unacceptable.

A.1.11.5 Corrective Measures

All defects, tears, sample holes or other physical damage to the membrane, must be patched with a piece of membrane of the same type and thickness as the parent membrane. This patch shall be welded over the defect using a weld of at least 10mm width, using the Extrusion Fusion Welding method.

A.1.11.6 Handover/Completion

Acceptance of the laid sheets by the *Engineer* will happen on a daily basis. This sign off will be based on approval of plastic, the welds, the foundation material and the ballast left in place after moving off the cell. However as plastic lifting is the Lining *Contractors* responsibility, the daily signing off will not exempt the *Contractor*/Lining *Contractor* from liability for damage caused to the liner and subgrade due to their negligence on adjacent cells. Taking over in sections as per sub clause 48.2 of the GCC will only occur if the *Employer* requests to start placing geofabric, pipes and gravel on a compartment before the final taking over certificate for the completed *Works*.

A.1.12 ISSUES FOR CONSIDERATION DURING TENDERING

This section of the specification outlines areas/items, which will require careful attention during construction.

A.1.12.1 Rain

The effects of rain on the project are significant and if proper precautions are not made to minimise the effect of rain, excessive delays may occur. To minimise the effects of rain the plastic liner installation should be scheduled during the dry season from April to August.

The nature of the material used for the final layer before the plastic liner is such that when it becomes wet no work can continue until it has dried sufficiently. This drying period can vary between 24 and 48 hours depending on the weather conditions.

The Lining *Contractor* must be aware that there could be delays due to rain and low temperatures and that he must allow for these both in the rates and when determining manning and equipment levels required to meet construction deadlines.

The plastic lining should be placed from the highest point on each compartment down to the lowest point in order to prevent storm-water flowing under the Liner. However, if the *Contractor* can shows means for protecting the Liner and substrate, he may obtain written permission from the *Engineer* to change this philosophy.

In addition, welding shall not take place in an area of ponded (standing) water.

Records shall be kept reflecting maximum and minimum temperatures, relative humidity and precipitation during the installation period.

A.1.12.2 Wind

Very strong winds can occur just prior to, and during, storm events. It is essential that the Lining *Contractor* utilises soilcrete (10% cement added to soil) filled bags at 20m cross centres during the laying operation to ensure that lifting followed by tearing, creasing and other damage is not allowed to occur. This type of occurrence will lead to time delays associated with relaying and rechecking, etc., which could have a severe impact on the project schedule. The soilcrete bags are to be left on the liner upon completion.

A.1.13 MEASUREMENT

The unit of measurement for the installation of a suitable type of impermeable lining by an approved lining *Sub-Contractor* in accordance with the specifications, shall be the square metre of lining placed according to the dimensions indicated on the drawings or as specified by the *Engineer*. No extras will be paid for overlaps at joints, waste, etc. The lining that is placed in the anchor trenches, to the dimensions shown on the drawings will be included in the measured quantity.

Payment will be as detailed in the *Bill* of *Quantities* and where required separate items will be scheduled for attachments to concrete structures, pipes, sumps, etc.

The rates in the schedule must include for:

- Supply of liner to the specifications (including compatible welding rods)
- Import taxes and duties
- All relevant insurances
- Transport and shipping costs (including delivery to site and offloading)
- Port clearance charges
- Storage,
- Laying,
- Welding
- QA/QC requirements,
- Experienced supervision,
- Labour, and
- Preparing the surface just prior to laying (picking and rolling), etc.

No additional payments or claims of any nature will be considered.

A.1.14 SUITABILITY OF LINING SUB-CONTRACTOR

In his assessment of the suitability of the Lining *Contractor*, the *Engineer* must be satisfied that such a *Contractor* can perform according to the functional and organisational requirement of the works to be undertaken and preference will be given to those contractors which are listed in accordance with the ISO 9000/ 2000 standards.

The Lining *Contractor* shall further be required to submit the following supportive documentation with his tender:

- Samples and specifications of all materials tendered;
- Chemical compatibility data sheets;
- Liner Production Quality Assurance/ Quality Control Schedule;
- On-Site Quality Assurance/ Quality Control Schedule;
- Experience list of all similar lining works completed over the last 10 years;
- Organogram and CV’s of site personnel to be employed in the works.

APPENDIX G: THERMAL MODELLING REPORT

Siyanda Ferrochrome Smelter

Thermal Protection Layer for the Containment Barrier System

CFD Based Study

Report Number 610.16856

1 November 2016

Siyanda Chrome Smelting Company Pty (Ltd)

Version: Revision 0

Siyanda Ferrochrome Smelter

Thermal Protection Layer for the Containment Barrier System

CFD Based Study

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DOCUMENT CONTROL

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EXECUTIVE SUMMARY

SLR Consulting (Africa) (Pty) Ltd (SLR) has been engaged by Siyanda Chrome Smelting Company Pty (Ltd) to prepare design documentation for two mineralised waste disposal facilities for the proposed Siyanda Ferrochrome Smelter Project (SFSP).

The project involves a 21 ha slag dump facility with a storage capacity of approximately 7 million tons. Molten slag at a temperature of approximately 1600^{o}C will be dumped directly from slag pots into the slag disposal facility.

The slag dump will be lined using a *Class C* barrier containment system. The lining system temperature (refer **Figure 1)** should ideally remain below 25^{o}C.

Due to the slag being deposited in molten form, the extremely high temperatures would cause damage to the underlying containment barrier system if not adequately protected from the slag.

SLR Africa engaged SLR Australia to undertake the current study has been undertaken to specify the thermal requirements for a proposed thermal protection layer to ensure that the lining system (liner) is not compromised.

Thermal simulations including multi-phase fluid flow and heat transfer have been carried out utilising advanced Computational Fluid Dynamics (CFD) modelling.

Multiple fluid flow, solidification and heat transfer are considered for the molten slag (liquid) and the surrounding cooling air (gas) in this study. Molten slag is assumed to flow for 10 seconds and the Volume of Fluid (VOF) model with a free surface between the molten slag, air and porous insulation layer is used to compute a time dependent solution. Heat transfer via natural convection and conduction is then predicted for up to Time = 806,600 seconds (Sec).

The following insulation layers are proposed:

- 2 m thick crushed slag with a maximum porosity of 34%
- 0.5 m thick sand with a permeability of 8e-8 m/s

The following major conclusions are achieved from the results of CFD simulations:

- The molten slag solidifies just below the upper surface of the crushed slag at Time = 10 Sec. The molten slag is assumed to solidify at 1300^{o}C.
- The slag is completely solidified at time = 250 Sec (Refer **Figure 13**). This study is considered conservative where a still wind condition with ambient temperature of 27^{o}C is assumed. This rate of heat transfer from the molten slag will increase with increasing ambient wind speed.
- It takes approximately 30 hours for the heat wave to pass through the liner. Liner temperature is increased by 0.33^{o}C at Time = 118,820 Sec (Refer **Figure 24**). The time delay is due to the thermal mass of the insulation material layer (2 m of crushed slag plus 0.5 m of sand). The thicker and more resistive the material, the longer it will take for heat waves to pass through.
- The liner temperature peaks at Time = 635,600 Sec (Refer **Figure 34**). The peak temperature is 298.82^{o}K (25.82^{o}C). The reduction in upper surface of the crushed slag is 1,558^{o}C at the same time. Thus, the liner system will experience a 4.82^{o}C variation while the slag will experience approximately 1,558^{o}C variation in external surface temperature at the same time.
- The temperature will fall to 296.39 K (23.39^{o}C) at 0.25 m below the liner.

If the thickness of the crushed slag is increased to 2.25 m (total insulation layers = 2.25 m crushed slag plus 0.5 m sand) the liner temperature will reduce to below 24^{o}C.

The thickness of the thermal protection layers can be reduced if a cooling water system is presented to reduce the slag temperature. Some of the by product for heating can be captured by a thermal energy storage to operate a combined heating and power system or can be used in absorption chiller to produce free cooling. A feasibility study can be conducted during the detailed design stage if this option is desired.

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FIGURES

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1 INTRODUCTION

SLR Consulting (Africa) (Pty) Ltd (SLR) has been engaged by Siyanda Chrome Smelting Company Pty (Ltd) to prepare design documentation for two mineralised waste disposal facilities for the proposed Siyanda Ferrochrome Smelter Project (SFSP).

The project involves a 21 ha slag dump facility with a storage capacity of approximately 7 million tons. Molten slag at a temperature of approximately 1600°C will be dumped directly from slag pots into the slag disposal facility.

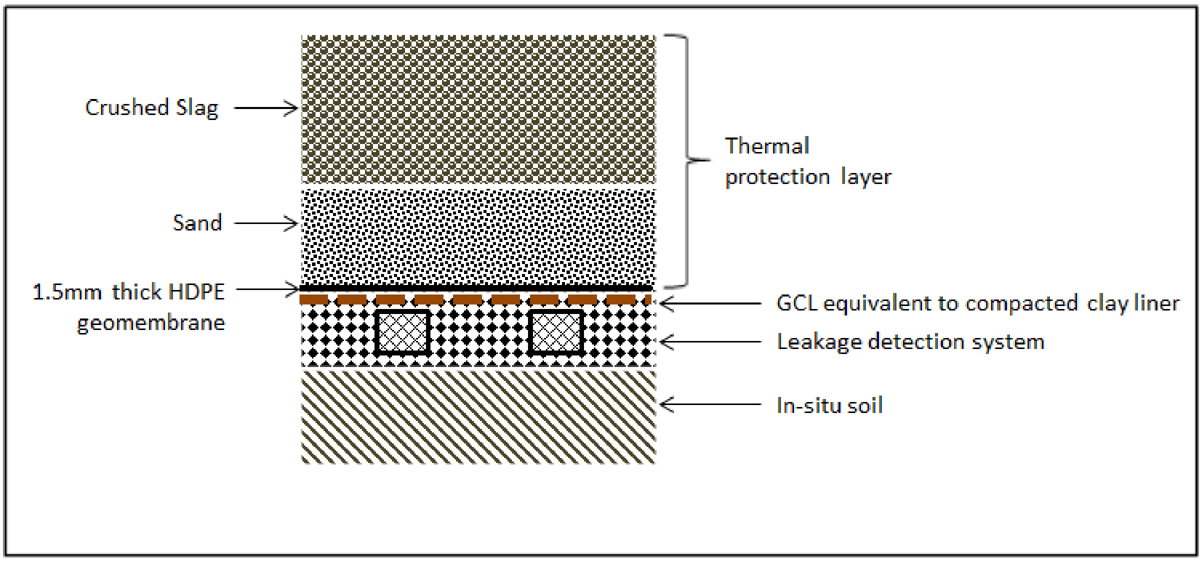
The slag dump will be lined using a *Class C* barrier containment system – refer to **Figure 1** and SLR Report 710.19057.00003 Revision 0 dated October 2016. The lining system temperature (refer **Figure 1)** should ideally remain below 25°C.

Due to the slag being deposited in molten form, the extremely high temperatures would cause damage to the underlying containment barrier system if not adequately protected from the slag.

The current study has been undertaken to specify the thermal requirements for a proposed thermal protection layer to ensure that the lining system is not compromised.

Thermal simulations including multi-phase fluid flow and heat transfer have been carried out utilising Advanced Computational Fluid Dynamics (CFD) modelling.

Figure 1 Proposed Class C Containment Barrier System



1.1 Background on Computational Fluid Dynamics (CFD) Modelling

Computational Fluid Dynamics (CFD) is the use of applied mathematics, physics and computational software to visualize how a fluid (gas or liquid) flows. Computational fluid dynamics is based on the Navier-Stokes equations [1] and uses numerical analysis and algorithms to solve and analyse thermo-fluid problems. These equations describe how the velocity, pressure, temperature, and density of a moving fluid are related.

The tool was initially used by commercial airlines [2] and using CFD has saved Boeing tens of millions of dollars over the past 20 years [3] and the tool is now covers the entire spectrum of fluid dynamics analysis from leading edge turbulence and reacting flow to multi-phase problems such free surfaces, solidification, cavitation, boiling, slurry and melting [4]. CFD is therefore used in a variety of applications and industries such as chemical, petroleum, aerospace, automotive, power generation, polymer processing, medical research, construction, meteorology, and so forth. Some of the key offerings include the design reliability and reduction in the time and cost of the product development.

With advances in computational processing power and commercial software combined with customised user-defined functions, CFD tools are now routinely used to produce a combined real time internal-external flow and heat transfer analysis [5].

The studies of hot metal flow has been analysed in a number of open literature forums. Early CFD models investigated the re-circulatory flow induced by natural convection and its effect on dissolution of carbonaceous refractory in the melt using a simplified single phase model [6]. CFD modelling of liquid metal and heat transfer in blast furnace hearth was analysed and presented in [7].

CFD modelling techniques were also applied to dry slag granulation [8]. The study simulated free surface flow and heat transfer of liquid slag on a spinning disc. The model used the thickness of the solid slag layer deposited on the disc's top face during the granulation experiments to indirectly validate the CFD model.

For the current study the ANSYS-Fluent [4] modelling package was used to model fluid flow and heat transfer in the slag disposal facility.

ANSYS Fluent is the world's leading CFD software tool available and includes well-validated physical modelling capabilities to deliver fast, accurate results across the widest range of CFD and multi-physics applications [4].

2 PROBLEM DESCRIPTION

1. Molten slag is deposited into a slag disposal facility with the following properties:
    - Temperature = 1600°C
    - Density = 1800 kg/m^3
    - Specific heat = 830 J/kg.K
    - Thermal Conductivity = 3 W/m.K
2. The slag solidifies as it cools by natural convection to a temperature of 1300°C.
3. The slag is then broken down to a poorly graded material.
4. The phenomena is further completed by conjugate heat transfer to thermal insulation layer and proposed Class C barrier containment system.

The physical problem is therefore a complex transient multi-phase flows coupled with solid/liquid interface heat transfer.

Example of molten slag is shown in **Figure 2.** One can see that there is a sharp interface between the molten slag and air.

Figure 2 Molten Slag

3 CFD MODELLING, ASSUMPTIONS AND ANALYSIS

The CFD modelling involved the following:

- Developing a numerical model for the dump facility. In order to solve the numerical model in a timely manner a two dimensional computational domain covering 5m of the slag disposal facility was created. The computational domain included the following:
  - Soil
  - Plastic liner (liner)
  - Thermal insulation layer. The following insulation materials are investigated:
    - Crushed slag with a porosity of 34%
    - Sand with a permeability of 8e-8 m/s.
  - Molten slag. The slag is assumed to flow continuously for at least 10 seconds.
  - Air surrounding the molten slag
- Developing hexahedra meshed cells for the computational domain.
- Modelling the porosity of the thermal insulation material and soils using porous media modelling techniques.
- Defining boundary conditions for the developed model.
- Selecting models and numerical scheme for the assessment.
- Predicting the transient free surface of the molten slag for the first 10 seconds.
- Predicting temperature profiles in the computational domain for the worst case scenario (still wind condition) where heat is transferred to air via natural convection and conduction.
- Providing guidance as to the liner area where the temperature criterion has the potential to be exceeded (Ideally below 25°C).
- Providing recommendations to satisfy the design criterion if required.

3.1 Modelling

3.1.1 Computational Domain

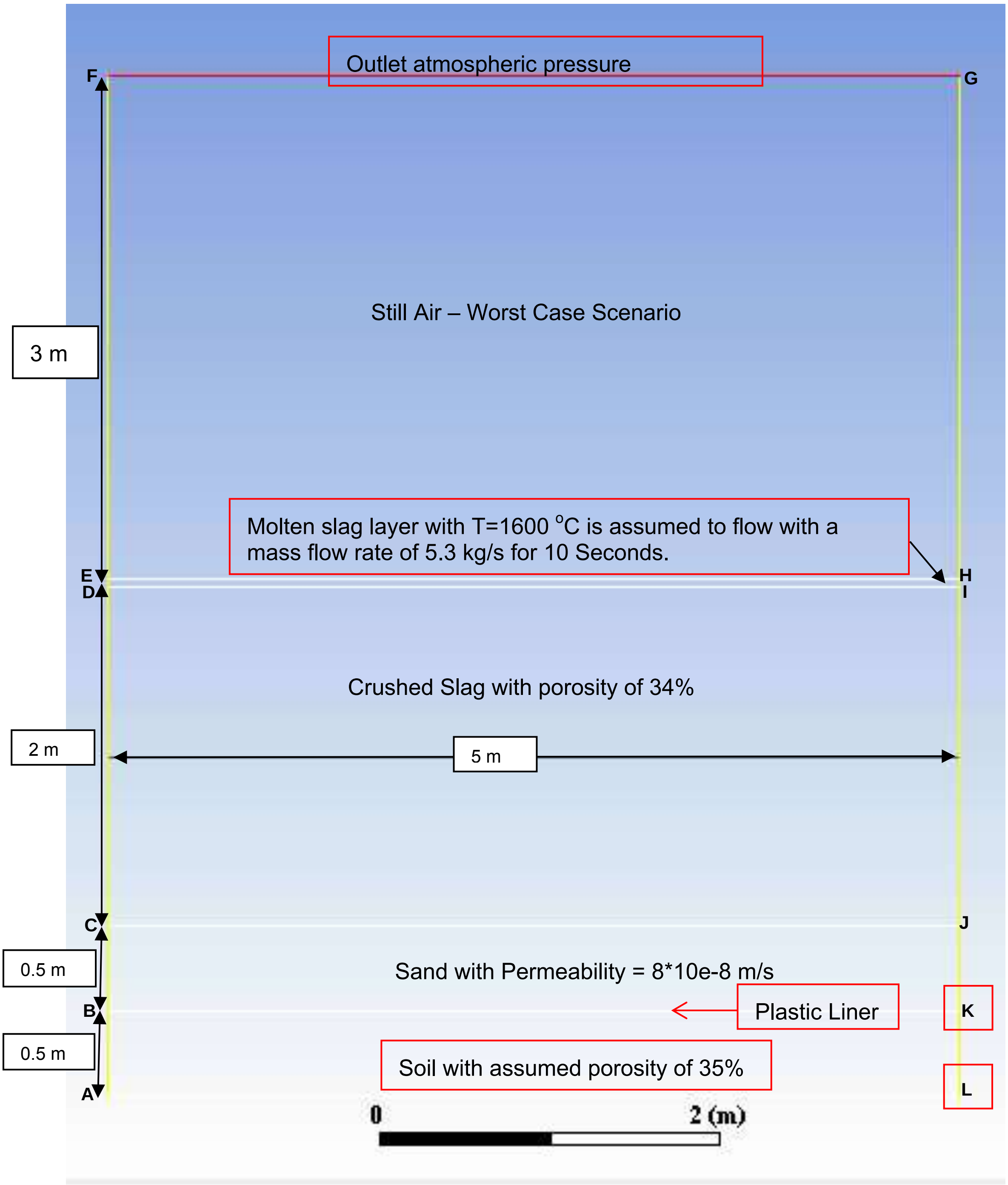
SLR has initially developed a single phase model assuming 1m thick thermal insulation layer beneath the slag dump. Results of simulation have shown that the temperature at the barrier containment system may reach 45°C.

Thermal layer insulation is then increased to reduce the temperature at the liner. Figure 3 shows the geometry for the final analysed scenario where the following two insulation layers are proposed:

- 2 m thick crushed slag with a maximum porosity of 34%
- 0.5 m thick sand with a permeability of 8e-8 m/s.

The computational domain includes the air surrounding the molten slag. Air is initially assumed to be at 300°C.

Figure 3 Geometric Dimensions of the CFD Model



3.1.2 Boundary Conditions

The boundary conditions are ladled in **Figure 3** and specified in **Table 1**

Tabl2 1: Initial and Boundary Conditions

Boundary	Type	Condition
ABCD	Symmetry	
LKJI	Symmetry	
HG	Symmetry	
EF	Symmetry	Heat Flux=0
AL	Wall	Constant Soil Temperature = 294^{o}K (21^{o}C)
KB	Wall	Liner temperature is predicted
HI	Mass flow rate	Mass Flow Liquid Metal=5.63 kg/s Molten Slag Temperature 1973^{o}K (1700^{o}C) The slag is assumed to flow continuously for 10 Seconds. A symmetry boundary condition is used at time>10 seconds.
DE	Pressure outlet	External Pressure = 0 Pascal for 10 seconds. A symmetry boundary condition is used at time>10 seconds.
FG	Pressure outlet	Still wind at external pressure = 0 Pascal and Temperature =300^{o}K (27^{o}C)
	Solidified Slag (Refer Section 3.4)	To couple the two side of the wall. A couple thermal condition is used and temperature is predicted

3.1.3 Modelling Approach

3.1.3.1 Multi-phase Model and Flow in Porous Media

Multiple fluid flow and heat transfer are considered for the molten slag (liquid) and the surrounding cooling air (gas) in this study.

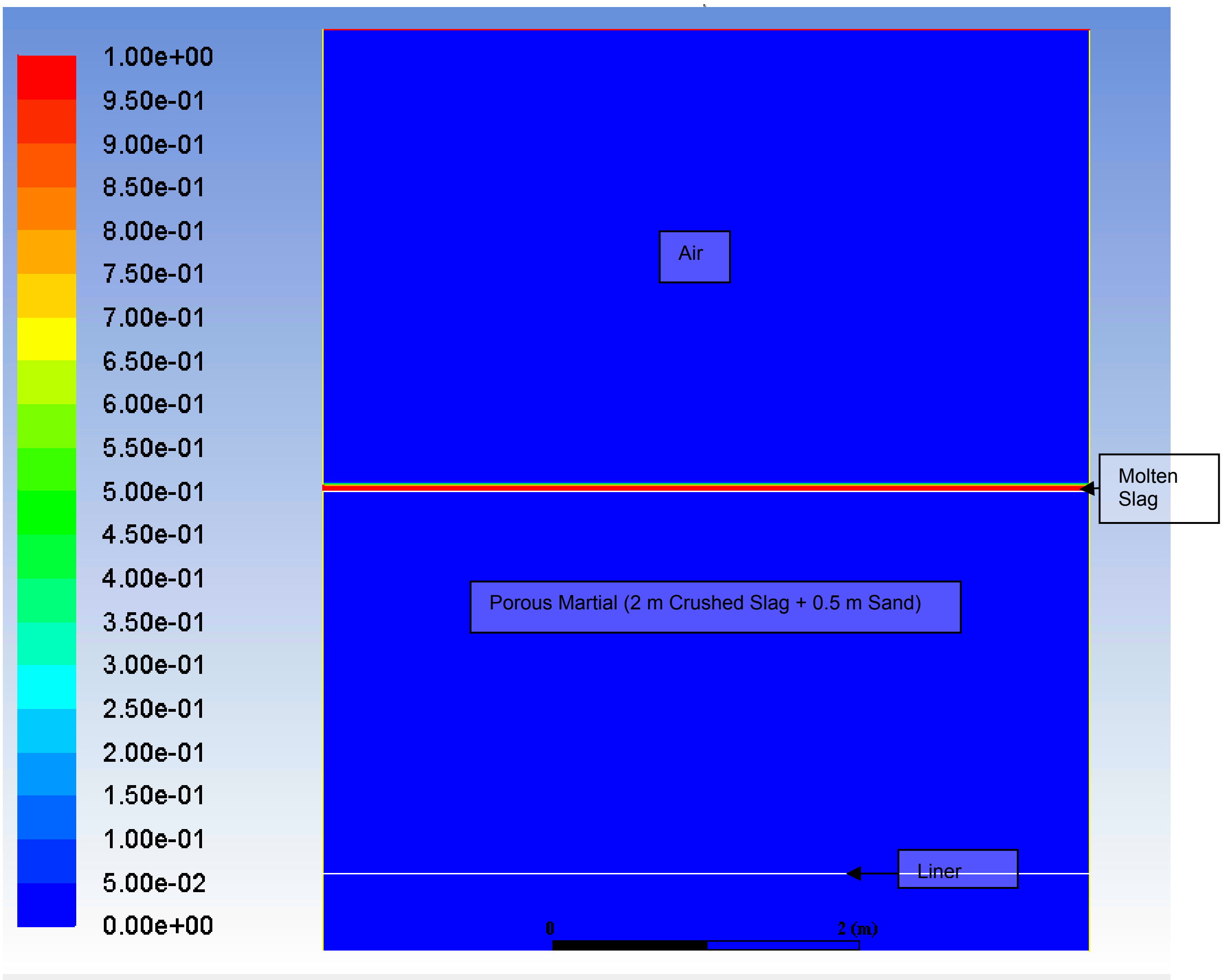
The Volume of Fluid (VOF) model with a free surface between the molten slag and air is predicted. The VOF formulation is used to compute a time dependent solution. The VOF model can model two or more immiscible fluids by solving a single set of momentum equations and tracking the volume fraction of each of the fluids throughout the domain.

Figure 4 shows the initial condition for the molten slag where a thick layer of 40 mm is assumed to flow over the thermal insulation layer (upper surface of the crushed slag).

Since the shape of the free surface will change due to the fluid flow condition over porous material. A combination for VOF and porous media modelling are considered in the current study.

Most commercial CFD software do not allow using VOF model with porous materials. The ANSYS software in its current Beta version allows for a combination for VOF and porous media modelling.

Figure 4 Initial Condition for the Liquid Slag Free Surface



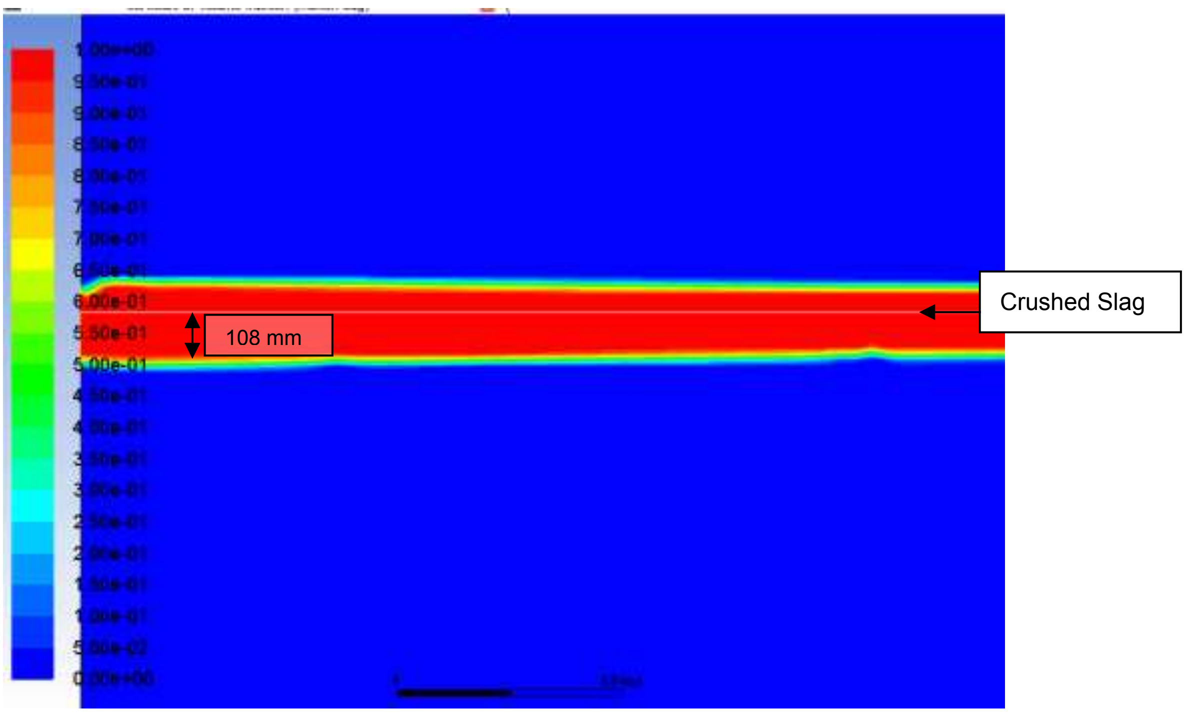
3.1.3.2 Phase Change Modelling

In order to reduce computational time, SLR has initially ignored the solidification process and concluded that the VOF model over predicts the molten slag penetration through the porous crushed material (Refer **Figure 5A**).

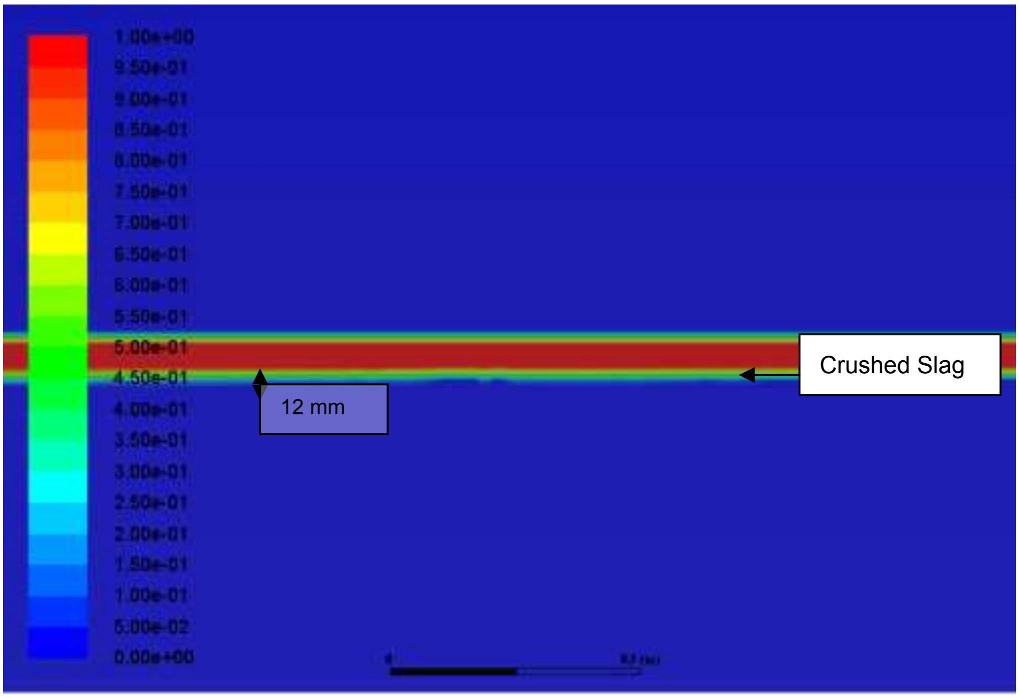
SLR has then included the solidification to track the molten slag and solid (crushed slag) front explicitly. The liquid-solid mushy zone is treated as a porous zone with porosity equal to the liquid fraction, and the pressure drop caused by the presence of solid material is accounted for. Result of simulation is shown in **Figure 5B**. One can see that the molten slag solidifies just below the top surface of the crushed slag.

Solidification of liquid slag into the solid slag is therefore modelled in this study without model approximation or trial and error method based on the temperature profile for each time step. The molten slag is assumed to solidify at T=1300^{o}C.

Figure 5 Liquid Slag Free Surface at Time = 10 Second with and without Solidification



A: VOF without Solidification



B: VOF with Solidification

3.1.3.3 Natural Convection and Conjugate Heat Transfer

When the molten slag flows or solidifies, heat is transferred o the air and the insulation layer. The buoyancy driven flow and heat transfer by conduction is therefore considered in this study.

Heat transfer is predicted through the two side of the solidified slag layer. The solver will calculate heat transfer directly from the solution in the adjacent cell based on the specified materials.

3.1.3.4 Flow Condition

This study involves a flow of a molten slag layer with a low velocity (0.07 m/s) during still wind condition (worst case scenario). Heat transfer is occurred via natural convection.

A laminar flow is assumed in this study.

This rate of heat transfer from a surface to a flow will be considerably greater than if the flow were laminar at the same Reynolds number [9].

This assessment of laminar flow is therefore considered conservative.

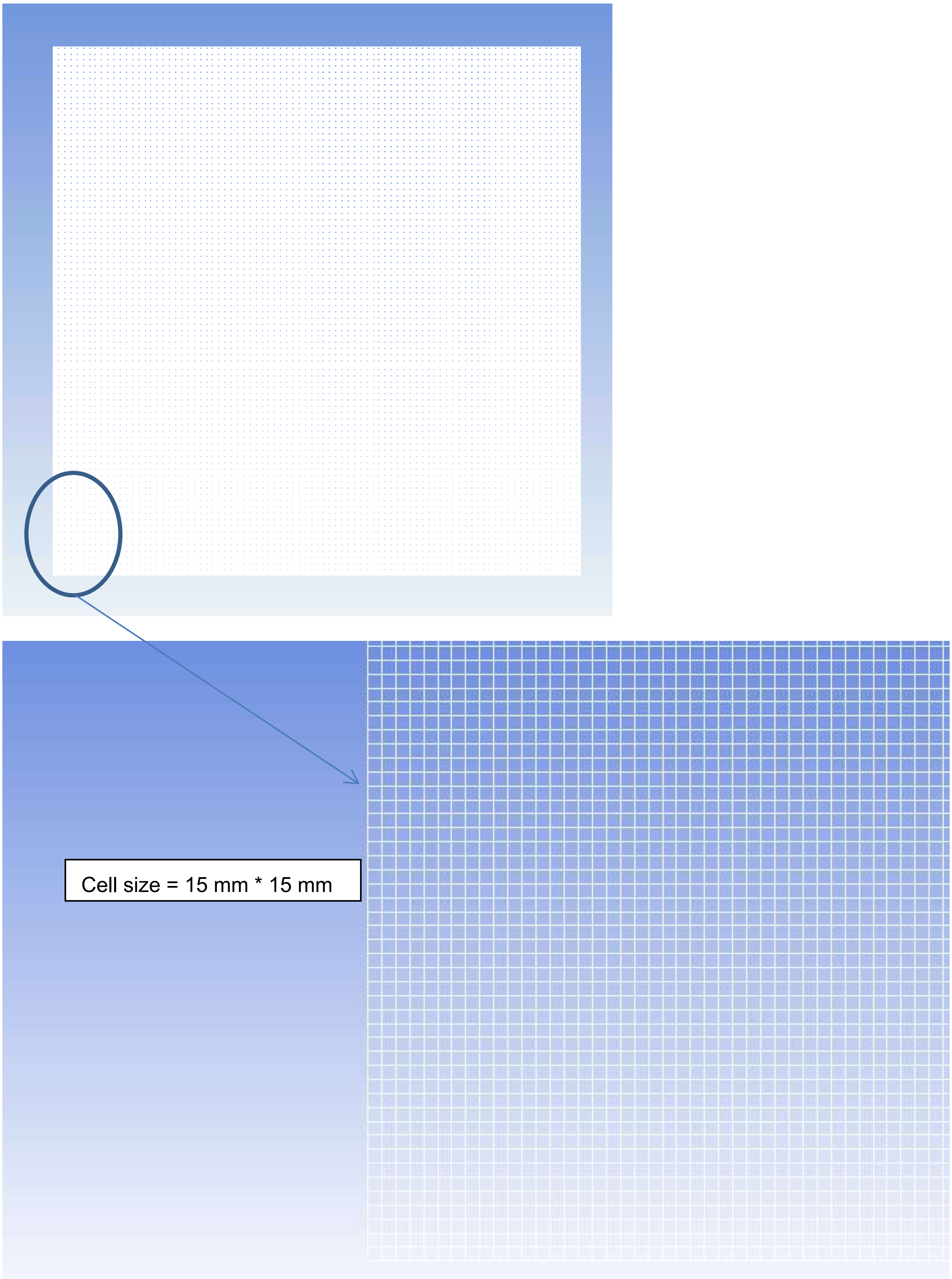
3.1.4 Discretisation

The software package utilised in the current CFD analysis is the commercially available code Fluent. The CFD model solves continuity and momentum equations in the computational domain to predict the transient temperature development at the liner.

For the current analysis approximately 134,000 square cells were used to cover the computational domain. The maximum cell size in the domain is 15mm * 15 mm (Refer **Figure 6**). The following techniques were used for discretization:

- A second order numerical scheme was used for discretisation of momentum and energy to obtain more accurate results.
- A PRESTO numerical scheme [10] was used for discretisation of pressure to obtain more accurate results. PRESTO is a second order scheme, which is often useful when there are strong body forces present such as natural convection.
- The pressure and velocity are coupled using PISO scheme [10].
- A very small time step between 0.001 – 0.01 Sec is used during the initial stage where the molten slag is started to flow for up to 10 Sec. Variable time step technique is then adopted to obtain valid numerical solution for up to time = 806,600 Sec of heat transfer simulation.
- An iterative procedure was used to estimate the free surface, air velocity in terms of two direction, pressure profile and temperature distribution.

Figure 6 Mesh for CFD Modelling



4 CFD RESULTS AND DISCUSSIONS

4.1 Time = 0 to 10 Sec

A very small time step between 0.001 and 0.01 Sec is used for the first 10 seconds of the simulation where the transient free surface of the molten slag is predicted. The study involved molten slag solidification at T=1300^{o}C.

Results of simulations are presented in **Figure 7** to **Figure 10**.

Figure 7 shows the temperature profile at time =0.1 Sec. Temperature distribution in **Figure 7a** is plotted on a colour coded scale between 294 and 1873 K. Dark blue represents soil temperature at 294 K and red representing the molten slag at 1873 K.

One can see that the molten slag layer has a fixed temperature of 1873 K as per the given boundary conditions. Heat is then started to transfer to the surrounding air via natural convection and to the insulated layer via convection (Refer **Figure 7b**).

The temperature profile at time =3 Sec is shown in **Figure 8**. The following conclusions can be achieved from **Figure 8**:

- The CFD model captures the heat transfer characteristic very well where convection heat transfer to surrounding air is rapidly increased due to the heat added to the surrounding air. The air density varies with temperature, air flow induced in the computational domain due to the force of gravity acting on the density variations.

Contours of molten slag volume fraction at time = 10 Sec is shown in **Figure 9**. Volume fraction is plotted on a colour coded scale between 0 and 1. Dark blue represents region with no molten slag and red representing the molten slag. One can see that the volume faction of the molten slag just below the top surface of the crushed slag is 0.65.

The molten slag solidifies at Temperature = 1300^{o}C. Temperature distribution of solidified slag is shown in **Figure 10**.

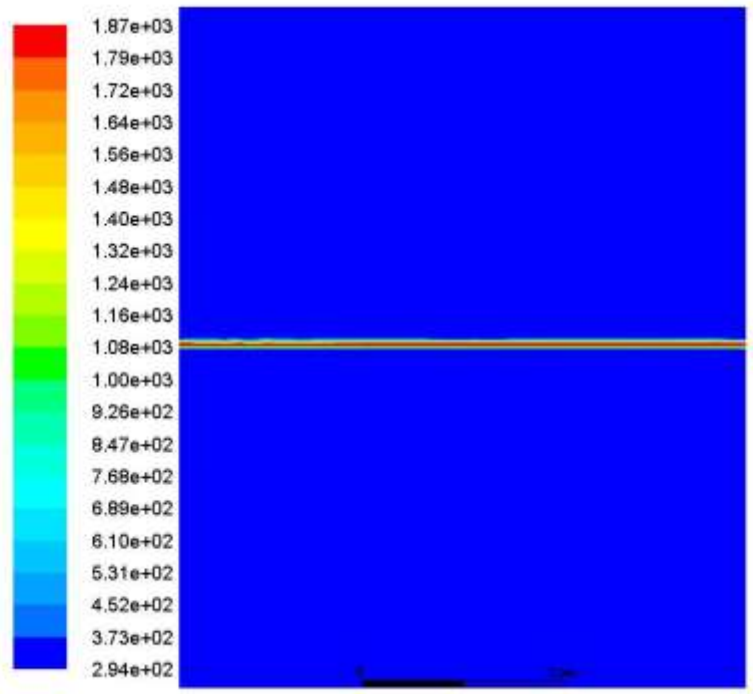
4.2 Time > 10 Sec

No molten slag is assumed to flow at Time>10 Sec. Results of simulations are shown in **Figure 11** to **Figure 36.** The following major conclusions can be reached from the above figures:

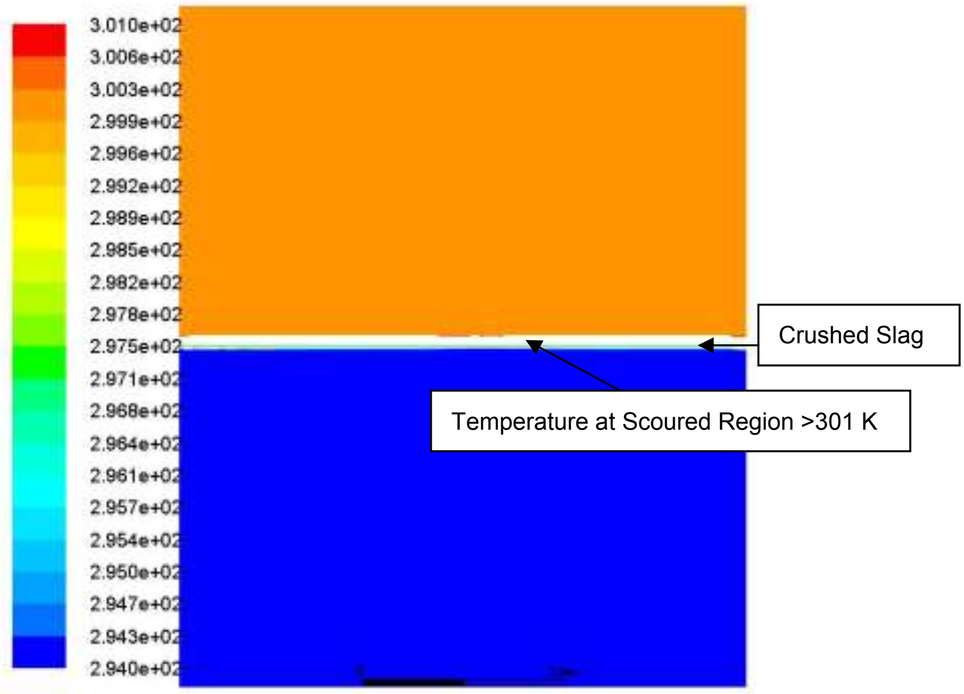
- Upper surface temperature of the crushed slag is rapidly reduced to 1182 K (909 ^{o}C) at time = 20 Sec (Refer **Figure 11**).
- The thickness of the solidified slag is increased at Time=120 Second (Refer **Figure 12**) and the maximum temperature of the molten slag is reduced to 1744 K (1471 ^{o}C). There is no change in the temperature at the liner area (Refer **Figure 13**).
- The slag is completed solidified at time = 250 Sec (Refer **Figure 14**).
- It takes approximately 30 hours for the heat wave to pass through the liner. Liner temperature is increased by 0.09 ^{o}C at Time =118,820 Sec (Refer **Figure 24**). The time delay is due to the thermal mass of the insulation material layer (2 m of crushed slag plus 0.5 m of sand). The thicker and more resistive the material, the longer it will take for heat waves to pass through.
- The liner temperature peaks at Time = 635,600 Second or 176.56 hours (Refer **Figure 34**). The peak temperature is 298.82 K (25.82^{o}C).
- Liner temperature will reduce after Time > 635,600 Second (Refer **Figure 35** to **Figure 37**).

Once the liner is cooled down, the additional solidified slag layer covering the thermal protection layer will provide additional protection for the liner.

Figure 7 Temperature Distribution (K) at Time = 0.1 Sec

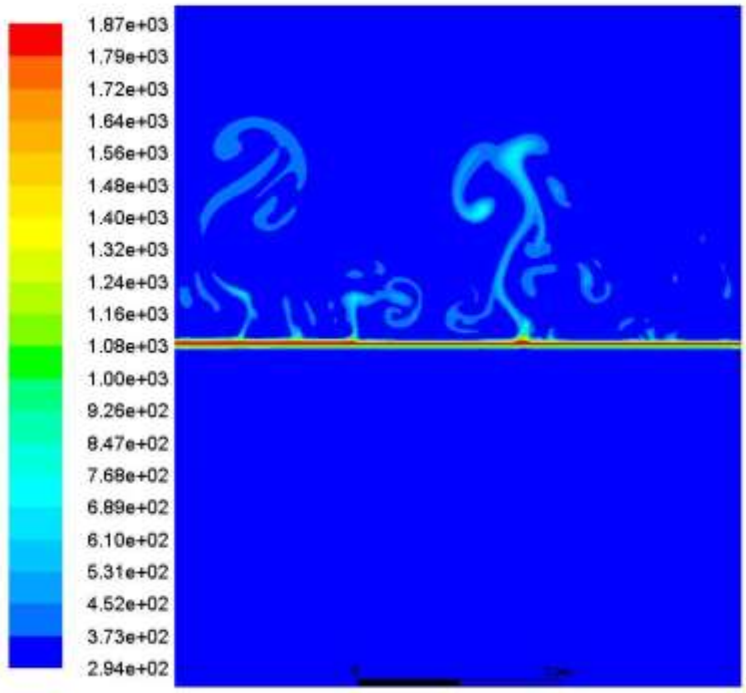


A: On 294 K (21°C) – 1873 K Scale(1600°C)

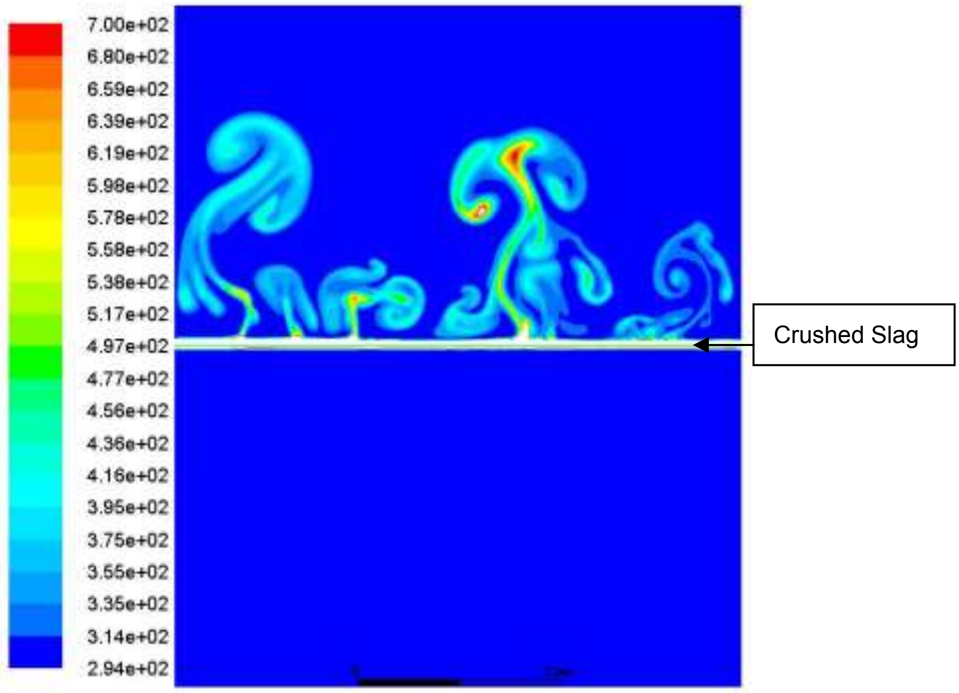


B: On 294 K (21°C) – 301 K Scale(28°C)

Figure 8 Temperature Distribution (K) at Time = 3 Sec

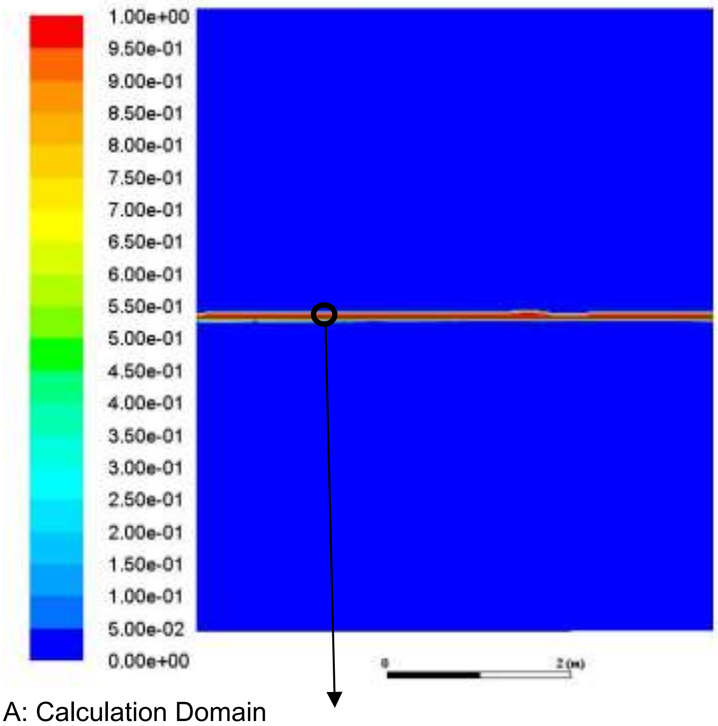


A: On 294 K (21°C) – 1873 K Scale(1600°C)

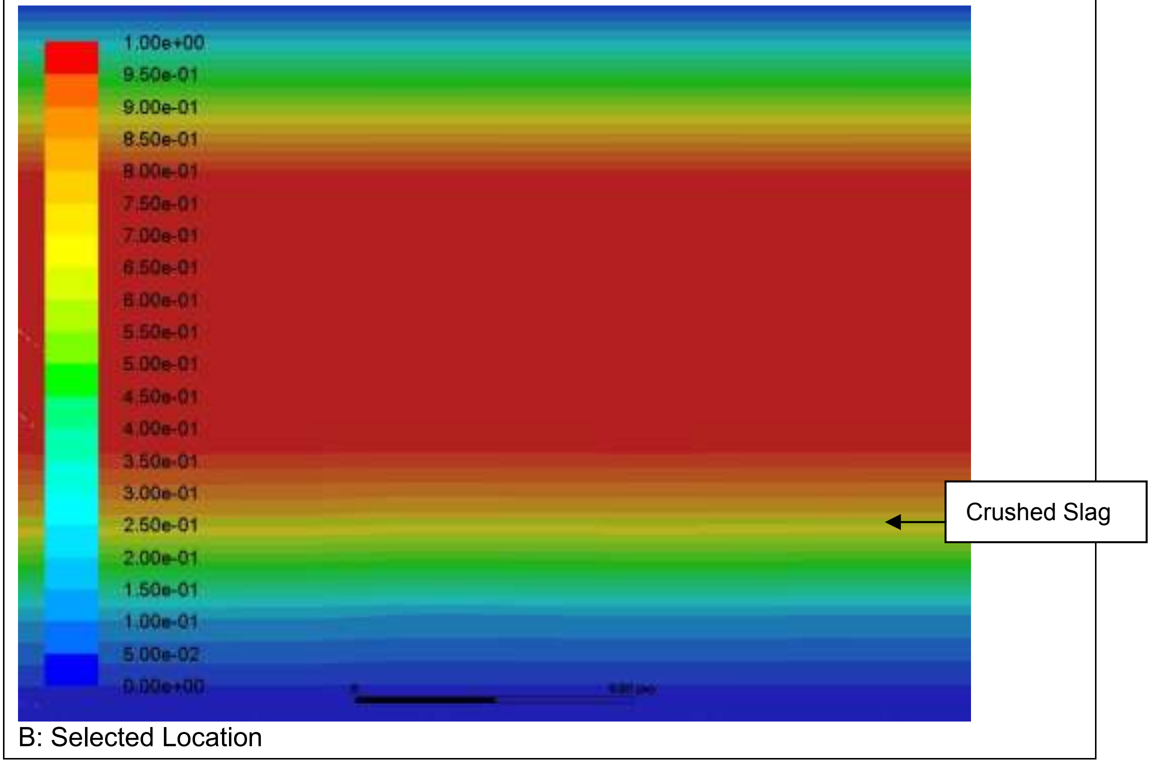


B: On 294 K (21°C) – 700 K Scale(427°C)

Figure 9 Liquid Slag Free Surface at Time = 10 Sec

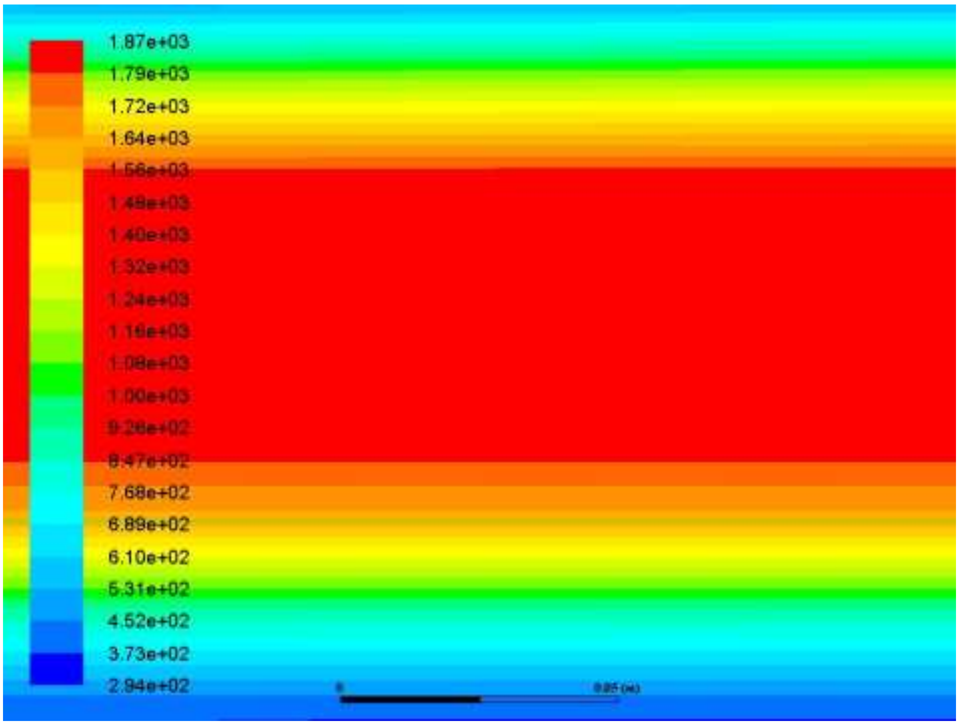


A: Calculation Domain

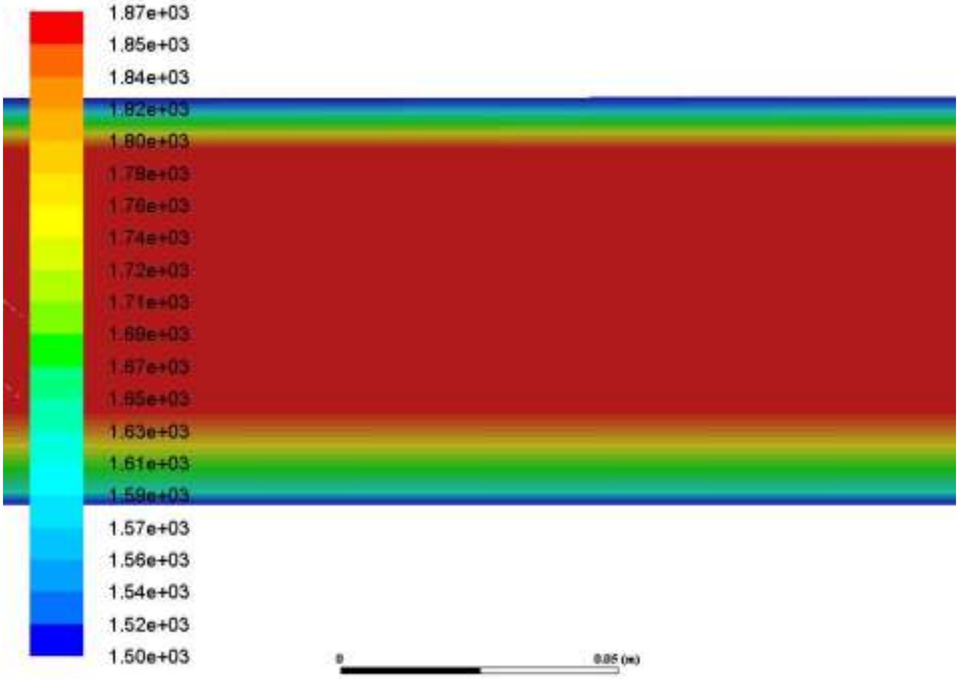


B: Selected Location

Figure 10 Temperature Distribution (K) at the Interface between the Molten Slag and Porous Crushed Slag at Time = 10 Sec (Continues Molten Slag flow with Solidification Modelling)



A: On 294 K (21°C) – 1873 K Scale (1600°C)



B: On 1500 K (1227°C) – 1873 K Scale (1600°C)

Figure 11 Temperature Distribution (K) at = 20 Sec

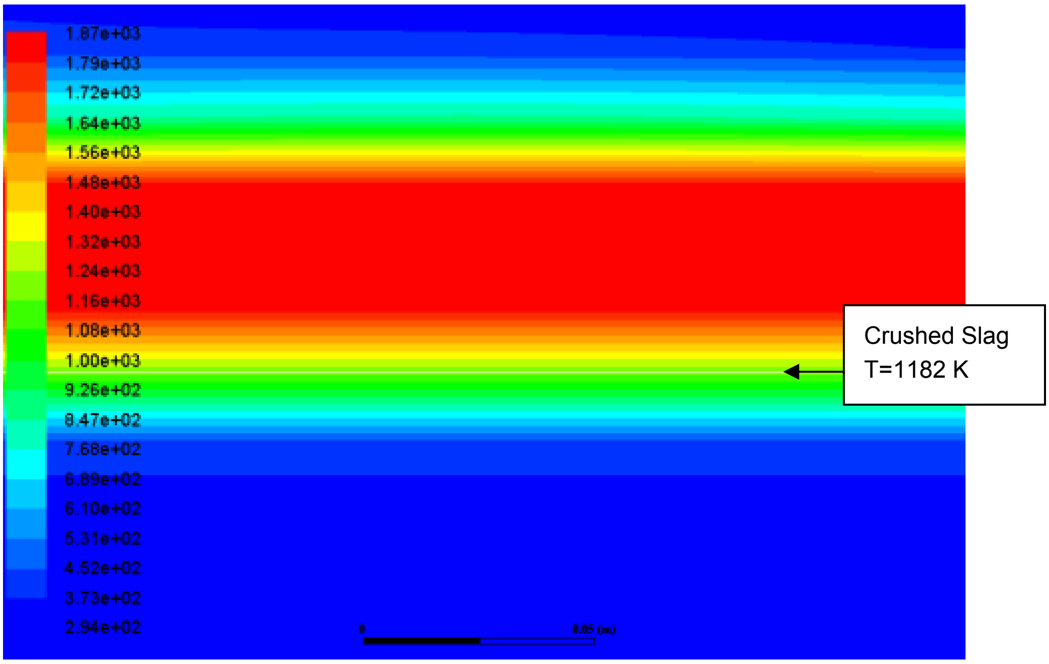


Figure 12 Temperature Distribution (K) at = 120 Sec

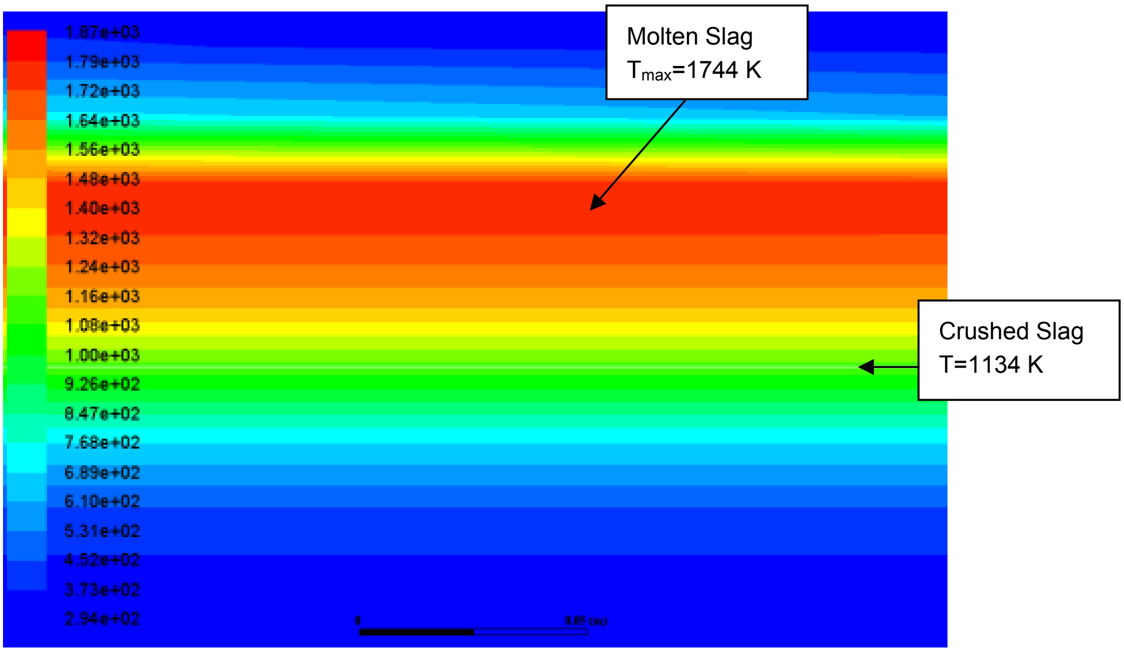
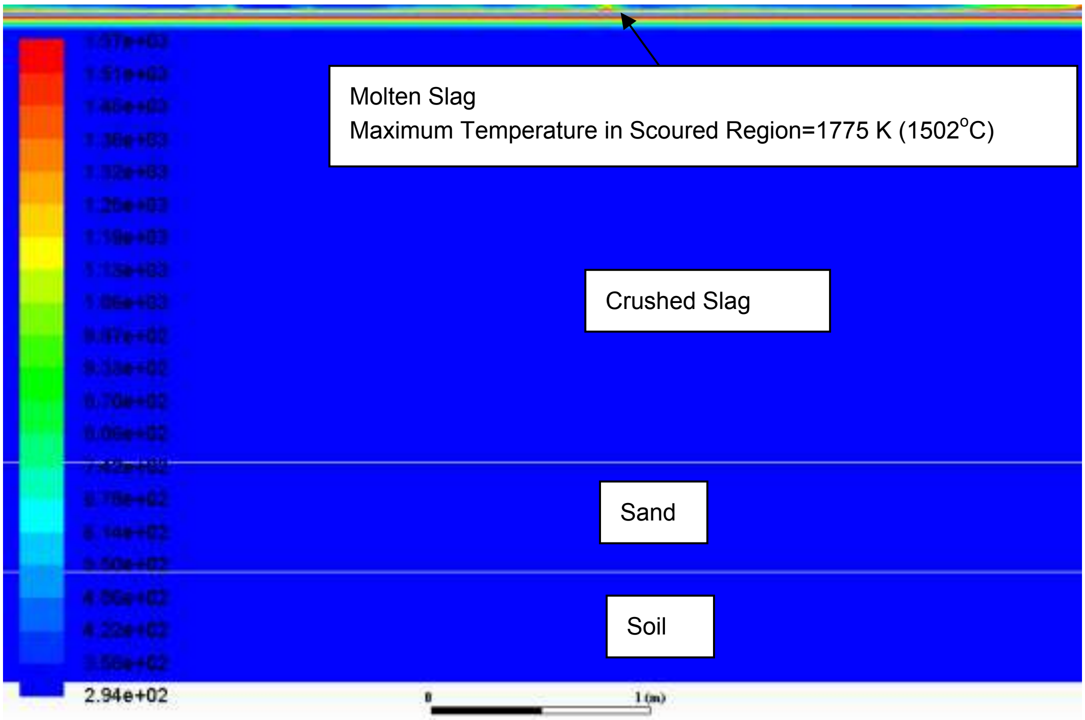
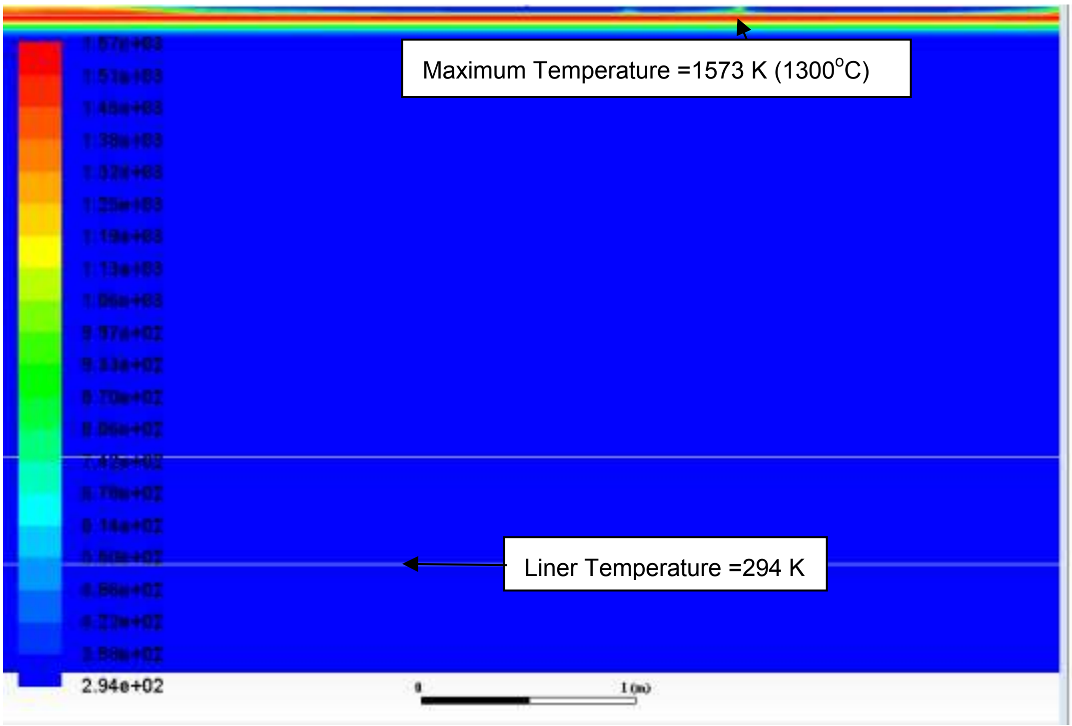


Figure 13 Temperature Distribution (K) at = 120 Sec



On 294 K (21°C) – 1573 K Scale (1300°C)

Figure 14 Temperature Distribution (K) at = 250 Second



On 294 K (21°C) – 1573 K Scale (1300°C)

Figure 15 Temperature Distribution (K) at Time = 600 Sec

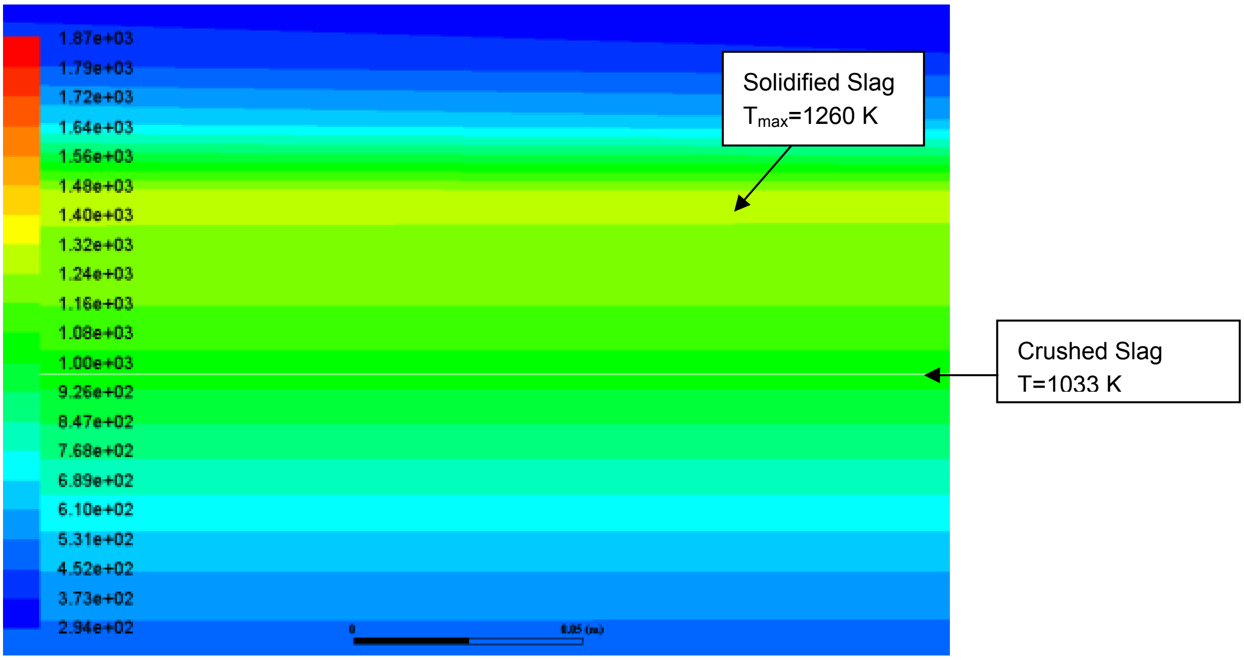


Figure 16 Temperature Distribution (K) at Time = 880 Second

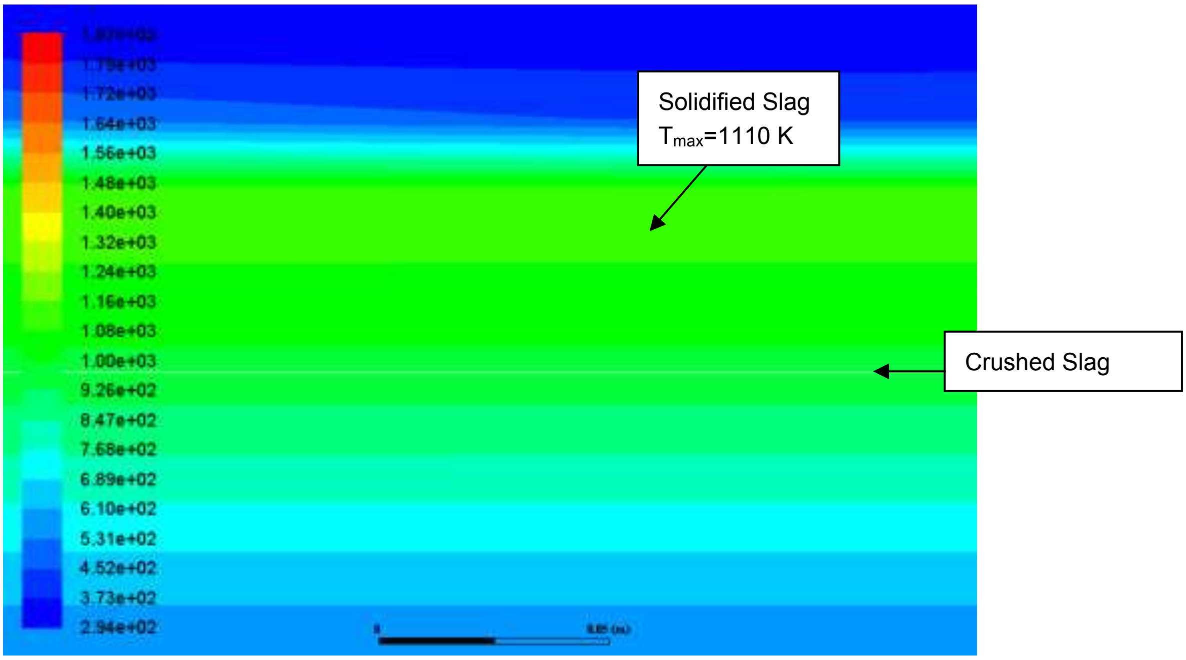
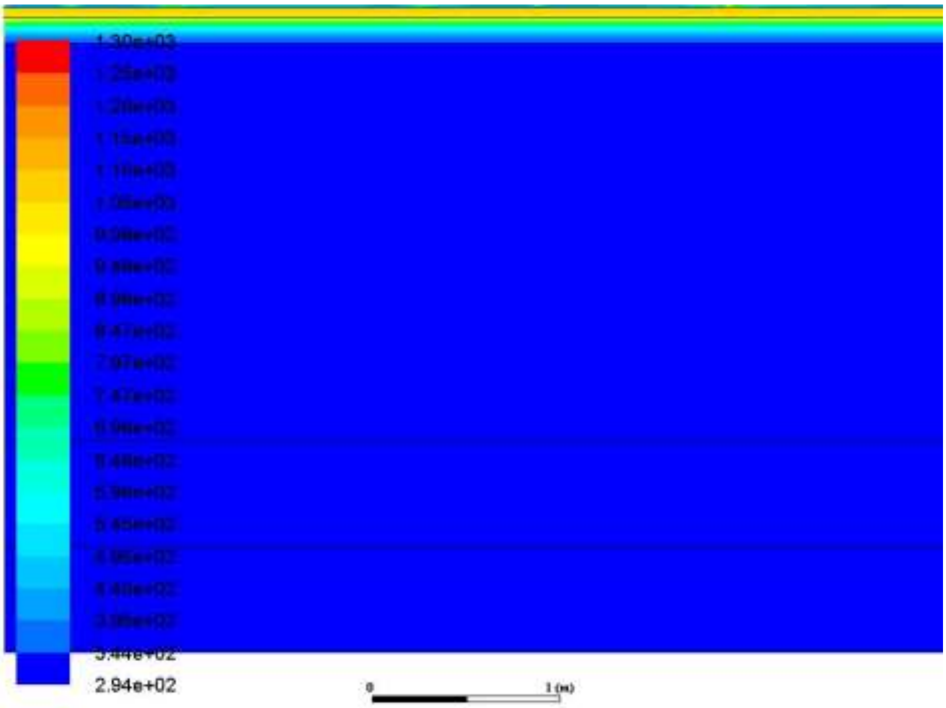
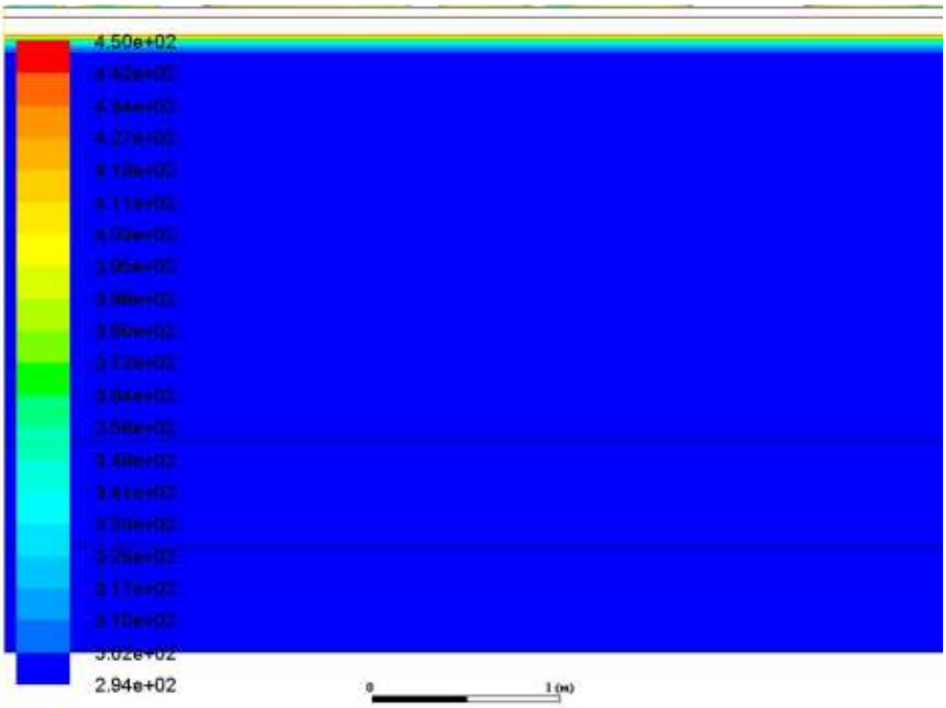


Figure 17 Temperature Distribution (K) at Time = 900 Sec



A: On 294 K (21^{o}C) – 1300 K Scale(1027^{o}C)



A: On 294 K (21^{o}C) – 450 K Scale(177^{o}C)

Figure 18 Temperature Distribution (K) at Time = 4,800 Sec

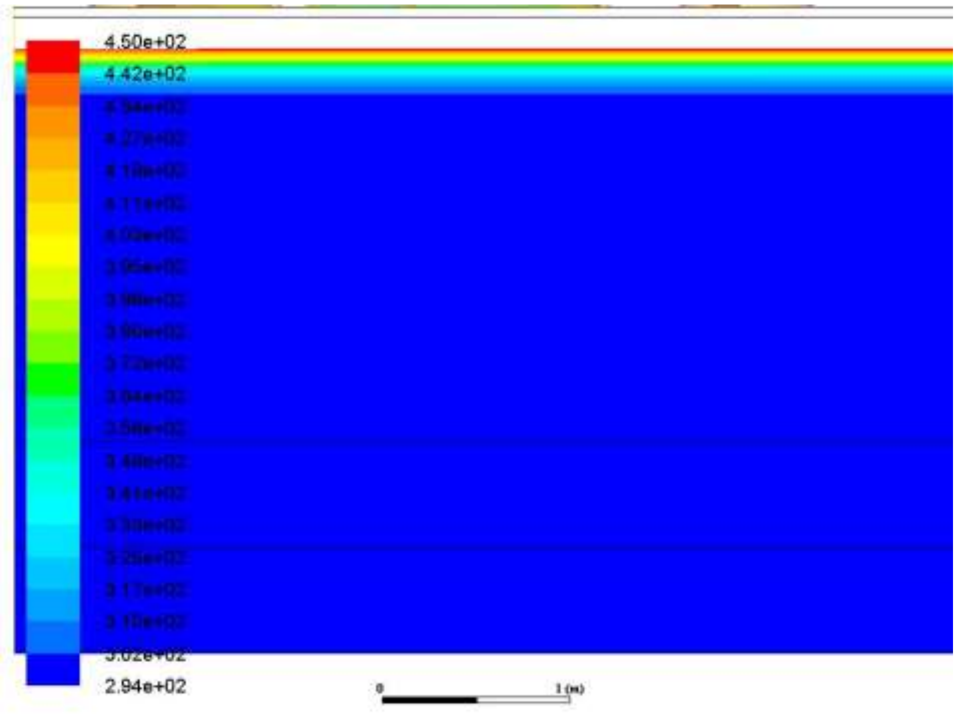


Figure 19 Temperature Distribution (K) at Time = 10,820 Sec

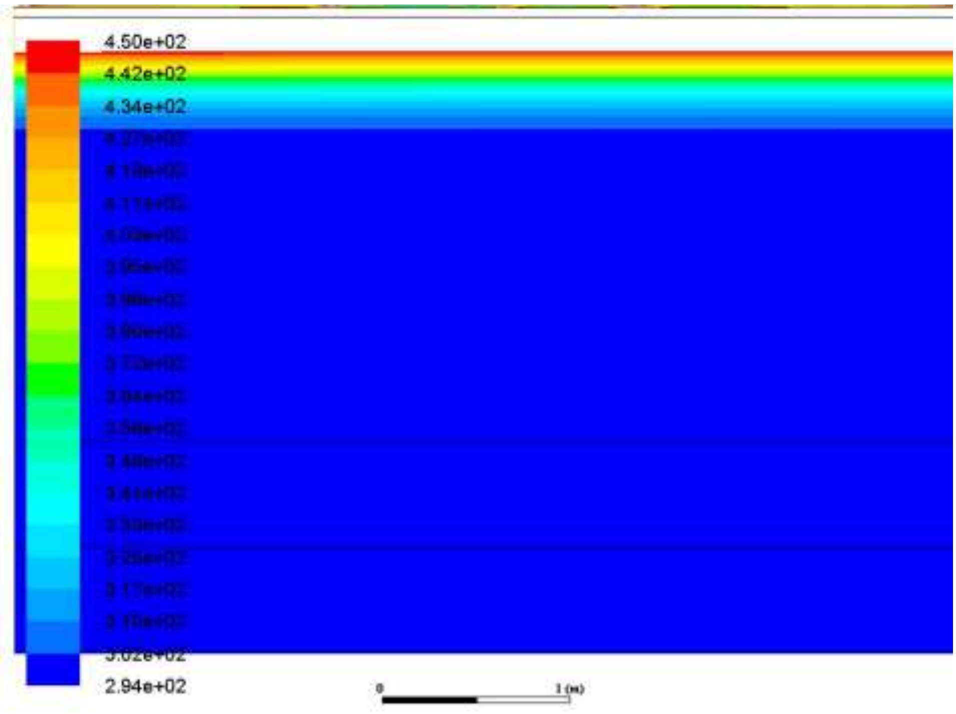


Figure 20 Temperature Distribution (K) at Time = 16,820 Sec

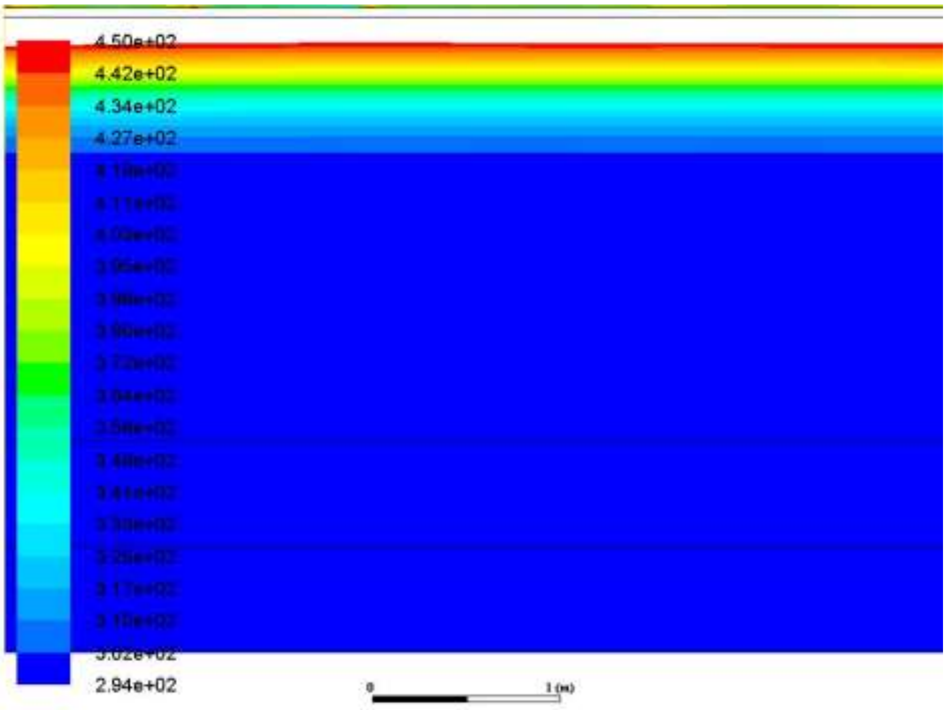


Figure 21 Temperature Distribution (K) at Time = 34,820 Sec

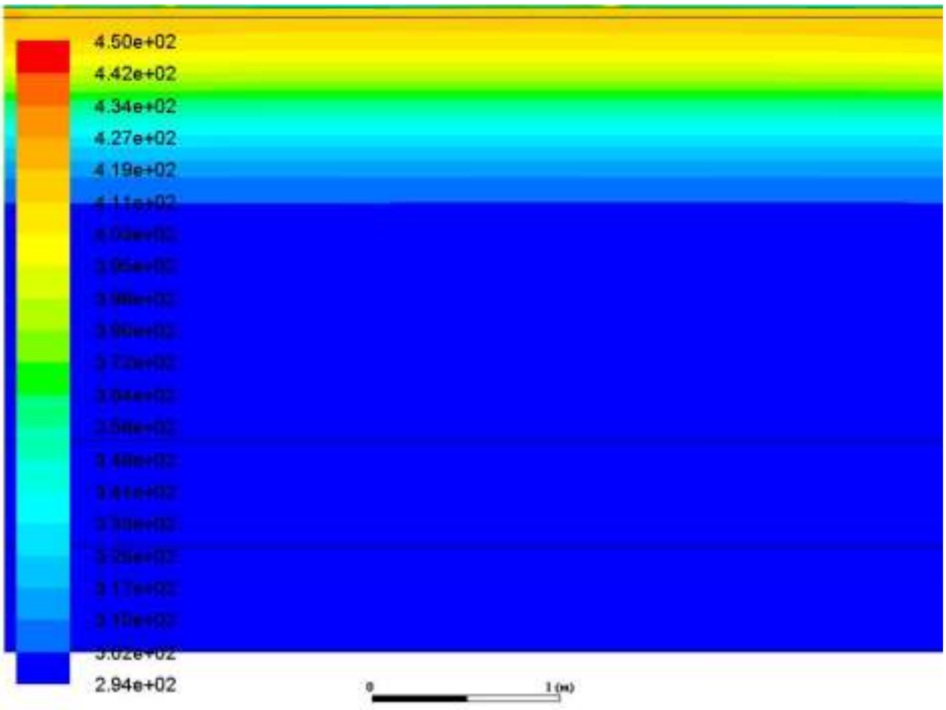


Figure 22 Temperature Distribution (K) at Time = 58,820 Sec

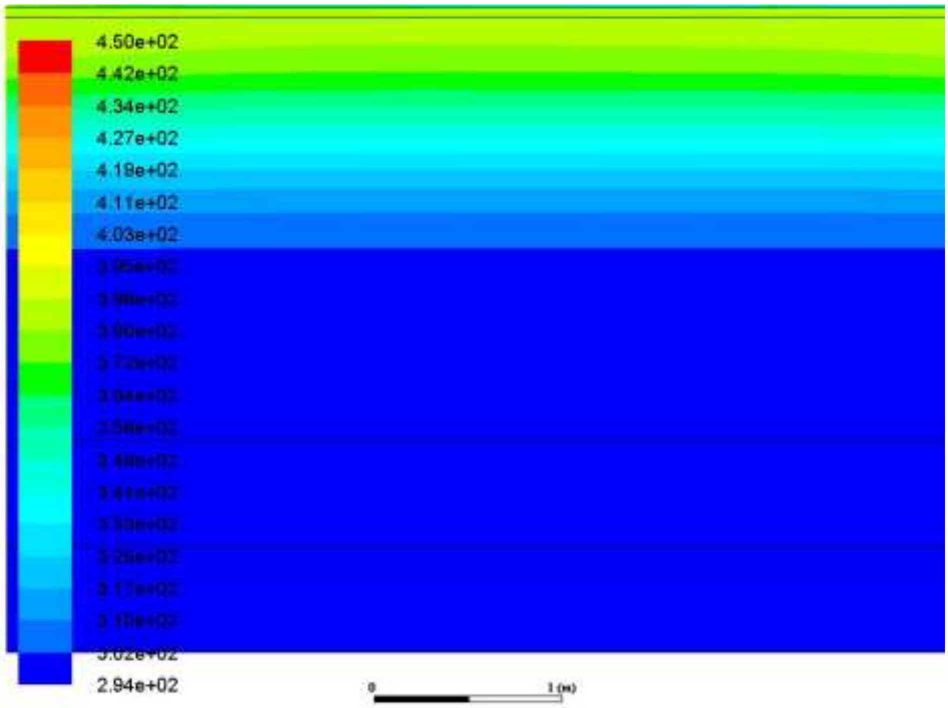
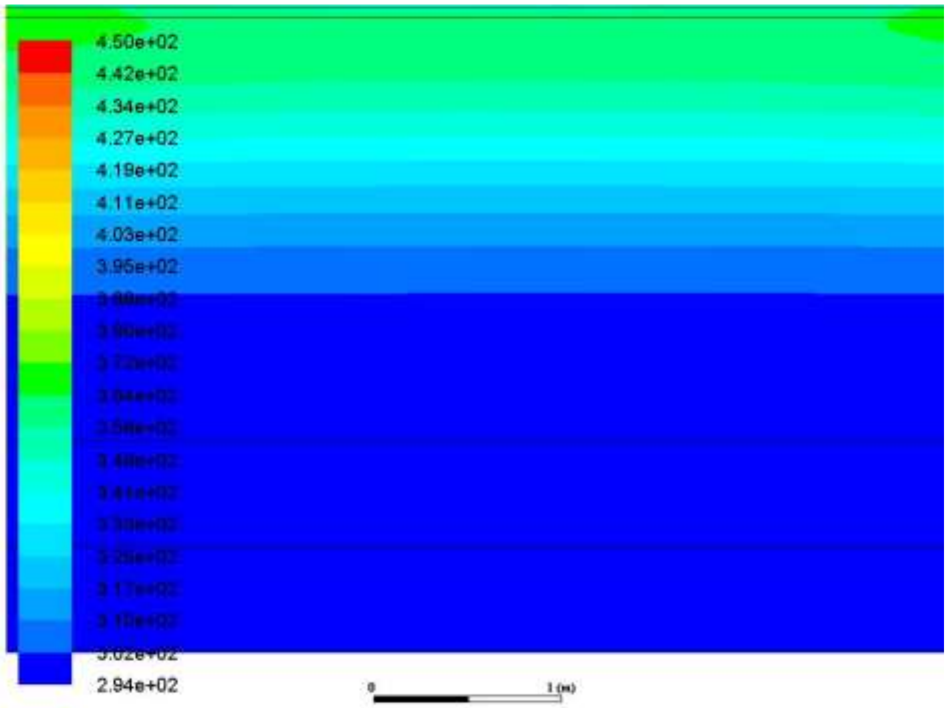
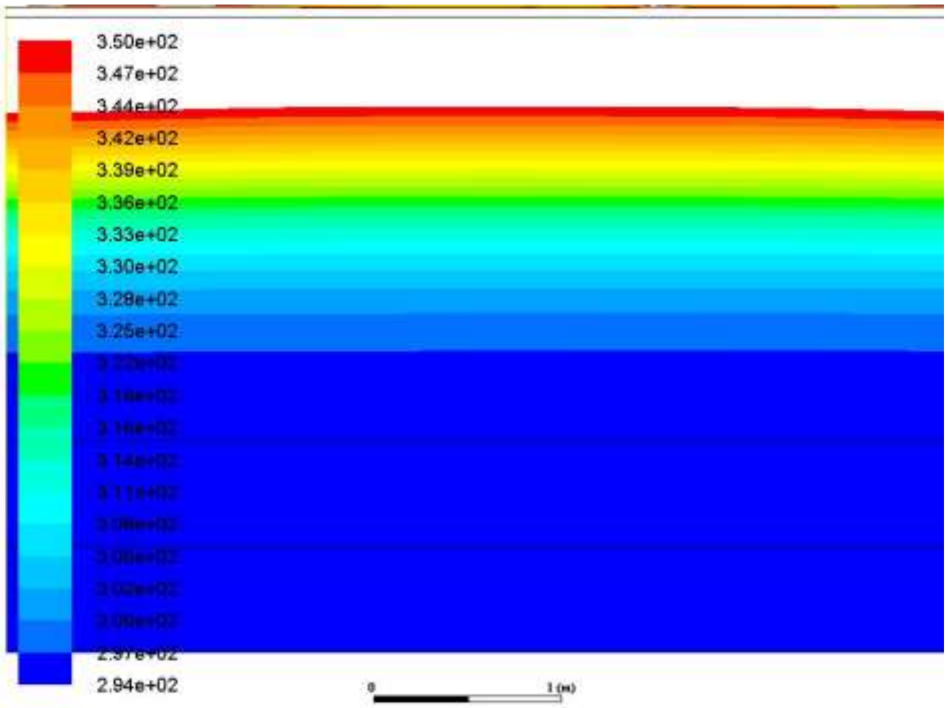


Figure 23 Temperature Distribution (K) at Time = 92,120 Sec

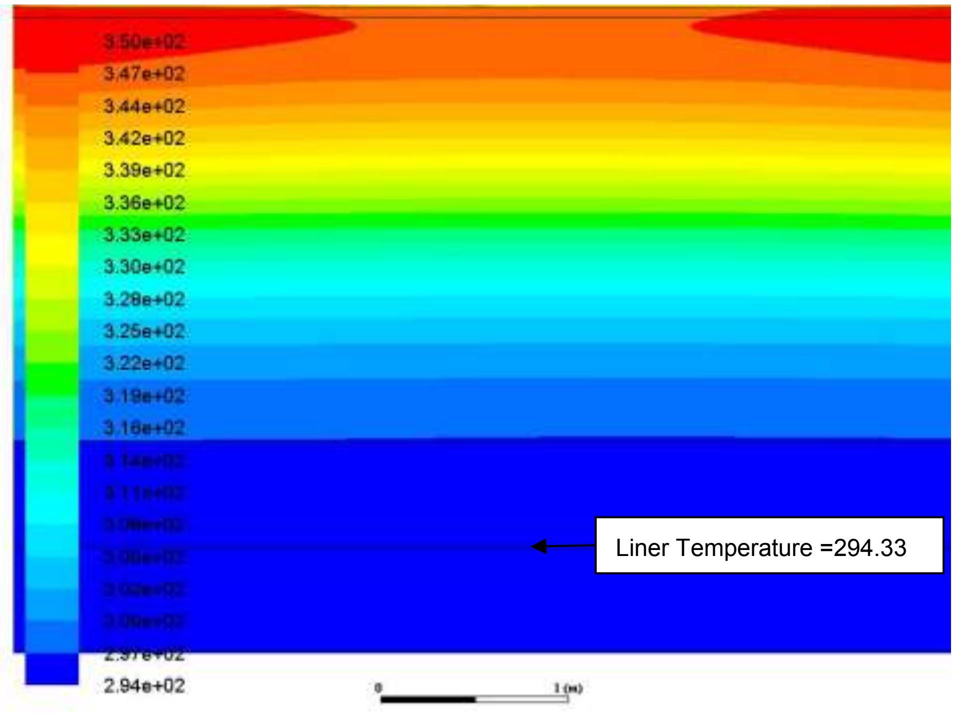


A: On 294 K (21°C) – 450 K Scale (177°C)



A: On 294 K (21°C) – 350 K Scale (77°C)

Figure 24 Temperature Distribution (K) at Time = 148,820 Sec



Liner Temperature =294.33

Figure 25 Temperature Distribution (K) at Time = 178,820 Sec

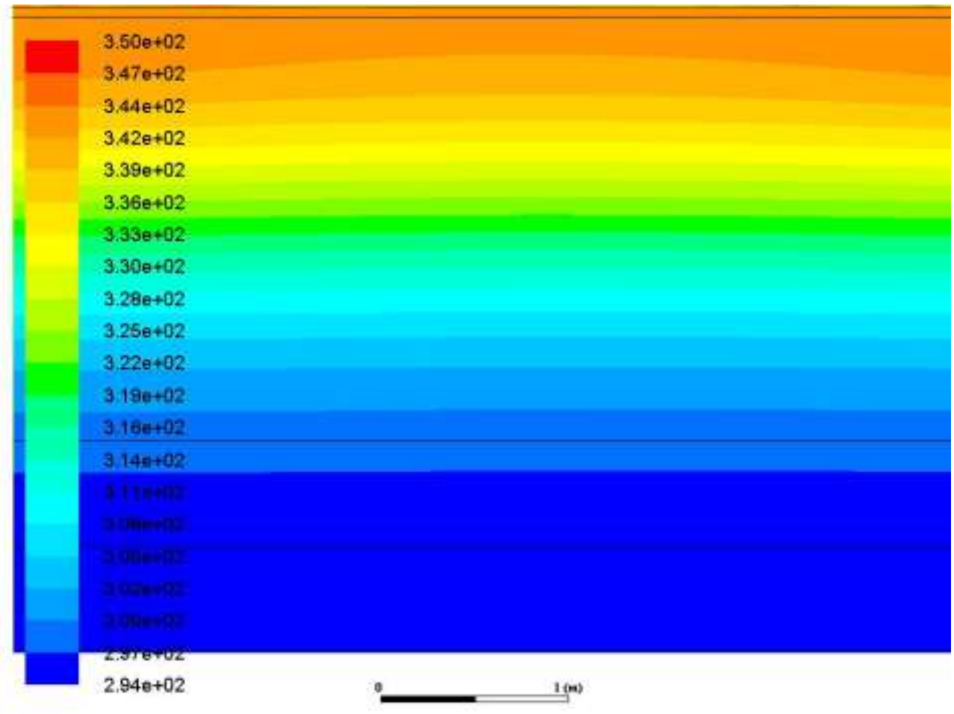


Figure 26 Temperature Distribution (K) at Time = 218,460 Sec

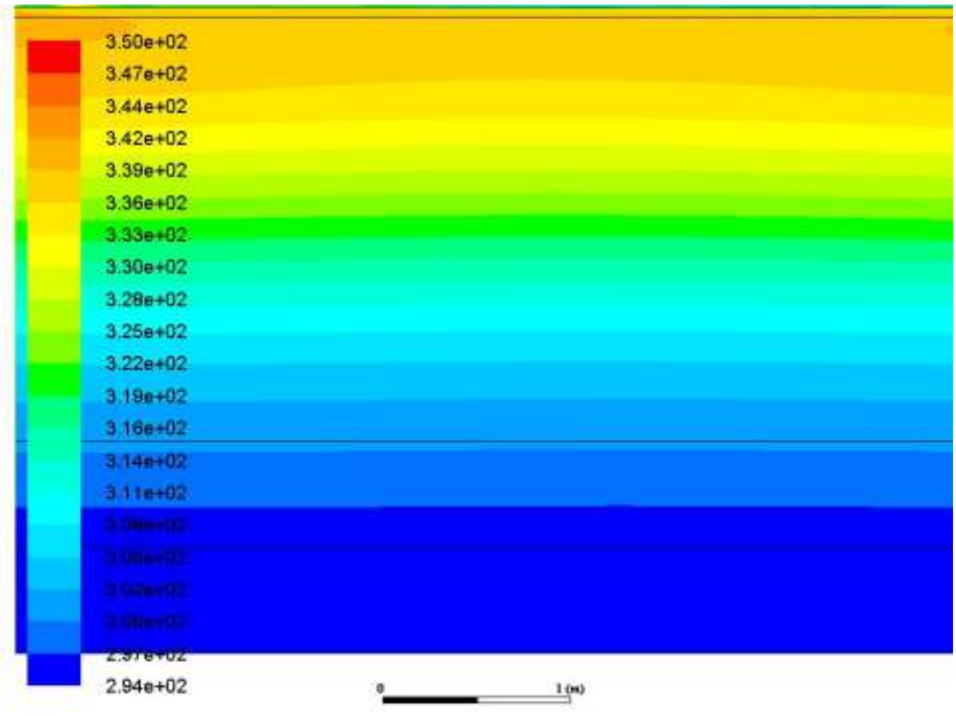


Figure 27 Temperature Distribution (K) at Time = 252,700 Sec

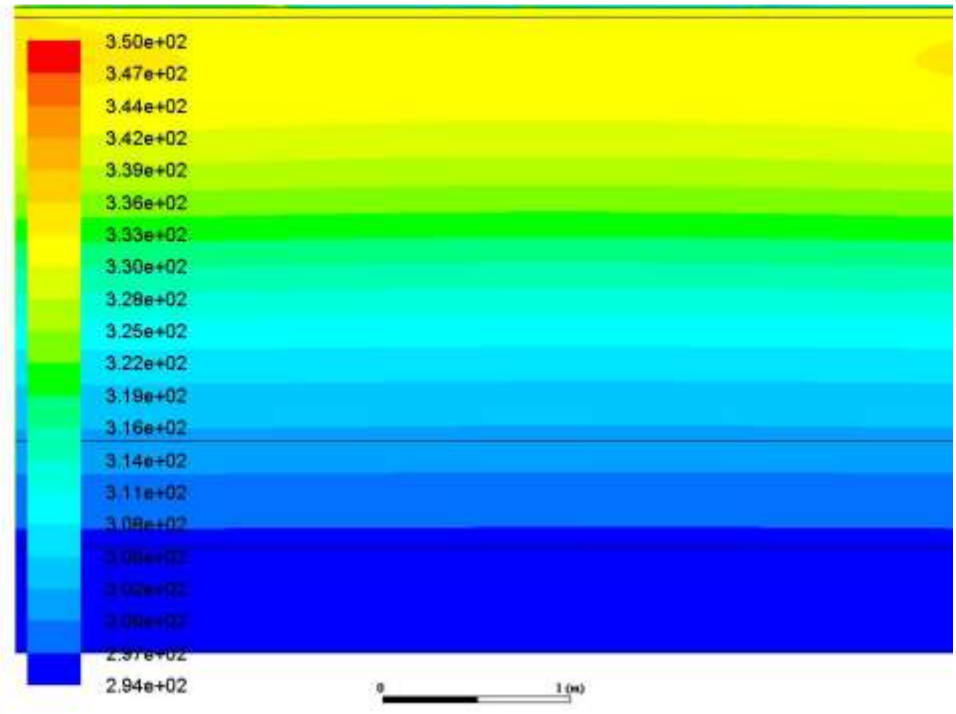


Figure 28 Temperature Distribution (K) at Time = 296.980 Sec

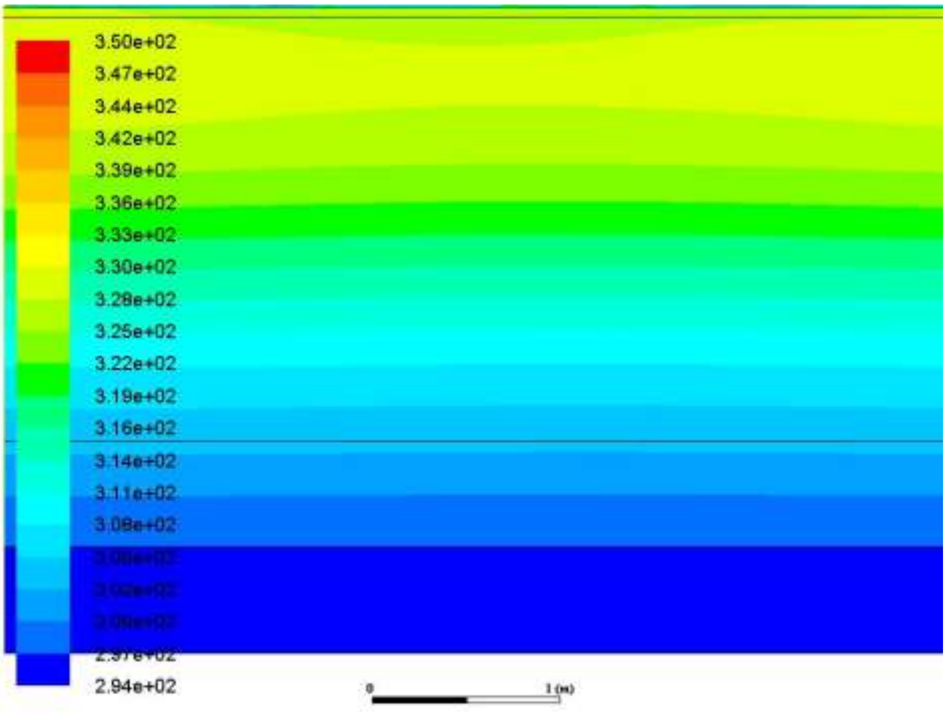


Figure 29 Temperature Distribution (K) at Time = 331,800 Sec

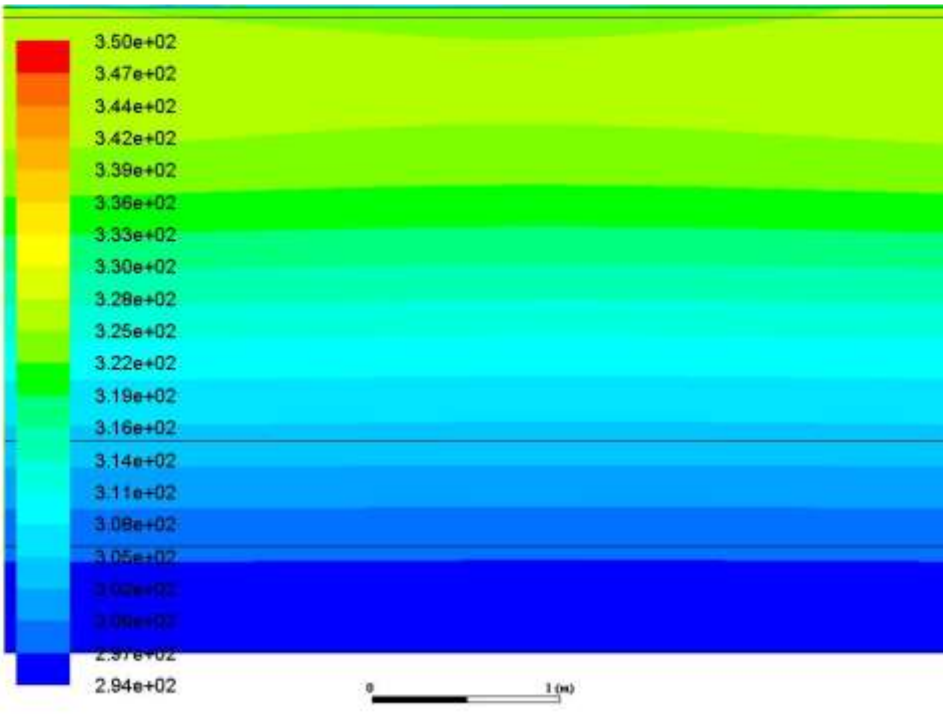
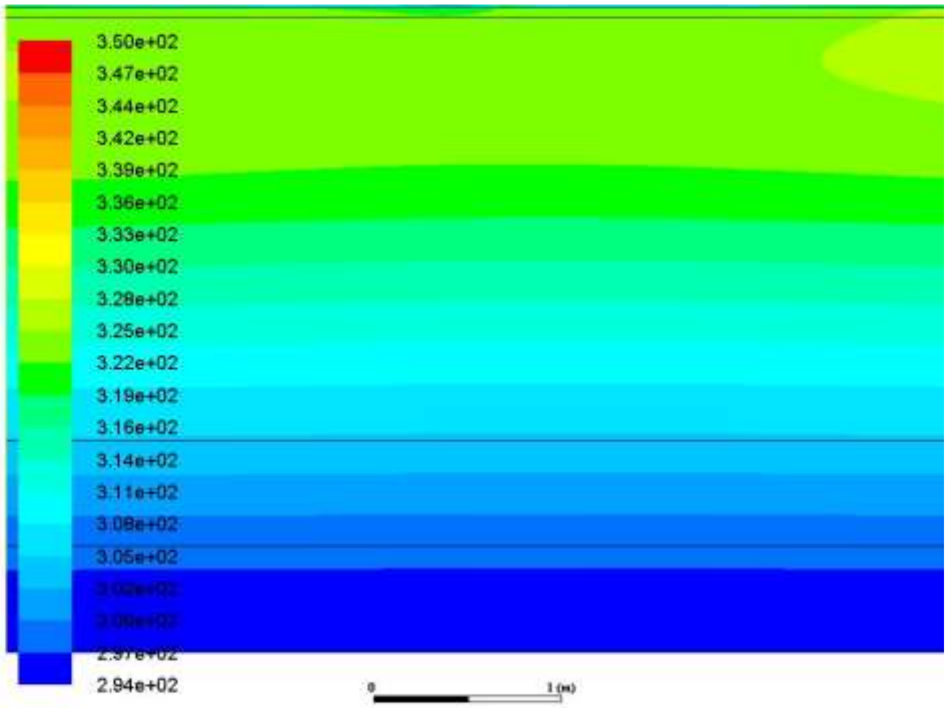
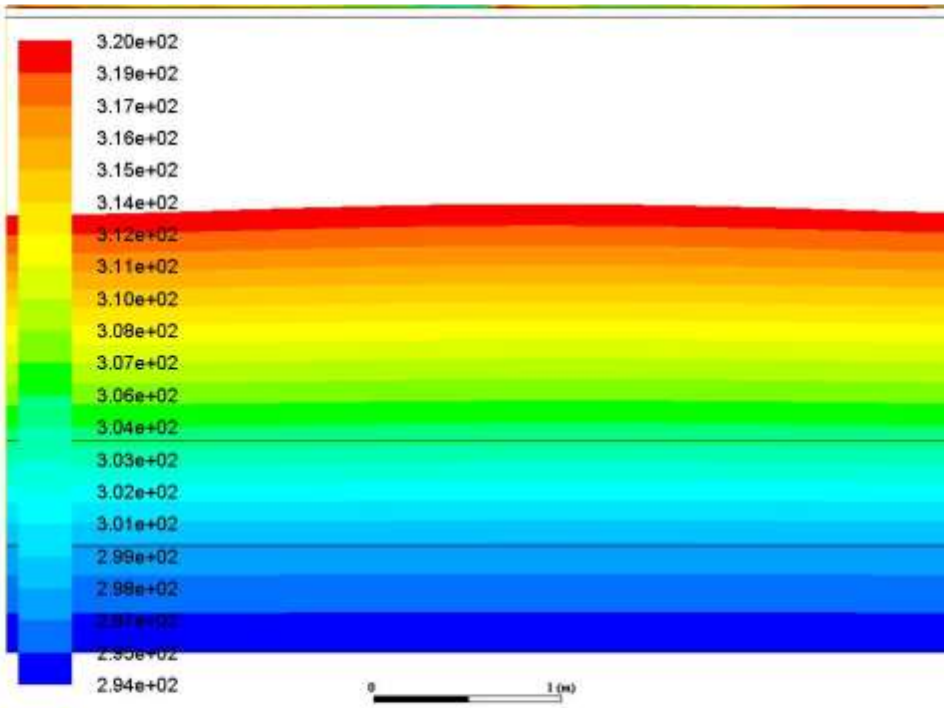


Figure 30 Temperature Distribution (K) at Time = 360,000 Sec



A: On 294 K (21°C) – 350 K Scale (77°C)



A: On 294 K (21°C) – 320 K Scale (47°C)

Figure 31 Temperature Distribution (K) at Time = 434,400 Sec

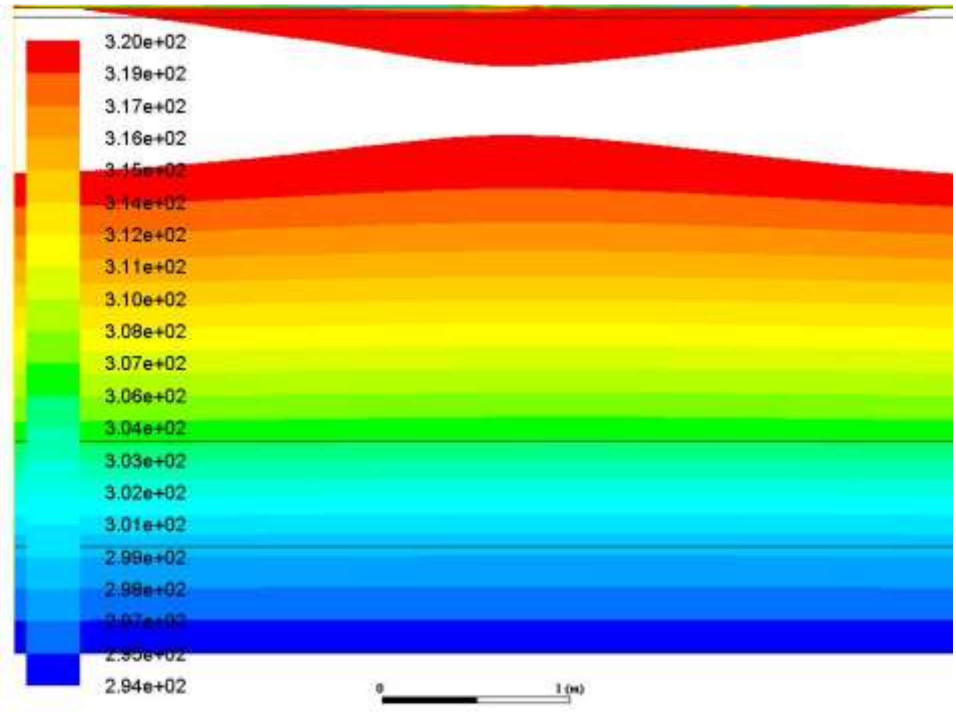


Figure 32 Temperature Distribution (K) at Time = 491,600 Sec

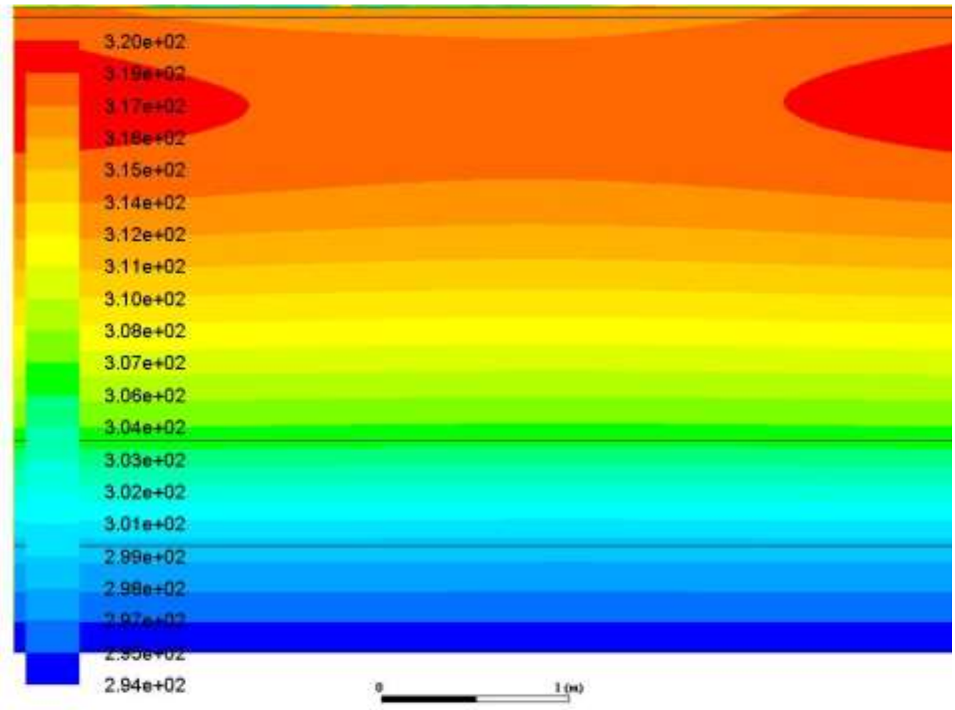
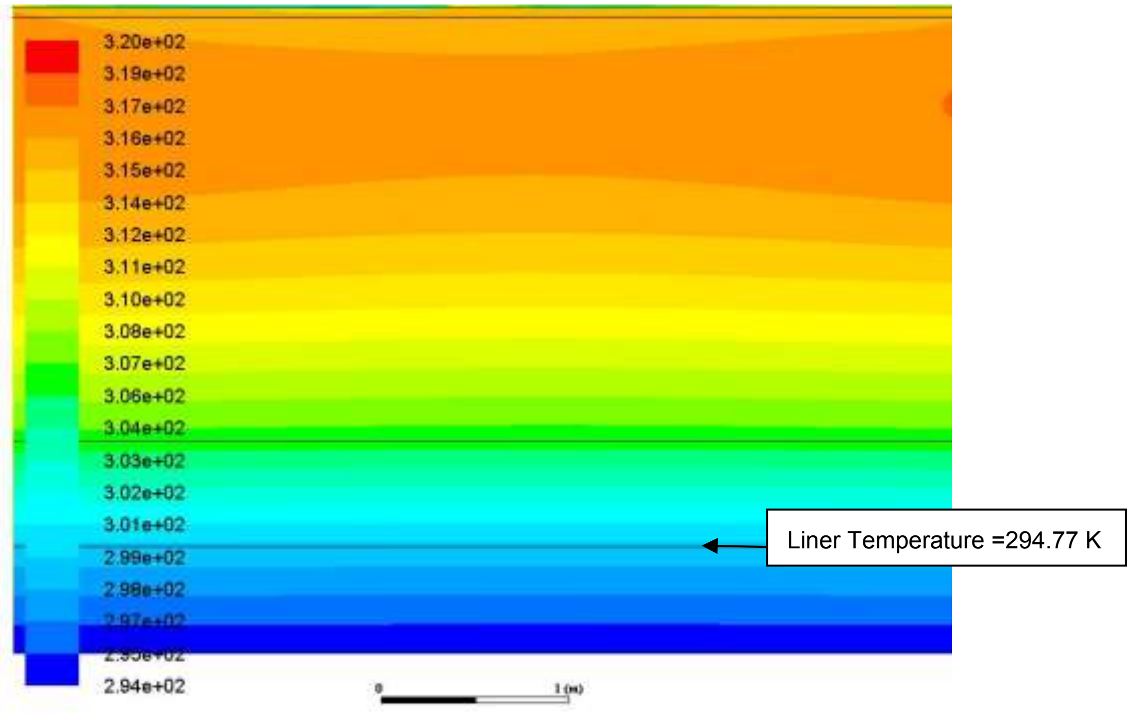
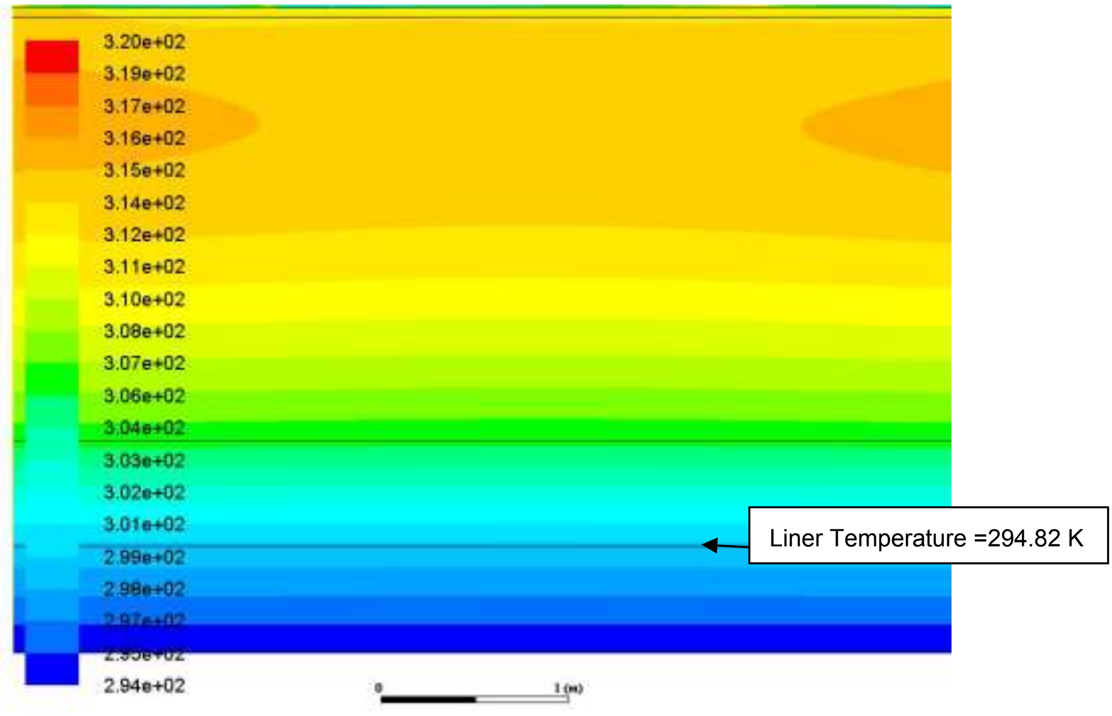


Figure 33 Temperature Distribution (K) at Time = 549,200 Sec



Liner Temperature =294.77 K

Figure 34 Temperature Distribution (K) at Time = 635,600 Sec



Liner Temperature =294.82 K

Figure 35 Temperature Distribution (K) at Time = 693,200 Sec

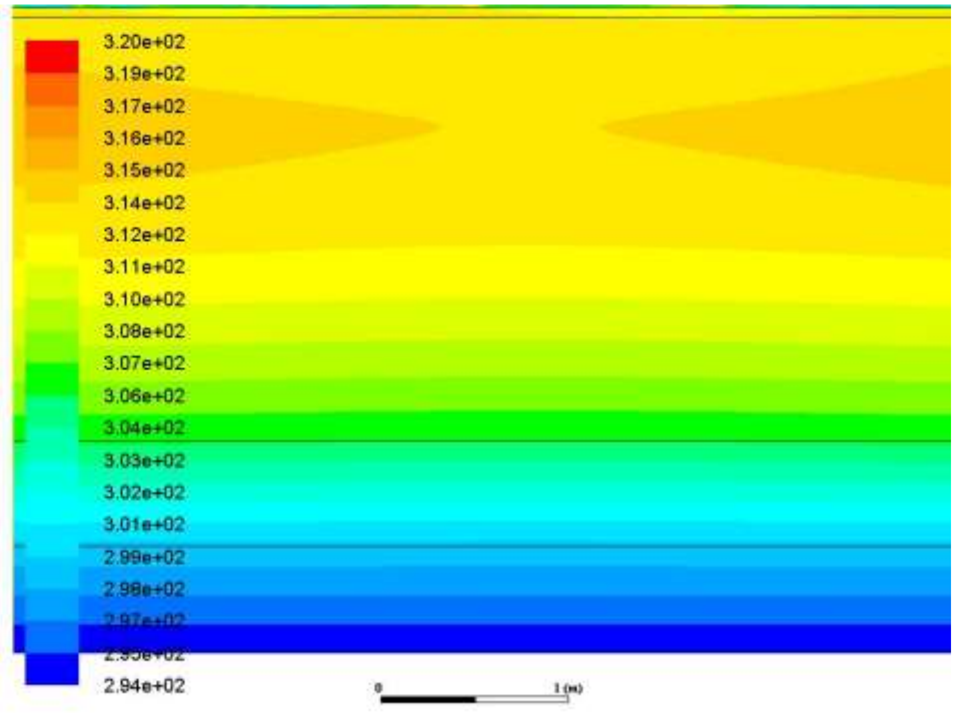


Figure 36 Temperature Distribution (K) at Time = 722,000 Sec

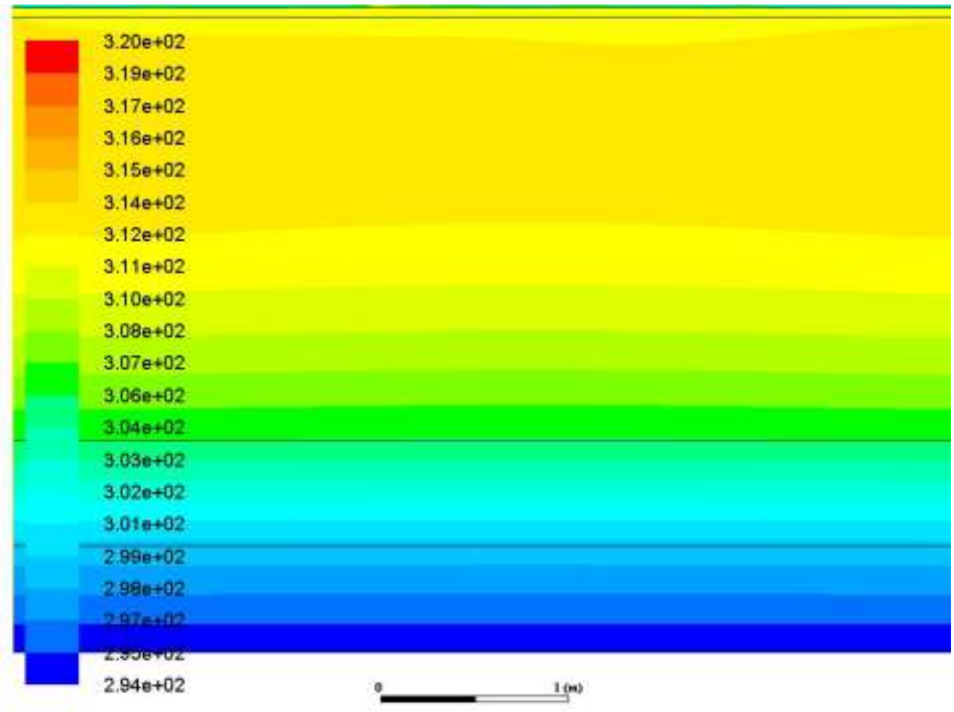
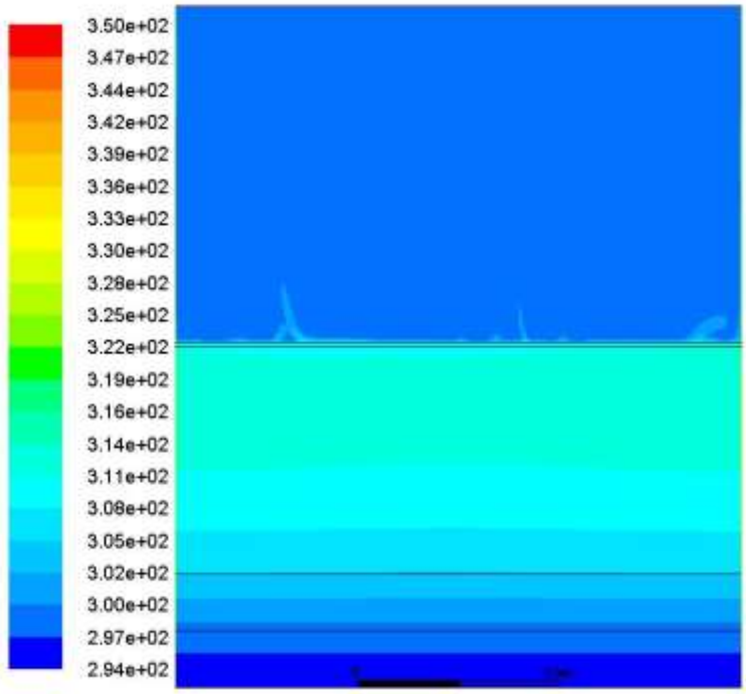
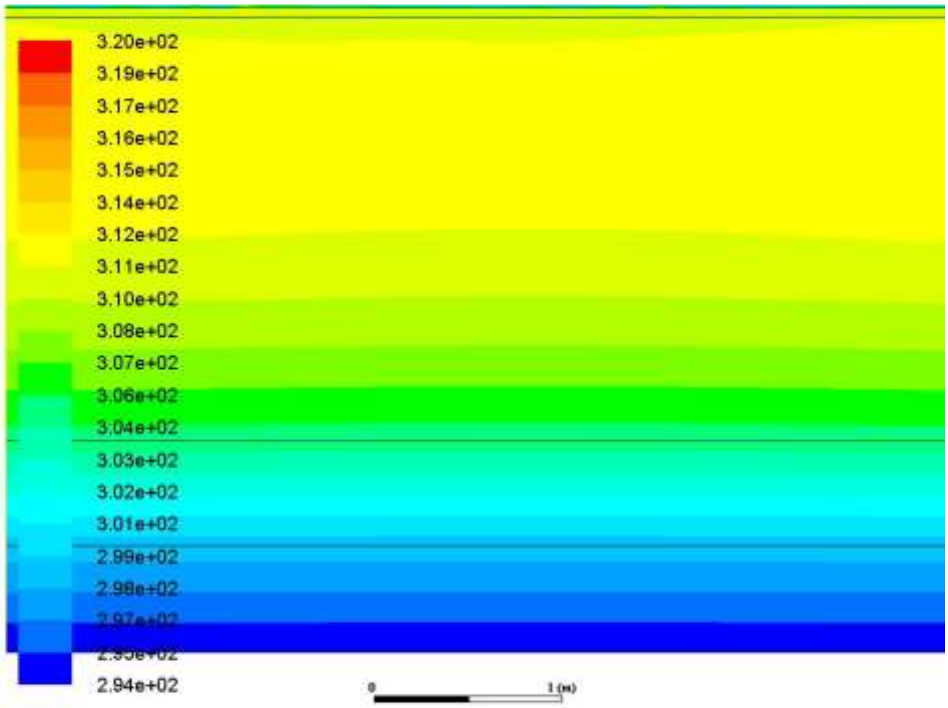


Figure 37 Temperature Distribution (K) at Time = 722,000 Sec



A: On 294 K (21°C) – 350 K Scale (77°C)



A: On 294 K (21°C) – 320 K Scale(47°C)

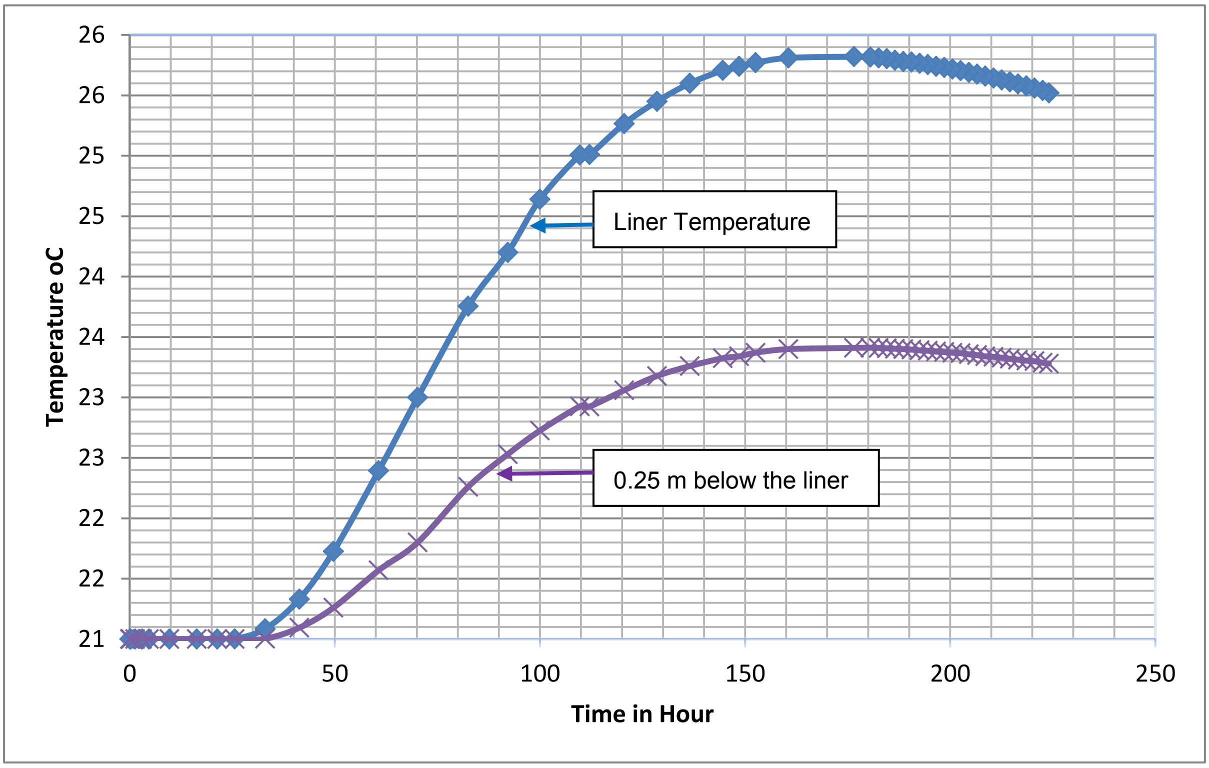
4.3 Summary Results

Figure 38 illustrates the temperature curve obtained from the CFD model (Refer **Section 4.2** for detailed results) at and below the liner.

The liner temperature peaks at Time = 635,600 Sec or 176.56 hours. The peak temperature is 298.82°K (25.82°C). The reduction in upper surface crushed slag, located 2.5 m above the liner is 1,558°C at the same time. Thus, the liner system will experience a 4.82°C variation while the slag will experience approximately 1,558°C variation in external surface temperature.

The temperature will fall to 296.39°K (23.39°C) at 0.25 m below the liner (Refer **Figure 38**).

Figure 38 Temperature Development (K) at and below the Liner



5 CONCLUSIONS

Multiple fluid flow, solidification and heat transfer are considered for the molten slag (liquid) and the surrounding cooling air (gas) in this study. Molten slag is assumed to flow for 10 seconds and the Volume of Fluid (VOF) model with a free surface between the molten slag, air and porous insulation layer is used to compute a time dependent solution. Heat transfer via natural convection and conduction is then predicted for up to Time =806,600 Sec.

The following insulation layers are proposed:

- 2 m thick crushed slag with a maximum porosity of 34%
- 0.5 m thick sand with a permeability of 8e-8 m/s

The following major conclusions are achieved from the results of CFD simulations:

- The molten slag solidifies just below the upper surface of the crushed slag at Time = 10 Sec. The molten slag is assumed to solidify at 1300^{o}C.
- The slag is completely solidified at time = 250 Sec (Refer **Figure 13**). This study is considered conservative where a still wind condition with ambient temperature of 27^{o}C is assumed. This rate of heat transfer from the molten slag will increase with increasing ambient wind speed.
- It takes approximately 30 hours for the heat wave to pass through the liner. Liner temperature is increased by 0.33^{o}C at Time = 118,820 Sec (Refer **Figure 24**). The time delay is due to the thermal mass of the insulation material layer (2 m of crushed slag plus 0.5 m of sand). The thicker and more resistive the material, the longer it will take for heat waves to pass through.
- The liner temperature peaks at Time = 635,600 Sec (Refer **Figure 34**). The peak temperature is 298.82^{o}K (25.82^{o}C). The reduction in upper surface of the crushed slag is 1,558^{o}C at the same time. Thus, the liner system will experience a 4.82^{o}C variation while the slag will experience approximately 1,558^{o}C variation in external surface temperature at the same time.
- The temperature will fall to 296.39 K (23.39^{o}C) at 0.25 m below the liner.

If the thickness of the crushed slag is increased to 2.25 m (total insulation layers = 2.25 m crushed slag plus 0.5 m sand) the liner temperature will reduce to below 24^{o}C.

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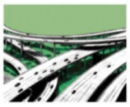
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