Paste 2026 – AB Fourie, M Horta, M Oliveira & S Wilson (eds)

doi:10.36487/ACG_repo/2655_02

The adaptability and management of an extractive waste facility under expansion: the case of the Cerro do Lobo tailings storage facility at the Neves-Corvo mine

Alfredo Nunes [a,*], Carlos Mata [a], Hugo Alves [b], Ana Rodrigues [c]

[a] *TPF Consultores, Portugal*

[b] *Boliden Somincor, Portugal*

[c] *Boliden, Sweden*

Abstract

Tailings storage facilities (TSF) are dynamic structures in constant evolution, with distinct phases such as design, construction, operation, expansion and closure. Their lifespans are not only directly linked to the mine's operational life but also to the closure period where the need for change and adaptation imposes increased attention to monitoring, as well as on structural, hydraulic, and environmental safety.

Cerro do Lobo extractive waste facility (IRCL), throughout its history, has undergone significant changes from operational aspects, such as the type of deposition methodology, the tailings production rates and their properties. More recently, the expansion of the deposition area, imposed significant challenges to the daily tailings deposition operation, as well as for the support design team in developing the best solutions to adopt.

The successful implementation of the IRCL's expansion, executed to increase the storage licensed capacity from 33–50 Mm^3, is presented. During this period, the structure remained in operation under the current project requirements for the thickened tailings deposition, requiring no adjustments to mine production plans. To achieve this, an alternative tailings deposition plan had to be developed due to a delay in the facility's expansion construction works.

The success in the execution and implementation of this plan resulted from the close collaboration between the operations teams and the Engineer of Record team. During this period, monthly updates to the deposition plans were carried out, which proved essential for adjusting the deposition model to operational needs and for proper water management within the facility. For this purpose, monthly digital terrain surveys were conducted using a drone, which allowed for the monitoring of both the geometry and the performance of the waste rock cover and berms. This procedure, complemented by ongoing observation instrumentation analysis, ensured the continued operation and safety of the facility.

Keywords: *tailings storage facility, tailings deposition, tailings rheology, monitoring, drone survey*

1 Introduction

Neves-Corvo mine is an underground mine of polymetallic volcanogenic sulphide ore from the Iberian Pyrite Belt, which extends from southern Spain into Portugal, as illustrated in Figure 1. The mine is situated in Alentejo region, approximately 200 km south of Lisbon, and currently produces copper, zinc and lead concentrates.

* Corresponding author. Email address: alfredo.nunes@tpf.pt

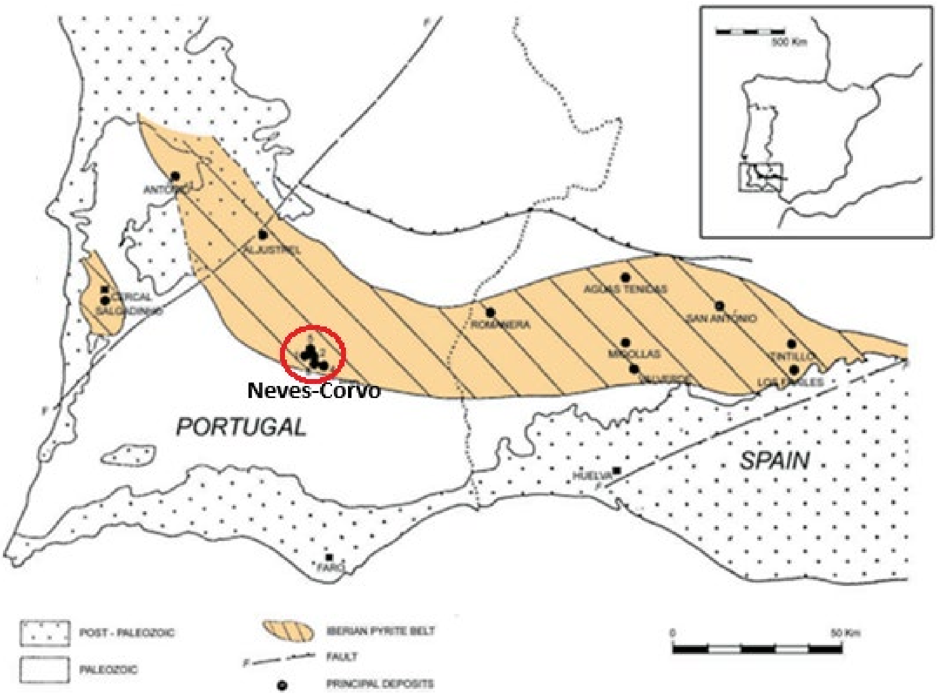


Figure 1 Neves Corvo mine location within Iberian Pyrite Belt (Verburg et al. 2003)

The deposit was discovered in 1977 and the mine has been in operation since 1988 by Somincor - Sociedade Mineira de Neves-Corvo SA and owned by Boliden since April 2025.

While additional deposits have been identified, 5 are currently under production: Neves, Corvo, Graça, Zambujal, and Lombador. Currently, mine operations reach depths of approximately 1,100 m.

The ore processing plant is constituted by 2 separate concentrators, one for copper and another for zinc and lead. The processing capacity is approximately 2.6 million tonnes of copper ore and 2.5 million tonnes of zinc ore per year.

Mining and concentrate production at Neves-Corvo generates 2 types of extractive waste, waste rock and tailings, both with potential acid generation properties. For the management of the extractive waste generated, the mine owns 2 active waste facilities – a temporary waste rock pile, that will be removed for closure, and the Cerro do Lobo extractive waste facility (IRCL) for tailings and waste rock co-disposal.

Extractive waste management in Neves Corvo has evolved over 36 years of operation, adapting to the different mine plans and production rates, best available techniques, and legislation.

Internal reuse of both waste rock and tailings in the underground stopes filing is one of the good practices in place and has been increasing over time, contributing to the reduction of waste that needs to be stored in IRCL. Nevertheless, increases in production still impose the need for expansion of the IRCL.

Over the years, the IRCL has been expanded several times. After the first construction stage in 1988, the facility underwent 3 downstream raises of the main dam embankment (1990, 1993 and 2005) and associated construction of adjacent saddle dams. In 2010, the deposition method shifted from subaqueous tailings disposal to subaerial thickened tailings deposition with co-disposal of waste rock. This new disposal methodology was initially carried out in cells, formed by waste rock dikes. Subsequently, in 2015, it evolved to a 5-tier vertical stacked deposition scheme featuring concentric tiers limited by a perimeter berm on top of a cover layer, both built using waste rock placed over thickened tailings. All these expansions were confined to the initial footprint of the facility.

The latest expansion of IRCL was undertaken as part of the zinc expansion project (ZEP) to ensure adequate and safe storage capacity for extractive waste in alignment with the current life of mine plan through 2033. This expansion involved a 25.9 hectare (Golder Associates 2021) extension on the southern side of the facility, as illustrated in Figure 2 (deposition area A2 =18.5 ha + South embankment implementation area A2´=7.4 ha), confined by a 20 m-high embankment dam that enables ongoing vertical stacking up to tier 13, increasing the facility storage capacity from 33–50 Mm^3.

Figure 2 Cerro do Lobo extractive waste facility expansion area (Golder Associates 2021)

2 Neves-Corvo expansion: zinc expansion project

2.1 Scope

The ZEP was implemented to increase the annual production rates of zinc ore, enabling economically viable extraction from the deeper sections of the Lombador ore body (PROCESL 2016). The project consisted of underground infrastructure development, ventilation systems, increased hoisting shaft capacity and construction or expansion of surface ore processing and tailings management infrastructures.

The zinc concentrator's processing capacity was expanded from 1.2 to 2.5 Mtpy alongside construction of a new tailings cycloning plant, upgrades in the paste backfill plant, new tailings pumping station and distribution lines, a new deep cone thickener in the Cerro do Lobo thickened tailings plant as well the associated thickened tailings distribution system, and the IRCL expansion.

IRCL needed to accommodate the tailings and waste rock production in accordance with the updated life of mine plan that results from the ZEP. The design and construction scope included not only the physical expansion of the facility but also the upgrade of the thickened tailings transport systems, the deposition and the surface water management infrastructure, integrated within the new IRCL layout. The surface water management infrastructure is not addressed in this article.

The studies for IRCL expansion for ZEP started in 2014 with a pre-feasibility study that supported the environmental impact assessment, followed by several phases of design and authorities' evaluation, approvals and permissions, with the major milestones shown in Figure 3.

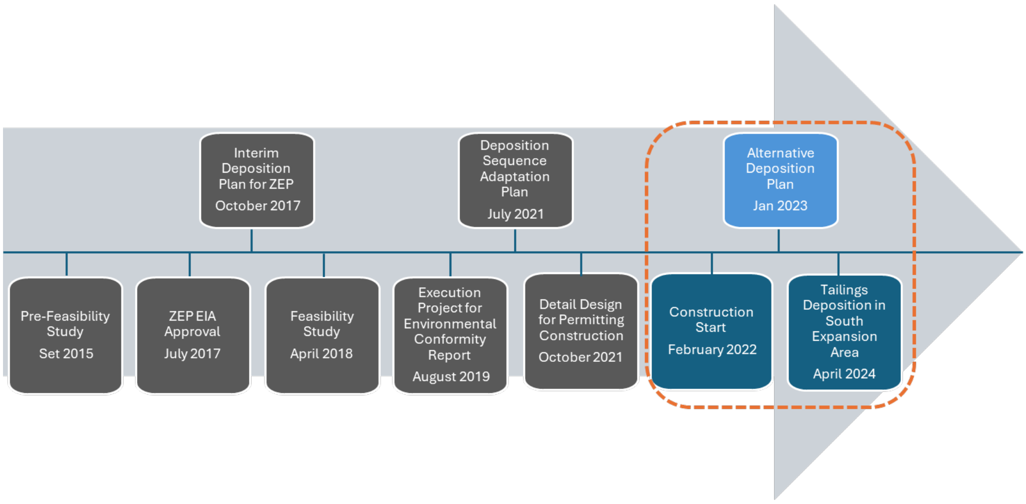


Figure 3 Cerro do Lobo extractive waste facility expansion for zinc expansion project (ZEP). Design, approvals, and construction milestones

Several delays occurred during the development of the studies, the obtaining of the necessary permissions, and during construction phases, including significant impact caused by 2019 COVID pandemic. In 2019, during the detailed design phase for environmental compliance, the timeline for the start of the construction works was March 2020 and tailings deposition at the new expanded area was planned to start in October 2021 (PROCESL 2019). Both key tasks came to occur more than 2 years later than previously estimated. This delay brought increased challenges to the tailings management operation and changes to the tailings deposition plans had to be implemented to allow the continuity of the tailings deposition within the authorised deposition conditions, without impact on the production, while assuring the safety of the facility.

This article outlines the importance of the alternative deposition plan implemented, the changes to the monitoring protocols adopted, and the design optimisation carried out during the IRCL expansion construction phase. These procedures were implemented to meet the operational requirements while maintaining both the original design intent and safety standards for the facility and personnel. During this phase, both a high adaptability in the management of the deposition operations and an effective collaboration between all parties involved – such as the tailings management team, the Engineer of Record (EoR), the design teams, and the Contractor teams – were required.

2.2 Tailings management and Cerro do Lobo extractive waste facility

The ZEP, as described in the previous section, brought changes to the tailings management infrastructure and operational philosophy. Consequently, the tailings management facilities had to be adapted to manage the increased volume of tailings produced, and to accommodate the changes in the composition and physical properties of the tailings produced.

Figure 4 shows the evolution from 1995 to 2024 of the total tailings production in Boliden Somincor, compared to tailings sent to final storage at IRCL and tailings reused in underground paste fill and backfill operations.

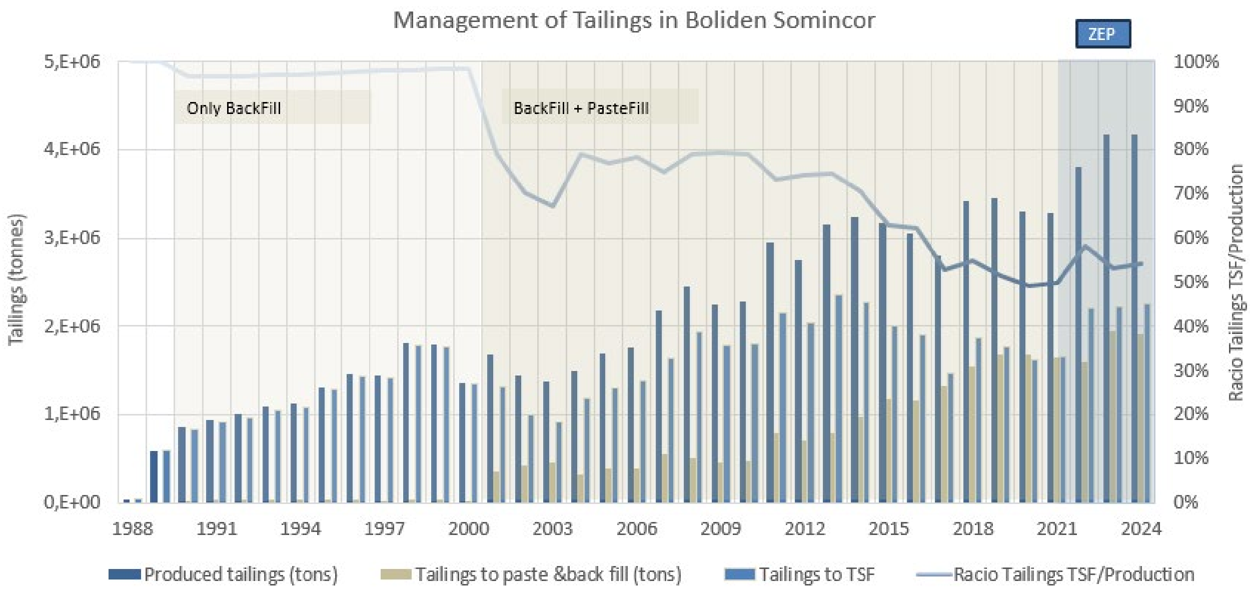


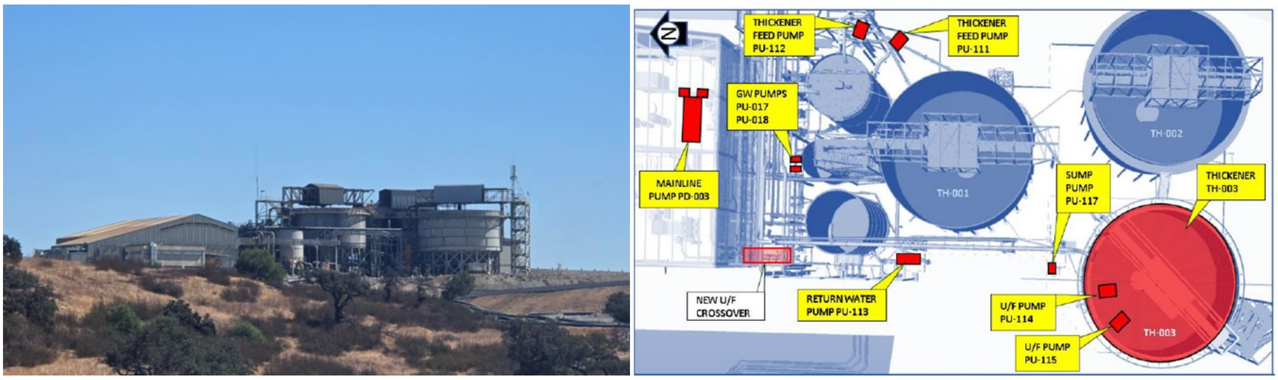
Figure 4 Historical tailings deposition and paste fill and backfill reuse from 1995 to 2024

The total tailings produced shows an increasing trend throughout the analysed period. From initial values of approximately 2 million tonnes per year in the late 1990s, the production progressively increased, reaching around 3.5 million tonnes per year in the years preceding ZEP, and slightly below 4.2 million tonnes per year in 2023–2024 (after ZEP ramp up). This increase reflects the intensification of mining operations and the corresponding increase in ore processing capacity.

The ratio of tailings disposed in the IRCL relative to the total tailings production demonstrates a gradual descending trend from the early 2000s onward. This indicates continuous improvements in waste management efficiency with an increasing portion of tailings being reused in mine processes (backfilling composition is 95% of tailings in paste fill and 5% of tailings in backfill). In the most recent years, this ratio shows a stabilisation around 50–60%, suggesting the consolidation of optimised operational practices. Despite sustained high levels of tailings generation, the company has managed to maintain a relatively balanced distribution between tailings deposition and backfilling. This reflects a mature and stable tailings management system aligned with contemporary sustainability standards and circular economy principles within the mining sector such as *Best Available Techniques (BAT) Reference Document for Waste Treatment Industrial Emissions Directive 2010/765/EU (Integrated Pollution Prevention and Control)* (Pinasseau et al. 2018) and *Directive 2010/75/EU- Industrial Emissions (Integrated Pollution Prevention and Control) (Recast)* (European Parliament and the Council 2010).

2.2.1 Tailings thickening plant

The tailings thickening plant constitutes an essential part of the IRCL. Construction began in 2009 and has since contributed to IRCL's extended lifetime. As part of the ZEP, the facility operational capacity was expanded with the construction of a third deep cone thickener and all associated infrastructure (Figure 5), as well as the installation of an additional positive displacement pump and increased water return capacity for the increase demand of the zinc plant process.



(a) (b)

Figure 5 Tailings thickening plant. (a) West view; (b) New infrastructure build during zinc expansion project (red)

2.2.2 Tailings properties: particle size distribution

The tailings particle size distribution (PSD) is a fundamental property that dictates its geotechnical, hydraulic, and rheological behaviour (Figure 6), as well chemical reactivity, all of which are critical for the safe and efficient management of a tailings storage facility (TSF). PSD refers to the range of particle diameters present in a sample, typically expressed as a percentage by weight (or volume) finer than a given size.

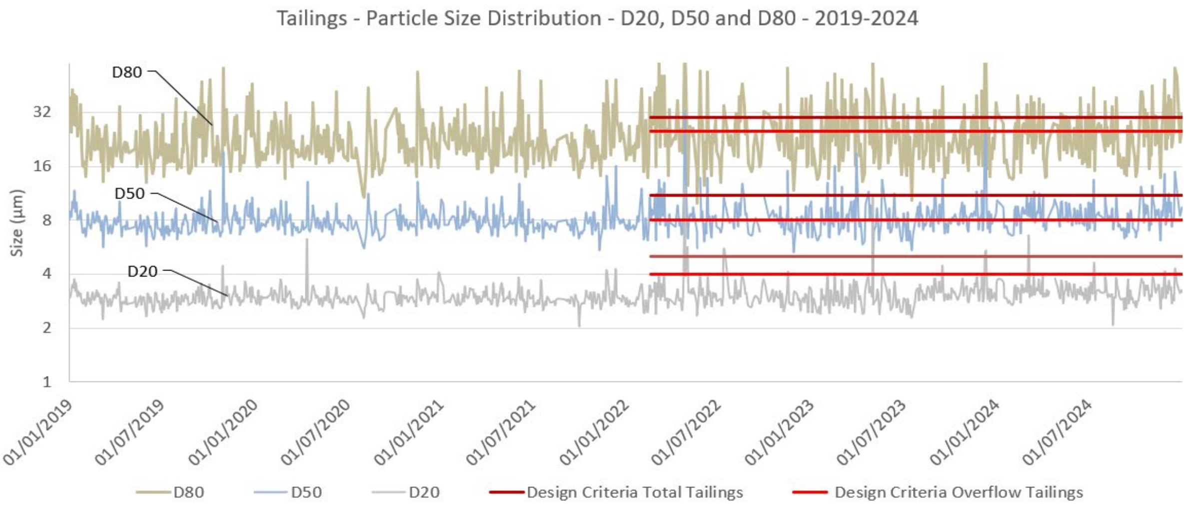


Figure 6 Tailings particle size distribution D20, D50, D80 (2019–2024)

In this analysis, the focus is set on 3 specific particle sizes – D20, D50, and D80 – which provide key insights into the material's particle dimension and uniformity:

- D20 (20% passing): the analysis of the D20 PSD from 2018 to 2024 indicates stable and consistent grinding performance, with values predominantly ranging between 2–4 µm and remaining below the design criteria of 5 µm for total tailings and 4 µm for overflow tailings.
- D50 (median size): the majority of the D50 values are consistently within a narrow, low-range band generally between 7–10 µm. Between 2022 and 2024, some rare but extreme spikes were recorded. Since the ZEP ramp up, the standard deviation has changed from 1.3 to 3.0 µm.
- D80 (80% passing): this particle size percentile, often referred to as the grind size, characterises the coarser fraction of the material. Before 2022, the D80 values were mostly located below both design criteria lines that indicates that the milling circuit was consistently producing material significantly finer than required. After 2022, the graph shows some instability on the beginning of ZEP ramp up with a significant increase in the standard deviation that reached 10.8 µm in 2022.

In 2023 and 2024, the standard deviation started to decrease showing the maturity and the continuous development of the process.

3 Cerro do Lobo extractive waste facility expansion project

3.1 Role of the engineer of record during the Cerro do Lobo extractive waste facility expansion project

A significant challenge for an EoR is assuming the responsibility for a tailings storage facility that was designed and supervised by a previous party. In this common scenario, the EoR cannot simply act as a reviewer, it must accept full technical responsibility for the facility's past, present, and future performance. This process involves a rigorous due diligence effort where the EoR must thoroughly review, understand, and formally take ownership of the existing design concept.

The role of the EoR during the expansion works of the IRCL can be divided into 3 main scopes that are the:

- follow-up of the performance of the existing structure
- evaluation of the potential influence of the expansion works on the operation of the existing structure and specific tasks requested by the IRCL owner mainly related with support in the evaluation
- follow-up of the design solutions and respective construction methods of the expansion works, assuring the full compatibility of the expansion works with the existing structure and the operation rules.

The tasks in the scope of the follow-up of the existing structure are not episodic or project-based – they are ongoing to ensure that the facility's performance during its operational life remains consistent with its design criteria. The continuous evaluation of the performance and safety of the existing structure was the condition that assured the safety during the expansion works. These tasks were not limited to the evaluation of the structural, hydraulic, and environmental safety of the IRCL. The implementation of the alternative deposition plan imposed a tighter temporal sequencing of deposition, consolidation, and construction cycles, which required support in the definition of the deposition sequence and in integrating the alternative deposition plan with auxiliary mining structures, in particular, the reservoir spillway.

The tasks related to the potential influence of the expansion works in the operation of the existing structure were mainly associated with the definition of short-term performance criteria of the IRCL in particular in the proximity of the new expanded area, the follow up and validation of design changes implemented during the construction and the follow up of the construction work site with bimonthly site visits and meetings with the construction, design, supervision and owner teams.

The additional tasks requested to be performed by the team that supported the EoR scope of works were mainly related to design changes to address integration of the existing structure with the new expansion structures. These designs were mainly focused on geometrical compatibility of the existing structures and were addressed to the EoR team to ensure the full compatibility with the licensed operation rules in force.

3.2 Adaptability of Cerro do Lobo extractive waste facility operations during expansion construction

3.2.1 Description of Cerro do Lobo extractive waste facility operations prior and during the expansion construction

As mentioned in the Introduction, since 2015, the disposal methodology has been implemented using a stacked deposition scheme, where tailings are deposited from the crest of waste rock perimetral berms. When the tailings deposition reaches an elevation of 1 m below the berm crest, the berm is considered exhausted, and the tailings is left to consolidate. Once the primary consolidation of the tailings' top layer reaches an adequate degree, a layer of waste rock is placed on top of it, followed by the construction of a new berm on the upstream side, forming a new higher elevated deposition tier level.

This type of stacked deposition scheme requires multiple work fronts in various stages of the deposition scheme (deposition, consolidation, cover and berms construction) to ensure the continuous operation without interruption. The challenge in maintaining this workflow arises from the mechanical behaviour of saturated tailings and as is commonly known, saturated tailings do not perform mechanically well due to their brittle behaviour when rapidly loaded, which can lead to unexpected failures.

This requires meticulous management and monitoring to prevent interruptions in the deposition scheme and to ensure the structural integrity and safety of the structure. To achieve uninterrupted operation, certain operational aspects must be controlled – the tailings thickening process and rheology and the pre-established construction rhythms. Additionally, monitoring the pore pressures in the tailings is crucial during all stages of the process, with particular importance during the construction of berms, where the shear stresses transmitted to the tailings are at their highest.

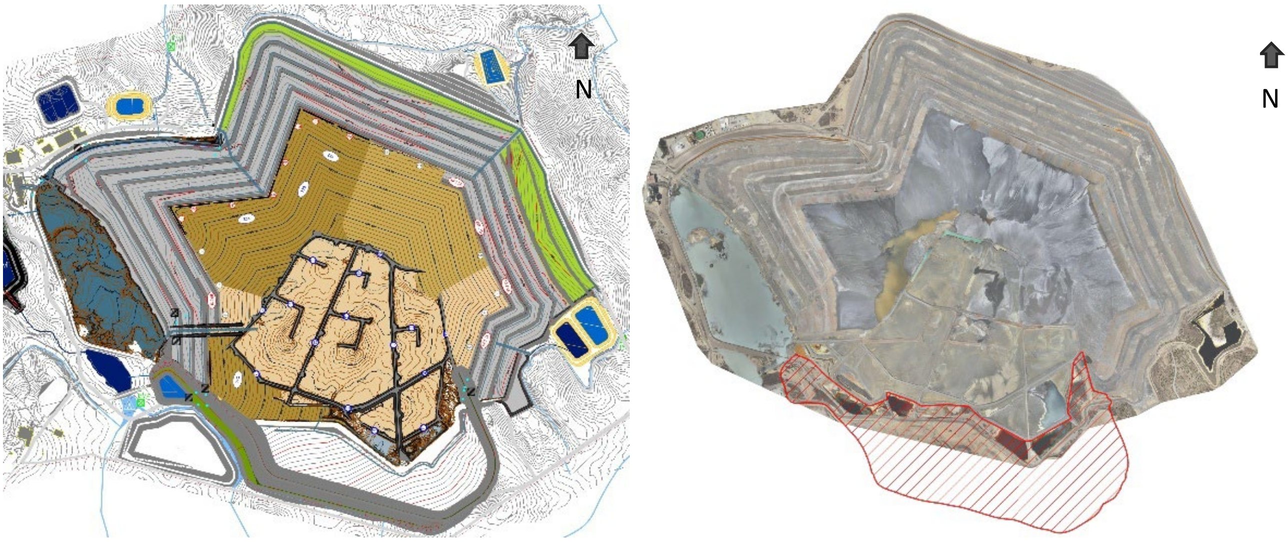
Regarding water management within the deposition area of the IRCL, it’s established that deposition must occur sequentially from east to west, ensuring always a highest deposition elevation at east, to minimise ponding and ensure gravity drainage toward the spillway on the west.

As mentioned in Section 2.1, the IRCL expansion project, authorisations and construction works suffered several delays. Figure 7 illustrates the difference between the expected completion time of the expansion works, that should have been finished to receive tailings at the end of 2022, and the actual works and deposition position at that date. As one can see in Figure 9, in November 2022, the tailings deposition and covers and berms construction were in an equivalent stage to what was anticipated in the IRCL expansion detailed design but there was still no construction ongoing at the expansion area. The actual conclusion of the IRCL expansion works only occurred in April 2024.

Thus, between February 2022 and April 2024, changes to the tailing’s deposition plan were necessary. In early 2023, due to the limited storage capacity of IRCL, an alternative deposition plan was developed (TPFD 2023) with the objective of continuous tailings deposition until the end of the IRCL expansion works. This plan was crucial to maintain the normal operating scheme of IRCL as the ZEP production ramped up and tailings production for deposition in IRCL reached its peak in a phase that the stacking area was substantially reduced in comparison to what was expected in the detailed design.

Although no changes to the final geometry of the structure were made, the Alternative Deposition Plan required the construction of the eighth and ninth tiers during 2023 and 2024, whereas the permitted design had foreseen the construction of these tiers only after the filling of the IRCL expansion area. The total deposition capacity during these years was limited to the ninth tier due to constraints related to the stack geometry and limitations on water management.

Another aspect worth mentioning is that although the changes introduced would meet the storage capacity requirements for 2023 and 2024, according to the mill plan, the covers and berms construction and tailings deposition sequence defined was highly restrictive and any deviations from the schedule could limit the availability of effective tailings storage capacity. Any significant increase in the mill plan could not be accommodated by the plan, as there was no flexibility to bring forward covers and berms construction to increase the available storage capacity. As the plan was based on tailings deposition simulations and expected construction rates, a monthly follow-up of the actual deposition and construction was mandatory to identify any changes of the plan.



(a) (b)

Figure 7 Comparison between the expected state of Cerro do Lobo extractive waste facility in the end of 2022 and the actual state at that date. (a) Detailed design drawing, phase 25, August to December 2022 (Golder Associates 2021); (b) Drone survey orthophoto, November 2022

3.2.2 Alternative deposition plan

The alternative deposition plan to enable the current mine operations to continue while the expansion works were underway, involved some risks for IRCL operations that were needed to be considered, namely:

- increased risk of potential instabilities of covers and berms due to the increase of construction demands, which could impact the alternative deposition plan planned schedule
- the reduced additional storage margin for emergency deposition situations during certain periods of operation could lead to the need to adjust the mine production plan in order to reduce the tailings production.

To reduce the likelihood of these risks the following measures were implemented:

- Reinforcement of berm and cover construction teams: it was estimated that in the most critical construction phases, up to 6 teams might be required to work simultaneously (2 teams are standard). This would enable the construction of several berms at the same time, complying with the waiting periods that have been established between tailings deposition and covers and berms construction and which have proven adequate for the nature and geomechanical behaviour of the tailings.
- Extension of working schedules: it was defined that in more critical periods, a change in the workweek from 5 to 6 days would be necessary, if it is found that the available storage margins were limited.
- Increase in emergency storage volume through the raising of internal embankments, in particular of the designated 'mezzanine', within the IRCL, although internal deposition was not originally foreseen at this stage.
- Coordination between the operations team, the EoR and the IRCL expansion project team: this implied reassessing the construction sequence of the new distribution lines planned under the IRCL expansion works to ensure that the tailings distribution lines required to comply with the alternative deposition plan were available when needed.

The operation sequence established was primarily aimed to mitigate the occurrence of critical operating periods in terms of available storage margin, seeking to ensure that the available deposition volume would always exceed the required deposition volume by 300,000 m³ (equivalent to about 3 months of deposition).

Accordingly, the volumetric capacity analysis was carried out as a function of time, as shown in Figure 8. The volumetric capacity (brown line), obtained by performing model simulations of tailings deposition, and the volume to be deposited (blue line), according to the production plans for 2023 and 2024, were prepared to verify the available storage margin over the period. In the same graph, 3 lines (coloured green, yellow and red) were also plotted to provide a visual reference of the remaining available volumetric capacity during the implementation of the plan. If the actual capacity (represented by the brown line) dropped below the green line, it indicated that the storage capacity had fallen below 300,000 m³, with the yellow and red lines representing 200,000 m³ and 100,000 m³ capacity available, respectively. This chart also revealed a critical period in the plan where, even if everything proceeded as planned, the storage capacity would have fallen below 300,000 m³ had the expansion works not been available to receive tailings (July to September 2024).

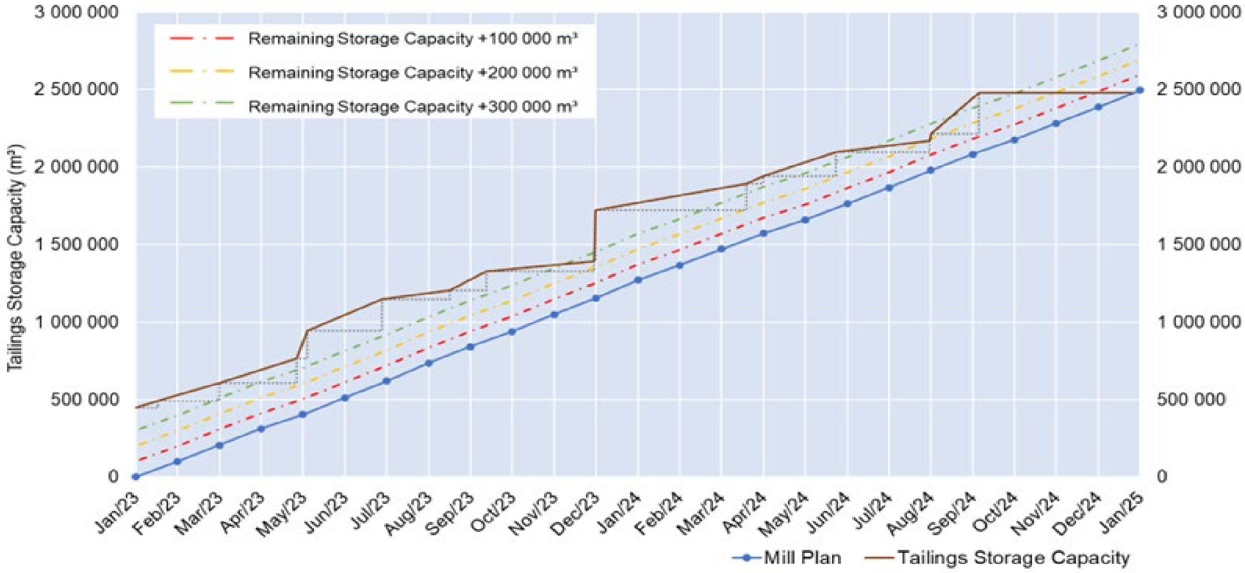


Figure 8 Tailings storage capacity during the alternative deposition plan implementation

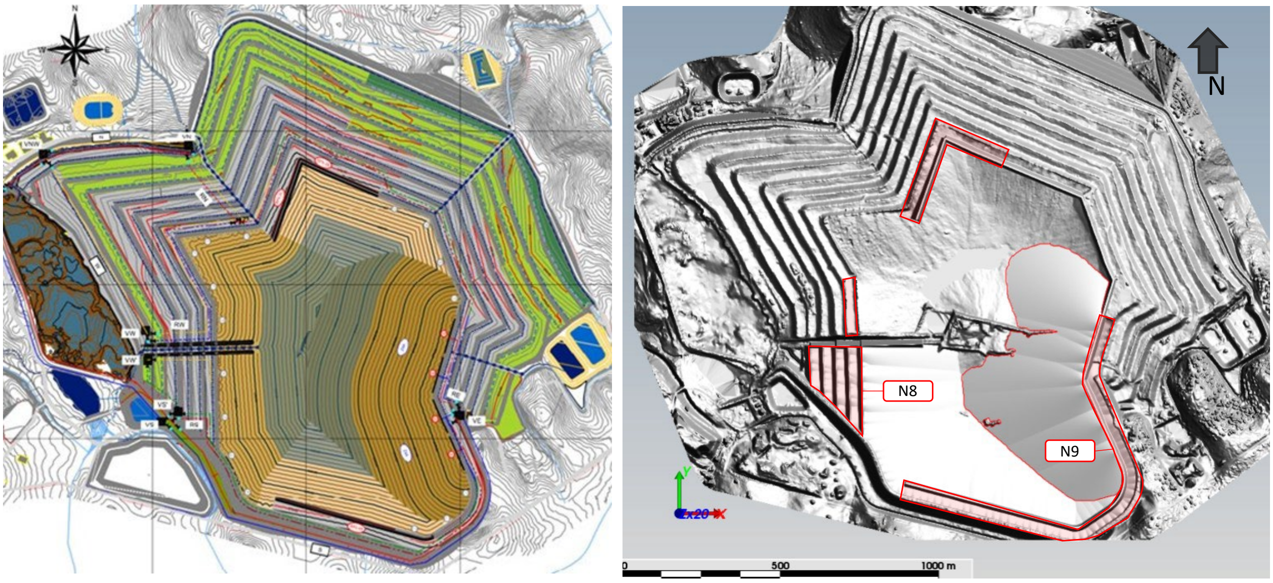
The established construction and deposition sequence served as guide for operations during the period in which the expansion works were underway. However, the actual deposition and construction rates were assessed monthly to identify any adjustments to the plan.

The alternative deposition plan was implemented from early 2023 until March 2024, when authorities approved the start of the deposition in the expansion area that effectively started on April 2024. The success of the implementation of the alternative deposition plan was largely due to the expertise of an experienced team of operational personnel skilled in the disposal methodology and type of construction implemented since 2015 (beginning of the construction of perimeter covers and berms), thorough due diligence of the EoR, and the robustness of the licensed design construction geometry that allowed the necessary adaptability.

Figure 9 Drone survey orthophoto from March 2024

Strong collaboration between the deposition operations personnel, the design team, and the EoR was crucial to the successful implementation of the alternative deposition plan. Figure 9 illustrates the situation just before the beginning of the deposition in the expansion area, which can be compared to the intended facility geometry anticipated in the design for the same phase (Figure 7). Due to the delay of almost 3 years between the conclusion of the expansion works and the intended date of completion defined in the design, the differences in tiers constructed are very significant.

Currently, a 3-year plan is being implemented to revert the IRCL construction sequence back to the original plan as defined in the original design, aiming for completion around Phase 35 of the original sequence (Figure 10). This plan is less demanding due to the absence of storage capacity constraints; however, the challenge lies in managing water flow to the spillway because of the significant level difference between the north and south sides of the IRCL.



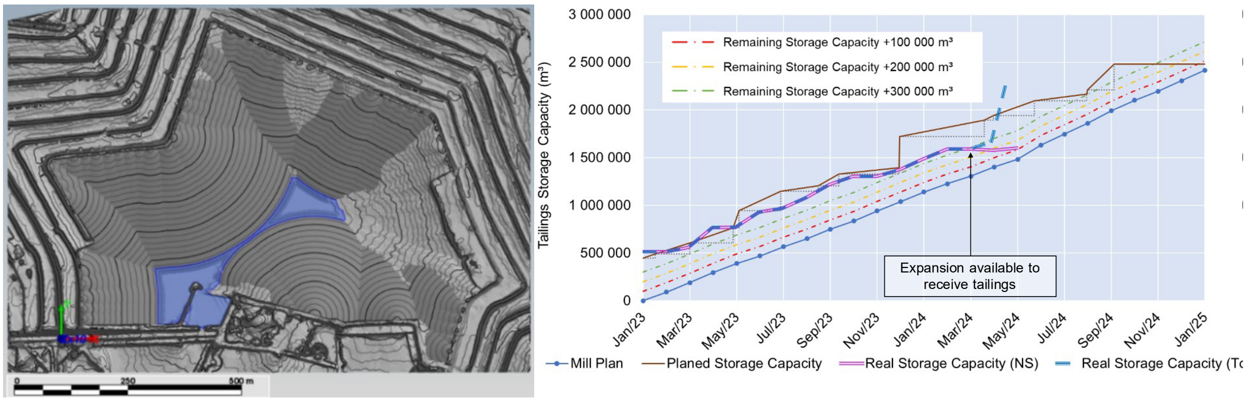
(a) (b)

Figure 10 Phase 35, August 2026 to February 2027. (a) Detailed design drawing (Golder Associates 2021); (b) Alternative deposition plan (TPF 2023)

3.2.3 Monitoring of the alternative deposition plan and deviation analysis

Due to the highly demanding and restrictive deposition sequence imposed by the alternative deposition plan, close monitoring of the stack evolution was required to always ensure a minimum operational storage capacity of 300,000 m³ within the north side of IRCL during the plan's implementation.

To achieve this, a monthly drone survey was conducted to assess the evolution of deposition and the construction of covers and berms. These surveys allowed the creation of digital terrain models (DTM) which were used to track the storage capacity against the estimated capacity in the alternative deposition plan, by modelling the deposition of the tailings in all available berms (Figure 11a) and plotting the total deposition capacity in the storage capacity chart of the alternative deposition plan (Figure 11b). The example provided illustrates this comparison, showcasing the progression of the storage capacity till the month prior to the tailings deposition in the expansion area. As can be seen, throughout the entire implementation of the plan, it was possible to maintain a minimum storage capacity of 300,000 m³.



(a) (b)

Figure 11 Deposition capacity assessment during the implementation of the alternative deposition plan. (a) Monthly capacity simulation of the total capacity; (b) Total storage capacity chart

Another aspect assessed in a monthly base using the DTMs was the inclination of the tailings beach (Figure 12). This evaluation was used as a guide for the equivalent parameter used in the tailing's deposition modelling, which could potentially impact the storage capacity. Throughout the implementation of the alternative deposition plan, a consistent average slope of around 2% was observed. This consistency was also reflected in the rheology and particle size distribution parameters, which were maintained statically constant over these 2 years.

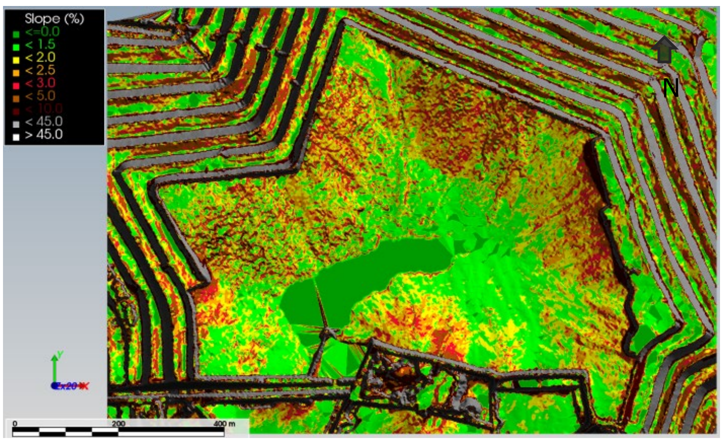


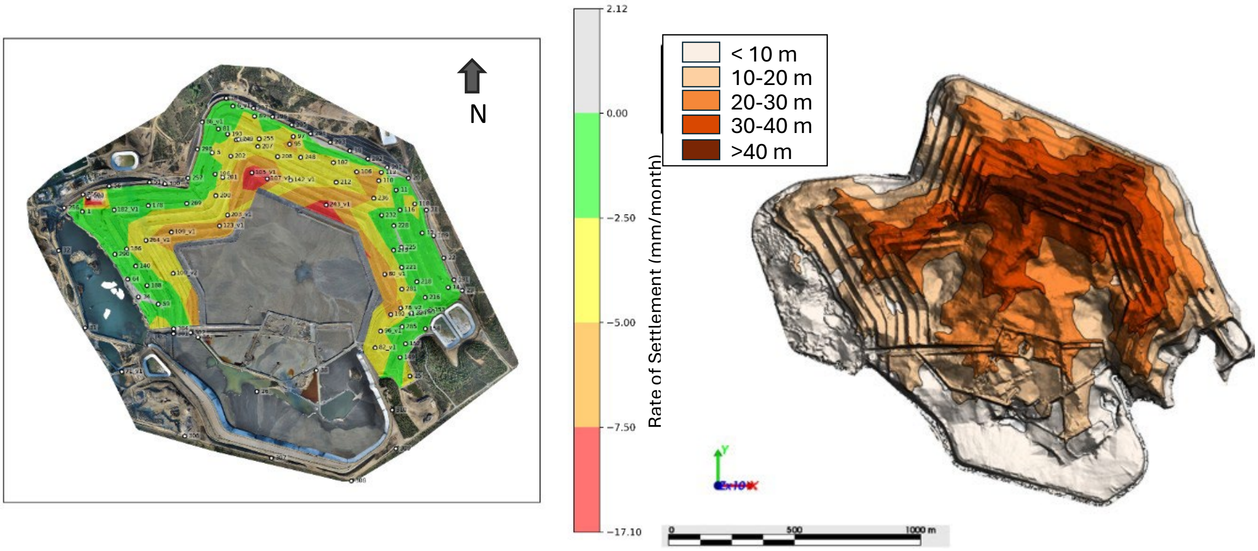
Figure 12 Colour map of tailings beach slopes

During the construction of the covers and berms with waste rock, a tight monitoring of the pore water pressure development in the tailings body was conducted using vibrating wire piezometers driven in the tailings. Despite the higher risk posed by the increased construction progress rate, it was nonetheless deemed unnecessary to increase the number of piezometers defined in the detailed design of the IRCL expansion. The grid spacing between piezometers was dense enough to ensure that at least one piezometer was installed in each segment under construction.

This setup, combined with a continuous construction rhythm and a thorough tailings thickening process that contributes to the general homogeneity of the properties of the tailings, was effective in the safety assurance of the stability of the executed covers and berms.

As the alternative deposition plan aimed to exhaust the capacity of a specific section before progressing to the next one, it was crucial to evaluate any significant excess pore pressure generated in the tailings prior to the subsequent advance of the construction, as the combined effect of the tailings deposition with the construction loads could lead to a brittle failure of the tailings mass.

The settlement of the IRCL surface was monitored on a monthly basis (Figure 13a) to assess whether the settlements expected from tailings consolidation, given the tailings thickness (Figure 13b), were being observed. This verification was not directly related with the structural safety or the risk of insufficient storage capacity, but rather to ensure that the geometry of covers and berms didn’t deviate from the IRCL detailed design geometry.



(a) (b)

Figure 13 Tailings settlement monitorisation of Cerro do Lobo extractive waste facility (IRCL). (a) Settlement observed on berms and covers of IRCL; (b) Colour maps showing the thickness of deposited tailings in IRCL

4 Conclusion

The successful execution of the expansion of the IRCL stands as a significant case study in the contemporary challenges and best practices implementation of large-scale tailings management. The focus view presented in this paper was the paramount importance of adaptability and robust management in face of unforeseen delays of the expansion construction works. The ZEP fundamentally changed the mine waste stream, leading to a substantial increase in total tailings generation, surpassing 4.2 million tonnes per year post ramp-up. The IRCL expansion allowed the increase of the facility storage capacity from 33 Mm^3 to a final designed storage volume of 50 Mm^3.

The true test of the project resilience came with the critical delay in the final construction and commissioning of the expanded facility. In a sector where the continuous, safe, and regulated disposal of tailings is non-negotiable, a delay of this magnitude could jeopardise the entire mine operation due to the limited available storage capacity at a given time. This situation moved the focus from a purely engineering challenge to one of integrated risk management and operational agility. The response of the Neves-Corvo team and the involved parties provided a crucial roadmap for the mine in mitigating complex, real-time operational risks.

To bridge the 2-year schedule gap, a multi-faceted and highly adaptive strategy was effectively implemented. The adoption of the alternative deposition plan was key as it was a detailed operational protocol that strategically utilised existing, non-critical areas of the facility's footprint while carefully managing the freeboard and structural stability of the current IRCL. This was not a simple stopgap; it required daily, rigorous monitoring of the deposition, consolidation rates, and beach formation to ensure that regulatory and safety compliance was never compromised. This proactive operational change was only feasible due to the facility's pre-existing, thorough characterisation and a comprehensive understanding of the tailing's properties, which were aided by a robust thickening process.

Furthermore, modifications to monitoring protocols were swiftly executed, involving an intensification of piezometric and structural readings, moving beyond standard routines to address the heightened risk profile. This enhanced observation provided the critical, real-time data necessary for informed decision-making during critical moments. The ability to rapidly implement the necessary changes – leveraging the existing instrumentation and adapting operational resources – underscores the need for management systems that are inherently flexible and can escalate monitoring intensity in response to unplanned project variances.

Crucially, the successful management of the delay was underpinned by the inherent principles of robust design, an aspect increasingly emphasised by global industry standards. The subsequent design optimisations implemented during the expanded facility's construction – often informed by lessons learned during the period of alternative deposition – ensured that the final structure was not merely built to specifications but was resiliently engineered against future operational uncertainties. This iterative, experience-driven design process underscores the benefit of integrating operational and engineering expertise throughout the project lifecycle.

The Neves-Corvo operation demonstrates a long-term commitment to sustainable extractive waste management, particularly through its effective implementation of circular economy principles. The continued practice of mine backfill significantly mitigates the environmental footprint of the operation. This increase of backfill, in the face of substantially increased production volumes, is a commendable achievement that stabilises the net volume of tailings sent to the IRCL, extending the facility's longevity.

Finally, the adaptability demonstrated at the IRCL aligns seamlessly with the ethos of the *Global Industry Standard on Tailings Management* (Global Tailings Review 2020). The successful routing of this expansion challenge – which involved managing a capacity crisis, maintaining structural stability, and enhancing governance under pressure – serves as a powerful, real-world example of how a major mining operation can meet an increase in waste volume while overcoming project delays. This was achieved by prioritising engineering flexibility, robust risk management, and a proactive, safety-first approach to tailings management, ultimately ensuring operational continuity, minimising environmental risk, and safeguarding the social welfare.

Acknowledgement

The authors would like to thank all the personnel of the teams of all the parties involved in the design, development, implementation, control, construction and supervision of the IRCL expansion works for the successful integrated management and full compromise to the success of the project.

We would also like to thank all technicians and engineers working on a daily basis at IRCL who committed to the effective structural, hydrological and environmental safety of the structure. We would like to thank senior personnel for their historical insight.

The authors would also like to thank Boliden Somincor management team for the opportunity given with the support in the presentation of the paper and wish to thank Boliden Somincor and TPF management teams for the approval of publication of this paper.

References

European Parliament and the Council 2010, *Directive 2010/75/EU- Industrial Emissions (Integrated Pollution Prevention and Control) (Recast)*, Brussels.

Golder Associates 2021, *Volume I – Projeto de Licenciamento da Expansão da IRCL para o PEZ (Volume I - Licensing Project for the IRCL Expansion to the PEZ)*.

Pinasseau, A, Zerger, B, Roth, J, Canova, M & Roudier S, 2018, *Best Available Techniques (BAT*) *(Reference Document for Waste Treatment Industrial Emissions Directive 2010/75/EU (Integrated Pollution Prevention and Control)*.

Global Tailings Review 2020, *Global Industry Standard on Tailings Management*, London.

PROCESL 2016, *Estudo de Impacto Ambiental – Proposta de Definição de Âmbito - Projeto da Expansão do Zinco*, Alfragide *(Environmental Impact Study – Scoping Report for the Zinc Expansion Project)*.

PROCESL 2019, *Relatório de Conformidade Ambiental do Projeto de Execução (RECAPE) do Projeto da Expansão do Zinco – Expansão da IRCL*, Alfragide *(Environmental Compliance Report of the Execution Project (RECAPE) – Zinc Expansion Project – IRCL Expansion)*.

TPF 2023, *Memória Descritiva e Justificativa, Projeto de Deposição Alternativa de Rejeitados (Alternative Tailings Deposition Plan Design)*.

Verburg, R, Johnson, B, Fordham, M & Logsdon, M 2003, 'A rapid and cost-effective method for bench screening of geochemical performance and disposal options for high-sulfide tailings', *Proceedings of the Sixth International Conference on Acid Rock Drainage*, Australasian Institute of Mining and Metallurgy, Melbourne, pp. 739–749.