

# An Energy-Efficient Alternative Comminution and Beneficiation Circuit for the Kanyika Niobium Project

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## 1. Introduction and Ore Context

The Kanyika Niobium Project in Malawi, developed by Globe Metals & Mining, includes pyrochlore as the primary niobium mineral, with tantalum and uranium as co-hosted elements and a discrete zircon silicate fraction. Extensive mineralogical characterisation, bench-scale testwork, and pilot campaigns have been completed to define an ore-specific flowsheet capable of maximising niobium recovery while limiting energy consumption and concentrate dilution.

Mineralogical analysis shows the ore to be dominated by hard silicate gangue, principally plagioclase feldspar (~50%) and alkali feldspar (~10%), with Mohs hardness values in the range of 6–6.5. Softer mica (~20%, Mohs 2–3) and iron oxides (~8.5%) are present, while pyrochlore itself (~1%, Mohs ~5–5.5) is softer than the dominant gangue. This hardness contrast between value mineral and gangue strongly influences comminution behaviour and downstream selectivity.

Bond testwork returned a moderate Rod Mill Work Index (RWI) averaging ~12 kWh/t and a higher Ball Mill Work Index (BWI) of 17.4 kWh/t, giving an RWI/BWI ratio of <1. This ratio indicates friable behaviour at coarse sizes with limited capacity to form competent autogenous grinding media. The elevated BWI reflects sharply increased energy demand at finer grind sizes.

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## 2. Limitations of the Conventional SAG-Based Circuit

Early engineering studies adopted a conventional jaw crusher followed by a SAG and ball mill (SABC) configuration, with steel balls added to the SAG mill to compensate for the low coarse competency implied by the RWI/BWI ratio. While technically workable, this configuration carried a high projected energy intensity of 12–15 kWh/t.

The SAG mill alone was designed to consume approximately 7.2 kWh/t while producing only a –10 mm transfer size to the ball mill. The downstream ball mill then required a further ~12.3 kWh/t to achieve the target grind size. This energy split was inefficient for an ore that breaks readily at coarse sizes but becomes increasingly energy-intensive at finer sizes.

Pilot testwork further confirmed preferential overgrinding of pyrochlore, with ultra-fine slimes containing a higher niobium concentration than the ROM. Although grinding below 100 µm improved pyrochlore liberation, applying fine grinding to the bulk ore increased niobium losses to slimes, offsetting the benefits of improved liberation.

The second challenge was flotation selectivity. The highly selective pyrochlore collector is also effective at floating zircon. In a single-stage flotation solution, this results in dilution of the niobium concentrate. Removal of zircon upstream is therefore strongly indicated.

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## 3. Gravity Response and Size-Based Mineral Partitioning

Gravity separation testwork provided critical insight into the size-based distribution of niobium and zircon. Cumulative recovery curves for spiral concentration (Figure 1) show strong early recovery of ZrO<sub>2</sub> at low

mass pulls (~10%). In a two-stage flotation solution, this significantly reduces the capital and operating costs associated with zircon flotation and its removal from the feed to pyrochlore flotation.

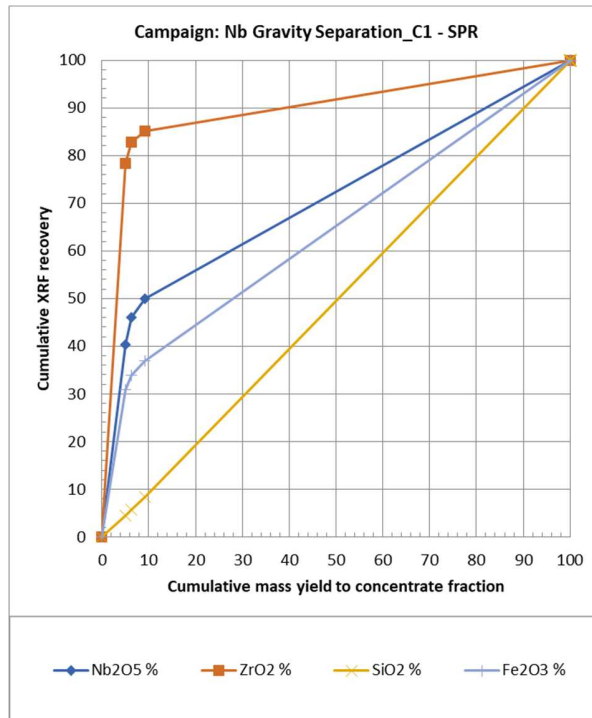


Figure 1: Cumulative spiral recovery curves ( $\text{Nb}_2\text{O}_5$ ,  $\text{ZrO}_2$ ,  $\text{SiO}_2$ ,  $\text{Fe}_2\text{O}_3$ )

Size-by-size analysis of the  $-150\ \mu\text{m}$  fraction (Figure 2) revealed a bimodal distribution. Zircon is concentrated predominantly in the coarser fractions centred around  $\sim 125\ \mu\text{m}$ , while niobium is enriched in finer material centred around  $\sim 45\ \mu\text{m}$ . This observation has important implications for regrinding strategy: selective grinding of the coarse spiral concentrate is required to liberate niobium associated with harder zircon and feldspar phases, while avoiding bulk fine grinding of the entire stream.

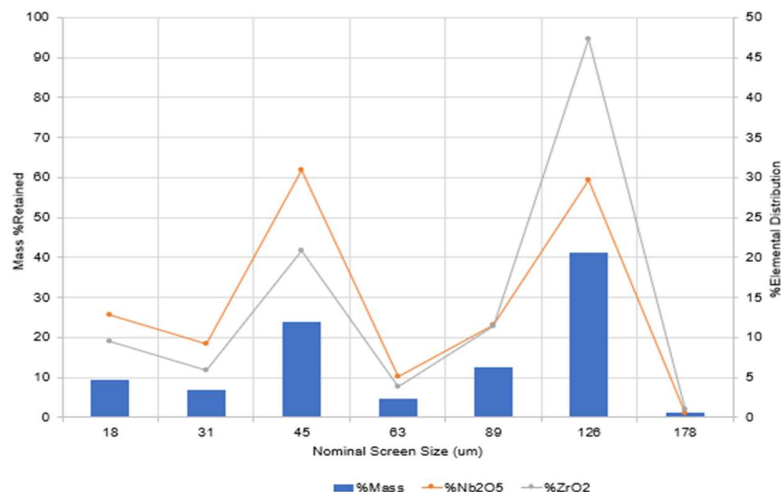
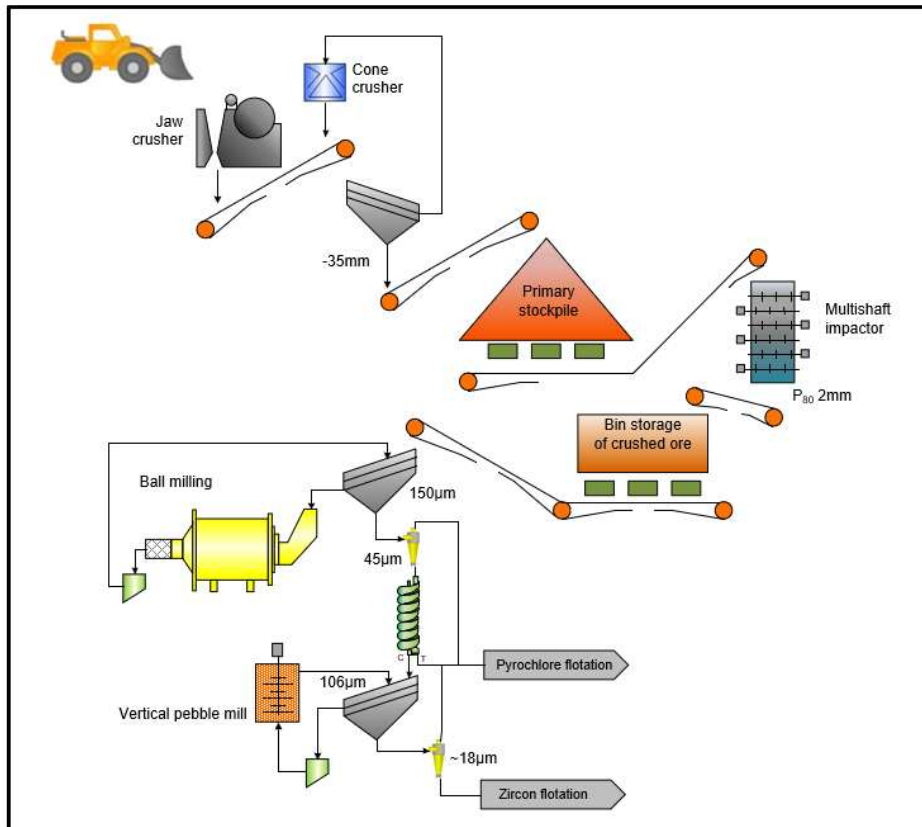


Figure 2: Size-by-size mass,  $\text{Nb}_2\text{O}_5$  and  $\text{ZrO}_2$  distribution

#### 4. Revised Comminution and Beneficiation Flowsheet

The revised flowsheet replaces SAG milling with three-stage crushing comprising a common primary jaw crusher followed by a new secondary cone crusher, and downstream EDS horizontal multishaft impactors. The secondary cone crusher treats the +40 mm fraction from primary crushing, a duty previously performed by the SAG mill in the original circuit. The impactors operate in closed circuit with 2 mm screening (Figure 3).



**Figure 3: Revised comminution and beneficiation flowsheet**

The EDS units exploit the friable nature of the ore at coarse sizes, delivering high reduction ratios at low specific energy. Including circulating load, the EDS circuit consumes approximately 3 kWh/t to produce a -2 mm product. When combined with ~1 kWh/t for primary and secondary crushing, this compares favourably with the original SAG mill energy demand of ~7.2 kWh/t.

Approximately 21% of the -2 mm EDS product reports as <150 µm fines. As these bypass the ball mill entirely, ball mill feed rate and installed power are substantially reduced.

The ball mill operates in closed circuit with cyclones and 150 µm screening and is designed for a specific energy of <10 kWh/t, compared with 12.3 kWh/t in the original SABC configuration.

Ball mill discharge is deslimed at 45 µm ahead of gravity separation. The +45 µm fraction feeds spirals, which recover approximately ~54% of total ZrO<sub>2</sub> and ~24% of total Nb<sub>2</sub>O<sub>5</sub> into a ~10% mass pull concentrate. This early zircon rejection materially reduces the load and reagent consumption of the downstream zircon flotation circuit.

## 5. Selective Regrind and Flotation Strategy

Given the bimodal mineral distribution identified in testwork (Figure 2), spiral concentrate is screened at 106 µm. The -106 µm fraction of the spirals concentrate bypasses regrinding and proceeds directly to zircon flotation. Only the +106 µm oversize fraction is treated in a vertical stirred mill (VSM), selected to minimise residence time and reduce the risk of overgrinding softer pyrochlore.

The reground spiral concentrate feeds a dedicated zircon flotation stage, where pyrochlore is selectively depressed, primarily using starch. Zircon flotation tails are subsequently acid-scrubbed at pH 2–3 in a high-intensity attrition cell to remove residual depressant and reactivate pyrochlore surfaces.

The cleaned zircon flotation tails then join the consolidated pyrochlore flotation feed, which comprises:

- -45 µm spirals desliming cyclone overflow containing the majority of the Nb<sub>2</sub>O<sub>5</sub>,
- Spiral tailings and middlings, and
- Cleaned zircon flotation tails.

This configuration ensures that virtually all recoverable pyrochlore reports to a single, dedicated flotation stage, benefiting from upstream zircon removal and comminution strategies that minimise overgrinding.

The combined effect of selective comminution and targeted regrinding has a material impact on overall niobium recovery and concentrate quality. By avoiding bulk fine grinding of the pyrochlore-rich streams, overgrinding is reduced and losses of niobium to ultra-fine slimes are minimised. At the same time, secondary milling of the +106 µm spirals concentrate fraction improves liberation of pyrochlore associated with harder zircon and feldspar phases, increasing the proportion of recoverable niobium presented to flotation. The early removal of zircon by gravity and dedicated flotation further reduces dilution of the niobium concentrate, resulting in higher concentrate grades. This has downstream benefits beyond the concentrator, as lower zircon content reduces reagent consumption in the refinery, where reagents are added on a mass basis per tonne of concentrate processed.

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## 6. Energy and Economic Outcomes

The revised circuit reduces overall specific energy consumption to approximately 7–9 kWh/t, compared with 12–15 kWh/t for the original SABC design. At a nominal throughput of 1.5 Mtpa and a power cost of US\$0.30/kWh, reflecting the higher cost of partial diesel generation, this equates to annual power cost savings of approximately US\$2.5 million.

Beyond direct energy savings, the flowsheet reduces zircon flotation feed to less than 10% of ROM, lowering both capital and operating costs, while improving niobium concentrate grade through reduced dilution and improved liberation control.

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## 7. Conclusions

The alternative comminution and beneficiation circuit demonstrates the value of ore-specific optimisation for soft-to-intermediate, friable niobium ores hosted in hard silicate gangue. By replacing SAG milling with EDS multishaft impactors, applying gravity separation to concentrate and remove zircon early, and limiting fine regrinding to a small, mineralogically targeted fraction, the flowsheet achieves:

- Substantially lower energy consumption,
- Reduced niobium losses to ultra-fines,

- Lower zircon flotation capital and operating costs, and
- Improved niobium concentrate grade.

The approach illustrates that selective size reduction and targeted regrind, informed by mineralogical characterisation and size distribution data, can outperform conventional SAG-based circuits for this class of ore.