Review of May 2020 Catastrophic Tank Failure, HPP-3, Norilsk

Independent Environmental Advisory Support to the Nornickel Environmental Task Team (ETT)

25 November 2020

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ERM

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Introduction

- Environmental Resources Management Limited (ERM) have been retained by the Board of Norilsk Nickel to provide Independent Environmental Advisory Support.
- This report has assessed the root causes, contributing factors and critical systems affecting the 29 May 2020 incident and is based on the information available to ERM at the time of writing.
- ERM was commissioned in July 2020 but due to COVID-19 restrictions was unable to gain access to the site until 15th September 2020. By this time the tank had been entirely removed. Consequently our assessment of the root cause of failure is based on available documentation, photographs and interviews only.
- The ERM scope of work was advisory and did not include any physical activities such as environmental sampling or analysis, borehole drilling or testing associated with the tank or foundations.
- We would like to acknowledge and thank the Nornickel management for their cooperation specifically the provision of the information requested and access to the site which together allowed ERM to conduct this assessment.

The Incident

- On 29 May 2020 above ground emergency diesel tank no. 5 at the Heat and Power Plant No. 3 in the Kayerkan neighbourhood of Norilsk ruptured catastrophically releasing the entire tank contents of approximately 21,200 tonnes of diesel in approximately 20 minutes.
- The diesel surged from the tank, overtopped the bund wall flowing via roadways and topography into the surface water network.
- The diesel release impacted surface waters for some 29km to its furthest point close to Lake Pyasino, before booming allowed control over its spread.

The dynamic force of the diesel release resulted in the overtopping of the bund wall

Diesel flowing through the fence and off-site

Photographs of Tank No. 5 taken from a video posted to Instagram (now unavailable)

Photographs: Tank No.5 Failure

Post Incident – Pile Damage

Failure of some of the reinforced concrete piles which supported the tank

Post Incident – Collapsed Tank Floor

Interior of the tank showing a large depression caused by pile failure which in turn caused failure of the common plates dragging the annulars inwards resulting in failure where the plates met the shell

Post Incident – Tank Shell Rupture

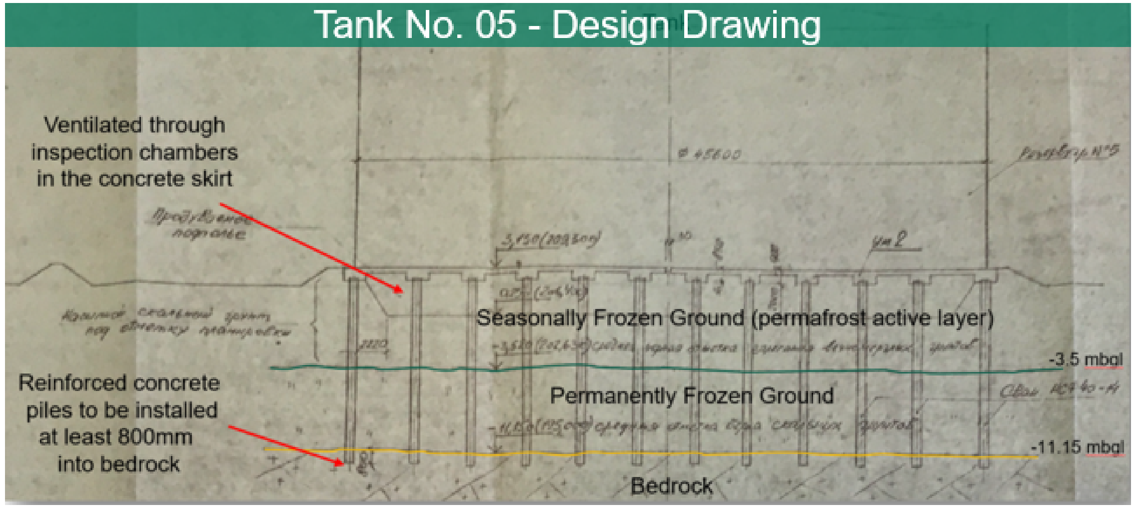
Rupture of the tank shell where the wall is welded to the floor

All photographs provided by Nornickel

Conclusions: Causes of Failure (1)

Design Consideration

- The likely cause of the tank failure was differential subsidence of the tank base foundation. This would appear to have been a result of the failure of some of the reinforced concrete piles which supported the tank.
- This subsidence resulted in a rupture of the tank shell where the wall is welded to the base.
- Preliminary results of the regulator incident investigation reported that several of the piles were found to be shorter than the design length and not installed 800mm into the bedrock. This would mean that these piles were supported by the permafrost soil layer rather than the bedrock.
- Any warming and melting of the permafrost would reduce the adfreeze and bearing capacity of these soils relative to that of the bedrock and render such piles susceptible to potentially rapid creep settlement as the permafrost warmed under and around the tank.
- This suggests that increasing permafrost temperature, linked to reduced adfreeze and bearing capacity of soils and resultant creep settlement of the piles not installed into bedrock was the likely failure mechanism.

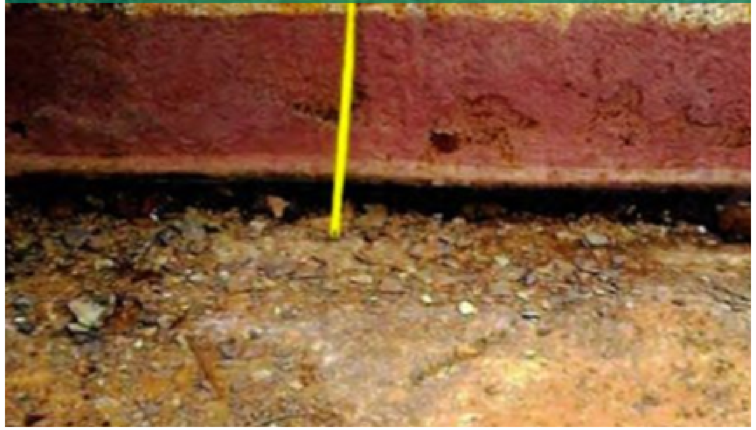


Conclusions: Causes of Failure (2)

Management & Systems

- Insufficient attention has been given to the emergency diesel tankage both in terms of its likelihood and realisation of the implications of failure.
- Consequentially the levels of management and safeguarding are below that expected from the volume of tankage present.
- There appears to have been a reliance on the tank having been considered regulatory compliant as a consequence of regulator inspections over the preceding 2 years, in part resulting from an inadequate understanding of the potential risks and management of them.
- This is highlighted by a series of missed signals and lack of specific monitoring which in combination could have been taken as warning signs of the subsidence and in hindsight avoided the failure. These were:
    - Loss of verticality and 80mm gap between the foundation and the tank floor detected during the Industrial Safety Expertise in 2018 that jointly could be considered indicators of subsidence
    - Lack of focus on the foundation during the tank inspection
    - Lack of permafrost monitoring (not required by the regulations due to the tank design)
- However underpinning all of this is the fact that if all piles had been installed as designed into the bedrock, this failure would not have happened.

Pre-Incident – Gap between tank shell and base - 2018



Summary Root Cause Analysis: Tank No.5 Failure

Catastrophic Release of Diesel from Tank No.5

Tank ruptured along the weld between the tank shell and base

Differential downward movement of a section of the tank concrete base

Creep subsidence of a number of the reinforced concrete piles

Root Causes

Number of piles not installed in bedrock as designed

Increasing permafrost temperature

Poor installation of piles?
Design based on insufficient geotechnical data?
Local variations in depth of bedrock?

With increased permafrost temperature, less pile adfreeze and less bearing capacity than bedrock

Lack of under tank ventilation to maintain winter time cooling

General increase in Arctic Siberia temperatures leading to increased permafrost temperature

Warning signs of tank foundation movement not investigated
Loss of verticality and a 80mm gap between the foundation and the tank floor detected during the Industrial Safety Expertise in 2018 that jointly could be considered indicators of subsidence

Compliance mind-set

Tank assumed to be in good order as passed by Regulator for continued use

No permafrost temperature monitoring under tank

Compliance mind-set

Not required by regulator

Conclusions: Factors Contributing to the Scale of Spill Impact

- The following key factors contributed to the catastrophic scale of the spill impact:
  - The bund was insufficient in size to accommodate the tank volume and the bund wall was not capable of preventing the dynamic forces of a catastrophic tank failure forcing diesel over the bund wall.
  - Inadequate risk assessment in the Safety Declaration (SD). The catastrophic tank failure scenario was assessed as non-significant due to the low probability ($1.5x10^{-5}$ per year) and minor consequence (limited impact on soils). The SD did not contain any recommendations to mitigate such scenario.
  - Inadequate tertiary containment measures to reduce the off-site impact of a catastrophic tank failure.
  - Lack of immediate resources and response planning required to swiftly react to such a major event.
  - No detailed spill modelling was undertaken to inform the Oil Spill Response Plan (OSRP). The OSRP estimated the impacted area even less comparing to the one calculated in the SD and therefore mitigation activities were limited to contaminated soil removal and pumping of diesel fuel from the tank bund.
- This reinforces the earlier point around insufficient appreciation of the potential implications of failure and the absence of a management system that allowed for the control and mitigation of such events.

Summary Root Cause Analysis: Environmental Consequence

312,000m² Impact from Tank No.5 Catastrophic Release

No emergency response plan for such an eventuality

Root Causes

Risk assessment concluded catastrophic tank failure non-significant due to the low probability and minor consequence

Diesel storage was emergency storage and not considered central to the operations of the site

Secondary containment appears to have been insufficient to hold the entire tank capacity

The proximity of the bund wall (secondary containment) rendered it incapable of withstanding the dynamic forces of a catastrophic tank failure leading to collapse of part of the wall and overtopping of the bund wall

There were no tertiary containment measures to reduce the off-site impact

Lack of immediate resources and response planning required to swiftly react to such a major event, including for example booming plans at strategic locations down the waterways to hold impacts and allow more measured and reduced impacts to be mitigated

Lack of emergency response access routes which led to increased impacts to the environment

Key Themes Observed

Overall the impression is that insufficient attention has been given to the emergency diesel tankage both in terms of a realisation of the implications of failure, its likelihood and as a consequence the levels of management and safeguarding that one would expect from the volume of tankage present.

In ERM's opinion the following were contributors to the tank failure and subsequent environmental damage:

- *Catastrophic tank failure risk (general not pile failure specific) identified but likelihood and significance underestimated*
- *Climate change risk not managed through inspection regime*
- *Compliance mind-set rather than risk understanding and risk management led to missed warning signs in 2018*
- *The importance of secondary and tertiary containment not appreciated*
- *Inadequate understanding of where a spill would flow, to allow effective spill response plans including booming plans and emergency access routes to be devised and installed*
- *Response measures inadequate for major spill events*
- *Tank storage is for emergency fuel and as such is on the margins of core operations and therefore not given the focus warranted by the high potential consequence*

Recommendations: Primary Containment (Short & Medium Term)

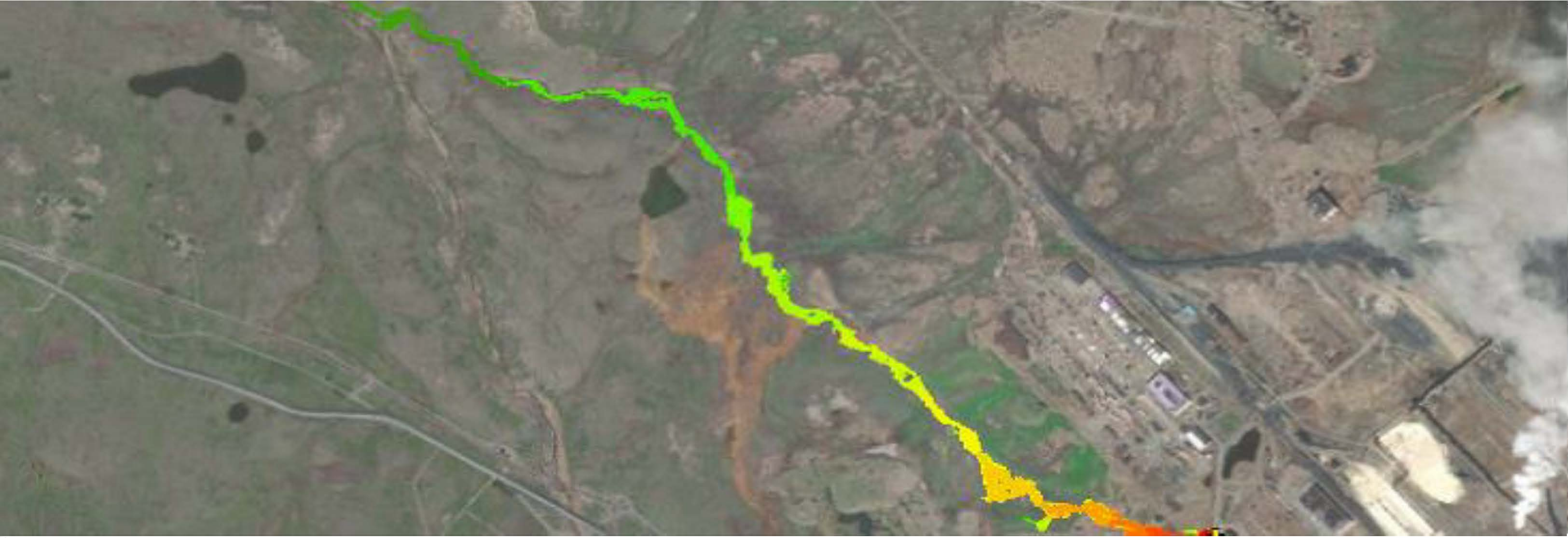
A robust risk-based Safety Management System would improve confidence in preventing catastrophic tank failures. Such a system would reduce the likelihood of the most hazardous scenario itself by investing in the most effective barriers and responding in case of emergency in a way to significantly reduce the scale of consequences and impact.

- *Inspect foundations of all tanks with the similar pile design as Tank No.5 to look for evidence of subsidence and confirm all piles installed as designed. Remove or reduce fuel level in "at risk" tanks*
- *Check to ensure they have adequate ventilation under the tank as per the design intentions in order to preserve the permafrost*
- *Extend assessment to all other tanks focused on review of tank foundation stability with respect to permafrost active zone and trend for climate warming reducing bearing capacities of soils – consider the need for any additional permafrost related protection measures, such as thermosyphons*
- *Design and instigate a permafrost monitoring system for all tankage*
- *Develop a management system to improve the integrity of the primary containment. We recommend strengthening the management systems supporting tank integrity, such as improved inspection and maintenance, anti-corrosion measures and possibly decommissioning tanks where it is considered there is a significant risk of catastrophic failure*

Recommendations: Environmental Consequence

Site management would appear to have recognised the risk of catastrophic failure (general not pile failure specific) and its low likelihood but wrongly ascribed a low consequence and therefore had no appreciation of the impact and no effective controls. This, in combination with inadequate appreciation of the implications of increased climate warming, missed warning signs and the apparent error in pile installation (only apparent post incident) created the conditions whereby such a failure becomes inevitable.

- *Check the bund capacity/ design of all tanks as it may be necessary to construct a secondary bund around these tanks, reduce the height of the bund wall between tanks or increase the overall bund capacity*
- *Undertake modelling to determine where to locate tertiary containment systems, inform emergency response planning and located spill response equipment*
- *Look to the provision of emergency response access routes and booming locations*
- *Update the spill response plan and carry out emergency response exercises*



Thank you

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25 November 2020

To whom it may concern,

ERM Independent Review of 29th May Tank Failure at Norilsk

In mid-July 2020 ERM was retained by the Environment Task Team (ETT), a special committee set up by the Board of Norilsk Nickel. ERM's role was to provide independent environmental advisory support relating to the failure of a diesel storage tank at Heat and Power Plant No 3 (HPP-3) at Norilsk on 29th May 2020.

Our assessment has reviewed the root causes, contributing factors and critical systems affecting the incident including the tank failure and the subsequent environmental impacts.

We would like to acknowledge and thank Nornickel management for their cooperation, specifically in the provision of the information requested and access to the site.

The findings of ERM's review, together with the recommendations for improved preventative measures, were presented to the ETT on 23rd November, and subsequently presented to the Nornickel board on 25th November.

ERM would like to thank the ETT for appointing us to carry out this important assignment. This was a serious incident and it is vital that the right lessons are learned so there are no similar events anywhere in the company's operations in the future. To this end, we would welcome Nornickel implementing our recommendations in full.

Any related enquiries should be directed to Nornickel at pr@nornik.ru

For and on behalf of ERM,