Tailings Facility Failures in 2014 and an Update on Failure Statistics

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ABSTRACT: In 2014, the failure of at least three tailings facilities was reported on the internet: Mt Polley in British Columbia, the Duke Energy Eden facility in North Carolina, and the Minas Geras failure in Brazil. This paper collates publicly available information about the 2014 tailings failures and examines the subsequent social and regulatory responses in the three different jurisdictions in which the failures occurred. The paper proceeds to update tailings failure statistics in the light of these and 2012 and 2013 tailings failures. The authors have no personal knowledge of any of these failed facilities, but draw instead on public reports and professional experience in discussing the perpetually fascinating and perplexing issue of continued failure of mine tailings facilities.

1 INTRODUCTION

Tailings facilities continued to fail in 2014. We, the authors, are aware of three major tailings facility failures in 2014. In Mexico there was a reported "spill" from a mine, but it is not clear this constitutes a tailing failure—so is not further addressed here. The information we have comes from the internet—we have no personal information or knowledge not available to those who use the internet.

In this paper, we briefly describe failure statistics, rates, the failures and the subsequent response of the politicians, regulators, professionals, and the industry to the failures. Hence we re-examine the statistics of failure of tailings facilities and the ways the failure rate may be reduced.

2 MAJOR FAILURES IN 2014

2.1 *Duke Energy*

2.1.1 *Failure description*

In February 2014 the ash tailings facility at the Duke Energy, Dan River Steam Station, Eden, North Carolina, USA failed and coal flyash tailings flowed out into the Eden River.

Apparently old pipes beneath the facility corroded and failed. The tailings and supernatant water flowed into the broken pipes and out to the river. The tailings flowed many miles down the river and was highly visible to the many folk who live along the river.

About 82,000 short tons of toxic coal ash and 100,000m^3 of contaminated water was released from the 27 acres facility. Since the failure, much of the tailings has been removed (dredged) from the river.

2.1.2 *Investigations & legal*

The U.S. Environmental Protection Agency has updated regulations on the operation of fly ash facilities. In essence the new regulations require the ash to be managed in facilities that replicate the details of landfills. This includes basal liners, placement of “dry” ash, and regular covers.

America’s legal system sprung into action. One report reads:

A federal judge ordered Duke Energy to pay a record $102 million criminal penalty for a humbling litany of ignored warnings that preceded last year’s coal ash spill into the Dan River. But Duke didn’t measure the water flowing from the pipes, to detect leaks, as a consultant recommended in 1986. No inspections of the flow from the larger pipe were done for nine years because of heavy undergrowth and snakes.

In March 2015 a shareholder filed suit against the board of directors and former board members and executive of Duke Energy accusing them of “breaches of fiduciary duties, waste of corporate assets, and unjust enrichment. This misconduct has exposed the Company to billions of dollars in actual and potential liability.”

The suit further alleges “The Dan River disaster was a foreseeable consequence of Duke’s years of intentional neglect of its coal ash ponds. Rather than take appropriate action to move the company toward compliance with the law, Duke, with the board’s knowledge, used its influence in the North Carolina state government to attempt to maintain the status quo.”

Duke has denied these claims. The suit is not going forward for now. The court is awaiting the outcome of five similar suits filed in the Delaware Court of Chancery that deal with essentially the same allegations and issues.

2.1.3 *Discussions*

First of all, let's note that the portfolio selected for the Mount Polley panel review (next section) would not have included this type of embankment.

To the best of our knowledge, many US power companies are undertaking major projects to upgrade their ash tailings facilities and comply with the new EPA regulations. Interestingly in 1985 the Stava Dam collapsed, killing 268 people, destroying 63 buildings and demolishing eight bridges, thus gaining the status of Very Serious failure, due to “forgotten” pipes. No Black Swan can be invoked for this 2014 failure!

2.2 *Mt Polley*

2.2.1 *Failure description*

On August 4th, 2014 part of the perimeter embankment of the tailings facility at Mt Polley, British Columbia, Canada (commissioned in 1997) failed and tailings flooded local streams and lakes. About 7.3Mm^3 of tailings, 10.6Mm^3 of water and 6.5Mm^3 of interstitial water were released.

2.2.2 *Investigations & legal*

An expert panel appointed by the British Columbia regulators concluded that the embankment failed as a result of a local layer of glaciolacustrine clay, the strengths of which was apparently not understood by the tailings facility designers. Additional factors that caused failure and exacerbated the consequence of failure include embankment downstream slopes that were too steep and high water levels in the pond, hence reduced beaches. The embankment was constructed as a “modified” centerline embankment, but, in practice, more closely resembled an upstream embankment— this too may have played a part in the failure.

The expert panel exonerated the regulators who had approved a factor of safety (FoS) of 1.3 instead of 1.5 which it may be argued is the valued required by relevant and potentially appropriate standards. To date no official assignment of responsibility or blame has been assigned, although there are reportedly still selected panels examining the issues. Note that recent papers (Oboni, Oboni 2013, Oboni, Oboni, Caldwell, 2014) have shown the very significant influence of that 0.2 difference in the initial value of FoS on the probability of failure p_f at service inception and also at various phases of the embankment's life.

The expert panel concluded in essence that the only “safe” tailings facility is one where there is no water on the surface of the tailings and no water in the voids of the tailings. The other recommendations made by the panel to improve tailings facility safety include: independent peer review boards (Morgenstern, 2010, Caldwell, 2011); better performance modelling and performance monitoring; use of best management practices (such as filter pressed tailings and underground mine back-filling).

2.2.3 *Discussions*

Tailings professionals have debated the failure and the expert panel report, but to date none have come to any definitive conclusions. Some professional organizations are reportedly upgrading their tailings practice guidelines, but none are currently published.

Based on a 2013 paper (Oboni, Oboni 2013), a dam with an initial FoS=1.3, belonging to CAT II or III (Silva et Al., 2008), merely looking at the way it was reportedly investigated, designed and managed, would have had an initial p_f of about 10^{-2}, to compare with “historic” rates of failure of 10^{-4} or 10^{-3} (during two different decades), i.e. one to two orders of magnitude more likely to fail. Conclusion? Certainly not a Black Swan here and actually a quite foreseeable end!

Some professionals have written articles pointing out that the no water in or on the tailings is not practical if the tailings are acid generating. Such professionals argue that the risk of acid drainage impact is so much greater than the risk of tailings facility failure, that water on and in the tailings should continue. With a known rate of failure (Oboni, Oboni, 2012; Bowker, Chambers, 2015) and solid experience on acid drainage around the world, a comparative, unbiased risk analysis could be indeed produced bringing solid answers to that discussion.

Some mines have noted that their mine sites are in such wet and cold locations that it is not possible to adopt filter pressed tailings. It is true that some places in British Columbia are just too snow-bound and rainy to practically place filter pressed tailings.

The British Columbia government has convened groups to further examine the issue of tailings facility failure, but no public reports are yet available.

The public was at first incensed. Now there are still isolated minor protests calling for no resumption of mining at Mt Polley— at the time of writing this paper, newspaper reports are that the provincial government will soon approve resumption of mining subject to unreported conditions.

It is reported that the salmon fry in Quesnel Lake where many of the tailings flowed are more numerous and larger than in previous years. Apparently they are thriving on the nutrients swept into the lake. Some are concerned these fry will be overly affected by elevated copper levels.

2.3 *Herculano Mine*

2.3.1 *Failure description*

While workers were working on the tailings facility at the Herculano mine, Itabirito, Região Central, Minas Gerais, Brazil, on September 8, 2014, the facility failed, killing two and effectively obliterating a third worker who has never been found.

2.3.2 *Investigations & legal*

Almost nothing has been reported on the failure, its investigation, or subsequent events. Informal discussions with junior Brazilian engineers inform us that the “*government is investigating and will report in due course.*”

2.3.3 *Discussions*

From the scant reports on the internet, it appears that the tailings facility was an old one. Sometime before the failure, fresh tailings had been placed near the upgradient side of the facility. The workers were reportedly there to implement stabilization works. Apparently they dug through an outer crust into liquid tailings which flowed out with deathly consequences.

3 FAILURE COMPARISON

We note the following common features of the 2014 tailings failures:

- Existing facilities that had been used for many years, reportedly following the "as it is impossible to anticipate everything, why bother" principle described in the first half of past century (Merton, 1936).
- Antiquated design and management practices, meaning poor initial conditions and overall structure category, as shown above for the cases where some data were available leading to substandard p_f.
- Absence of risk assessment or even of common health and safety programs. Let's note that typical, common practice, risk matrices can only correctly and unambiguously compare a small fraction, reportedly less than 10%, of randomly selected pairs of hazards. Furthermore, they can assign identical ratings to quantitatively very different risks, a phenomena often referred to as "range compression" and can mistakenly assign higher qualitative ratings to quantitatively smaller risks and vice versa. These inaccuracies can lead to mistaken resource allocation. (Oboni, Oboni, 2012)
- No peer review. Independent peer review of water dams is a long-standing practice. It is disgraceful that all regulators do not insist on it. Until they do, and peer reviews are performed very seriously, we see no hope of reducing the incidence of tailings facility failure (Morgenstern, 2010, Caldwell, 2011)
- Limited engineer involvement that appears to have been aware of potential problems but not heard or acted on. Alarming disconnect comes from the poor definition of potential consequences of mishaps and their societal ripple effects. This aspect is indeed mostly ignored in codes, leaving professionals ample room to biases and censoring applied to potential losses (Oboni at Al., 2013, CDA, 2014).
- Overconfident mining companies that did not act when prudence may have so dictated. Risk assessments are almost always censored and biased towards "credible events". However history, even recent, has shown that major failures occur when "incredible events" occur, or long chains of apparently benign events are produced and the public has now got that clearly in mind, generating widespread controversy and projects' opposition (Oboni at Al., 2013).
- Absence of significant regulatory oversight or involvement. Risks assessments are "at risk" if plagued by conflict of interest or overly optimistic cognitive biases, or censure. (Oboni, Oboni, 2014).

While there are similarities in root causes, there is an amazing difference in the response of the societies affected by the failures. From swift and dramatic, with new regulations and large fines for the responsible parties, to the usual committee meetings, review reports soon ignored, calls for action yet to be undertaken, finally a sort of void: no reports, no action, and the mere hope of something in the unspecified future.

4 DISCUSSING FAILURE STATISTICS AND RATES

4.1 D*efining failures*

In the recent years two studies have tackled (Oboni, Oboni, 2013; Bowker, Chambers, 2015), from a slightly different point of view, the estimation of the TD accident rates, on top of the very narrow portfolio tackled by the Mt. Polley Review Panel. The 2013 study looked at major accidents reported by various sources (UNEP, 1996, 1998; USCOLD, 1994) considering those that had a widespread media/public opinion impact. The 2015 study looks at Serious (S) and Very Serious (VS) failures defined as follows:

Type	Release greater than	And/or Loss of life	And/or Travel distance
Serious (S)	100,000m^3	YES	N/A
Very Serious (VS)	1Mm^3	≥ 20	>20km

The common practice approach of using oversimplified consequence functions (with "and/or" clauses as just defined above) is often used in research papers because of scope/budget limitations, but should not be accepted for a rational world-wide approach to decision making and tailings risks management for an industry that has significant societal impacts like mining. Tailings accidents generate multiple direct and indirect consequences on the environmental, human, H&S, operational and reputational areas (CDA, 2014) and we believe it is time for the mining industry as a whole to adopt a uniform consequence function. Such a function would allow a better understanding/comparison of potential risks of tailings dams failures and, of course, also to better address emergency situations/communication, as dicussed later (Section 5.2). Each one of the consequences' "dimensions" would need to be expressed as ranges, to include uncertainties. (MVREIB, 2012).

4.2 Discussing rates of occurrence

The 2015 study states that catastrophic tailings spills are occurring with increasing frequency around the world. The report states that half the serious (Serious and Very Serious) dam failures, 33 of 67 in the past 70 years, have occurred in the 20 years between 1990 and 2009.

In order to allow a comparison between the 2013 and 2015 studies, a rate of failure of 67 over 70 years, with a world-portfolio of estimated 3,500 dams, was evaluated as 67/(3,500*70) = 2.7*10^{-4}. The same was performed for 33 accidents over 20 years leading to 33/(3,500*20) = 4.7*10^{-4}.

From Appendix 1 of the 2015 study the following rates were extracted:

Period	Interval years	Very serious/ Serious failures	Very serious
1990-2009	20	33/(3,500*20) = 4.7*10^{-4}	16/(3,500*20) = 2.3*10^{-4}
1990-1999	10	18/(3,500*10)= 5.1*10^{-4}	9/(3,500*10)= 2.6*10^{-4}
2000-2009	10	15/(3,500*10)= 4.3*10^{-4}	7/(3,500*10)= 2.0*10^{-4}

The 2013 study was a "quick and dirty" approach, based on general failure data and certainly less complete records than the 2015 one. The 2013 paper showed that for the 1974-1984 decade the world-wide rate was 10^{-3}; and for the 1994-2004 decade it was 2*10^{-4}. The rate was constant in the US in those two decades at 7-8*10^{-4}. It is comforting that the results of the "quick and dirty" 2013 study reached globally comparable results to the 2015 very deep and solid analytical approach. We note that the selection of the time frame has a large influence on the conclusions of the 2015 study and therefore we recommend these comparative studies to be performed with constant duration (for example decade by decade) to avoid the hazard of drawing misleading conclusions. "Averaging" over 70 years, during which so many conditions have changed, may indeed mask decennial spikes. To prove this it is enough to look at the Table above which shows that the accident rates have actually decreased by 15%-24% from the 1990-1999 to the 2000-2009 decades using the 2015 study's own data.

The three major failures in 2014, described in this paper, indicate a rate very near 10^{-3} (thus similar to the 1974-1984 decade stated in the 2013 study). However, that again may simply be the result of a local spike. Time will tell if climate changes, and/or other factors, are starting to influence world-wide statistics.

5 DISCUSSING FAILURE CONSEQUENCES AND THEIR EVOLUTION

5.1 Mortality

Let's first discuss tailings dam failure accident mortality (Figure 1), a relationship obeying the Bendford law, expressed up to date, for tailings dams by:

$$Casualties_{(1962\text{-}2014)}=499.9*e^{(-0.2372*\text{number of accidents})} \text{ with a } R^2=0.987$$

Should future accidents significantly alter the graph and the relationship, this would indicate that some parameters have changed, possibly in the number of people exposed downstream, working on or by the dams, climate change, etc.

There have been:

- 68 VS,S accidents between 1917 and 2009 (92 years);
- 67 between 1940 and 2009 (69 years), and
- 54 between 1962 (date of the first recorded casualties) and 2009 (47 years).
- 6 events with more than 50 casualties add up to 1503 casualties occurred from Wales to Bulgaria, China, Italy and the US.
- The total casualties for the whole accidents record totals 1996.
- The average casualties count per VS,S accident is in the order of 1996/47=42 to 1996/68=30 (NB: this equates, for example, to evaluating the average number of casualties for deadly car accidents).

However, to better express the hazard we should look at the total casualties/total accidents or 1996/226 = 8-9 (NB: this equates, for example, to evaluating the average number of casualties per car accident). This last number is what has to be expected from a generic tailings accident and the relationship described in Figure 1 should allow to determine if the future rates will align with past records and detect anomalies. Finally, if we try to evaluate the rate of casualties for the whole industry, we can use, as an approximation 1996/(92*3,500)= $6.2*10^{-3}$ and 1996/(47*3,500)=$1.21*10^{-2}$ casualties/year dam: both these values are at least two orders of magnitude above commonly accepted thresholds for mortality in hazardous industries (Comar, 1987, Wilson & Crouch, 1982, Renshaw, 1990) and well above ANCOLD (2003) threshold of "safety."

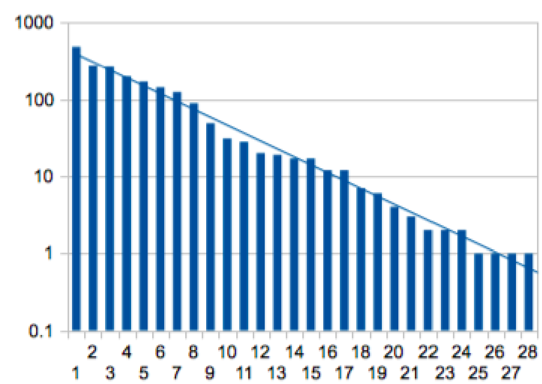

Figure 1 Accidents' casualties vs. number of accidents causing casualties, between 1962 and 2014 included.

In the 2013 study it was shown how tailings accidents had come close to the Whitman's societal tolerance threshold, the exceedance of which has been seen, in other instances, in other industries, to have crippling effects on the industry (Oboni, Oboni, 2013).

5.2 *Failure consequences scale*

The Nuclear Industry has long understood that there needs to be two approaches regarding the risk of their facilities. On one side there need to be a simple scale to be used after an incident to communicate the outcome to the public and media. Indeed we read in INES (INES 2013): “The primary purpose of INES is to facilitate communication and understanding between the technical community, the media and the public on the safety significance of events. The aim is to keep the public as well as nuclear authorities accurately informed on the occurrence and consequences of reported events.” On the other side there need to be a comprehensive metric for risk management and decision making encompassing the various dimensions of potential accidents' consequences.

The INES looks at three components:

- people and the environment,
- barriers and controls,
- defence in depth.

For a tailing dam failure the evaluation of consequences on people and the environment should look at how many 1) live lost, 2) damaged surface (including type and value following a schematic scale), and 3) persistency of the damages (or ease of cleanup, or ease to return to previous state) (Klinke and Renn 1999).

If we look at Volume released vs. lives lost (Fig. 2), it would be preposterous to see any correlations. The same could be performed with the dam height or the runout distance with the same conclusions.

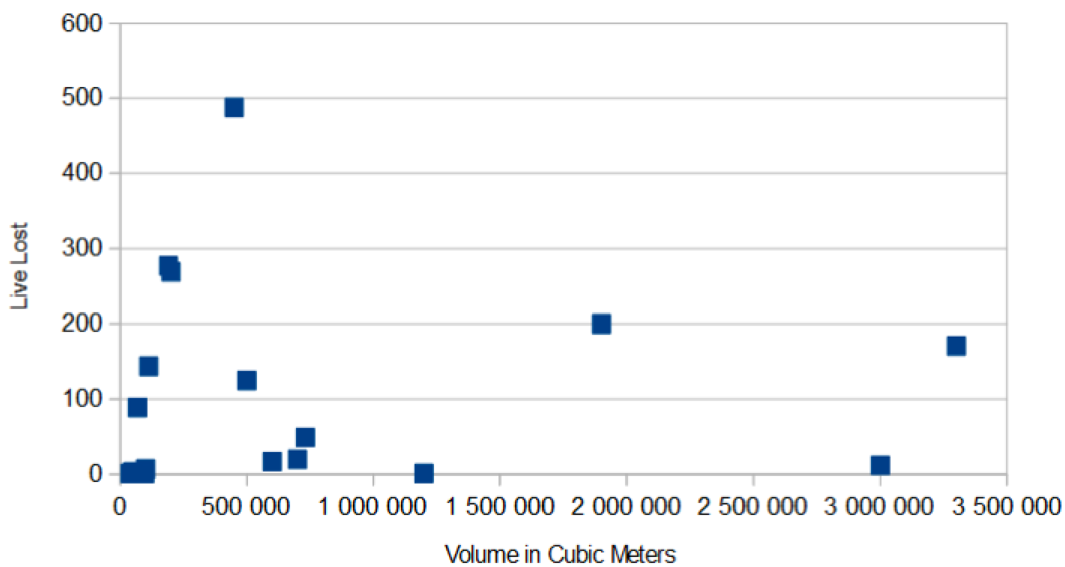

Figure 2 Volume in m3 vs Lives lost in TD accidents.

Codes (CDA, 2014) remain silent on most dimensions quantification, leaving ample margin to interpretations and biases.

The damaged surface is an interesting parameter as it is somewhat influenced by the total volume, the height of the dam and the volume released, but, from a consequences perspective, only is meaningful, whereas dam's parameters (height and volume) are not.

Lastly the persistence of the damage encompasses the availability of cleanup means, the funds allocated for it, the type (toxicity) of released material, and the fragility of the ecosystems present in the damaged area.

From past records the mining industry seems quite far from releasing the appropriate information in the immediate aftermath of a tailings accident. Lack of information often conducts media to consider that all tailings are "toxic", that all failures are "catastrophic" and generate "huge environmental disaster", this should not occur.

5.3 *Predictions*

Predictions formulated in the 2015 study consider 11 VS,S failures costing approximately 6B$ between 2010 and 2019. The average cost of each spill being 543M$, as measured by the attempts of regulators to recoup cleanup costs from mine operators. Using the 2013 rates for the 1994-2004 decade we would have a prediction of 7 failures over ten years.

Finally the 2014 study (Oboni, Oboni, Caldwell, 2014) showed that, as dam life evolves, possible hits from natural or man-made hazards happen, and the probability of failure rises in an exponential way, and more significantly so if the dam starts with a low FoS (1.3) and poor overall conditions (investigations, design, construction, maintenance). This observation is particularly important during cycles of low base metal/coal/oil&gas valuations.

6 FINDINGS AND RECOMMENDATIONS

We reiterate that the aim of zero tailings failures is impossible to achieve. There will continue to be tailings failures. In fact, in the long term all tailings facilities will spiral toward significant increases of their p_f and when they fail the tailings will go to downstream rivers, lakes, and the ocean as they did at every failure to date.

We have demonstrated that consequences are not necessarily correlated, in one way or another, with dam height or pond volume. As in many industries the "scary stuff" is not necessarily the riskier one.

Our practice and research have shown that the probability of failure is, or will be, often way higher in smaller structures than in major ones, simply because more care is taken for larger structures than for "insignificant ones". And examples like Stava or Bafokeng are there to show that "extreme" consequences can actually occur.

We have also demonstrated that the rate of fatalities in the tailings "industry" lies way above the generally accepted "safe" thresholds for hazardous industries.

The number of existing, operational, and closed tailings storage facilities around the world makes it necessary to prioritize the mitigation tasks, if we want to achieve a higher quality, be it at corporate or at national levels. The unfolding drama of the Kings Mine in Colorado and the attention it has stirred are there to show what the social consequences can be.

One of us worked with the UMTRA Project in the US, reportedly closing tailings facilities to be stable for 1,000 years to the extent reasonably achievable. Closure works were designed to remain stable in the probable maximum precipitation, the probable maximum flood, and the probable maximum earthquake. The investment was very high, paid with public money, and most likely unsustainable for most mines around the world.

The trend is nowadays to only consider mines with no water on or in the tailings. Maybe acid generating tailings facilities should not be developed, for it is not possible to keep the tailings wet and safe in perpetuity.

Clearly professional practice re tailings facilities can be improved. But we do not believe this will ever reduce the incidence of tailings failures, however successful such practice improvement is. The onus for improving tailings facility safety lies with the owners and the public by way of its regulators. Law must be clear, specific and demanding. Codes have to avoid complacency and simplistic approaches. Regulations must be clear and demanding. Regulators must be able and willing to challenge substandard practice.

And the mining industry must accept that some ore bodies should not become mines, that some places are not suitable for mining, however valuable the ore body, and some tailings practice should not be implemented regardless of how cheap they are.

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