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Improving Risk Management in Tailings Deposits and Dams

Challenges and Proposals

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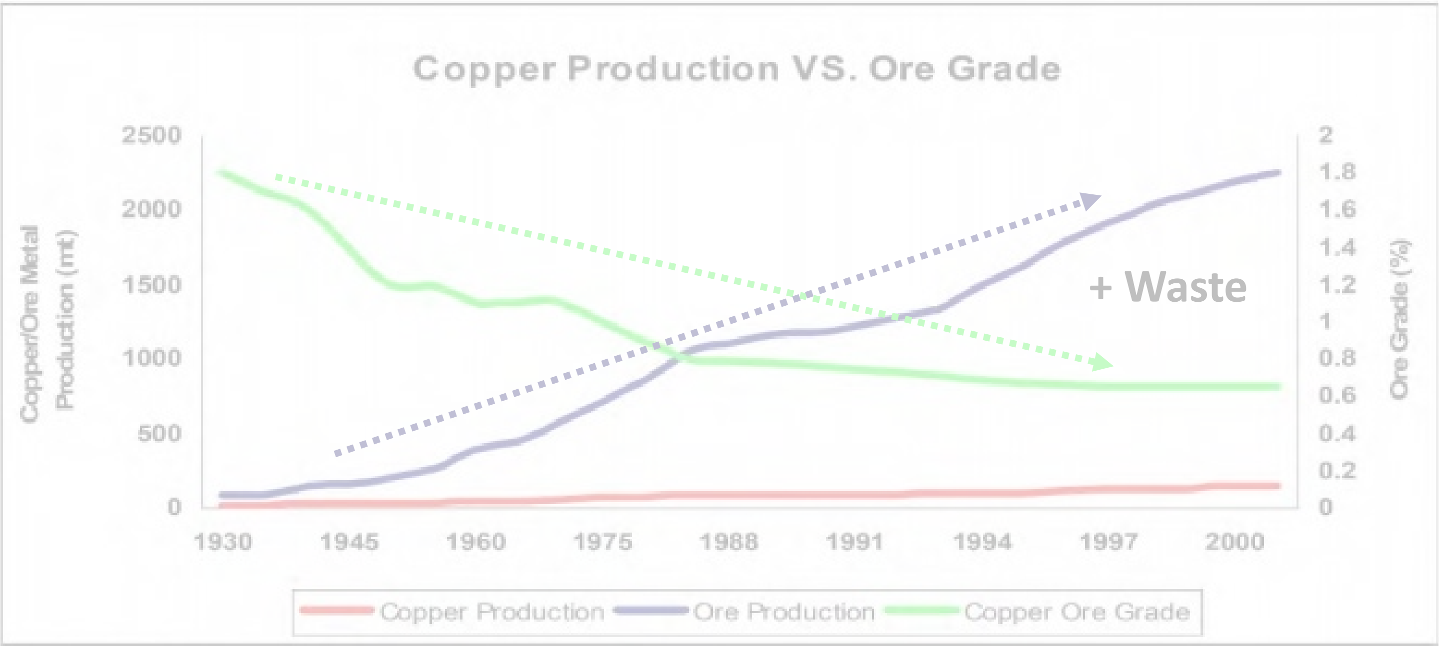
The challenge mining industry is facing

- **Mining industry requires to increase its production** (in terms of treated ore) to attend metal demands and the decline in ore grade.



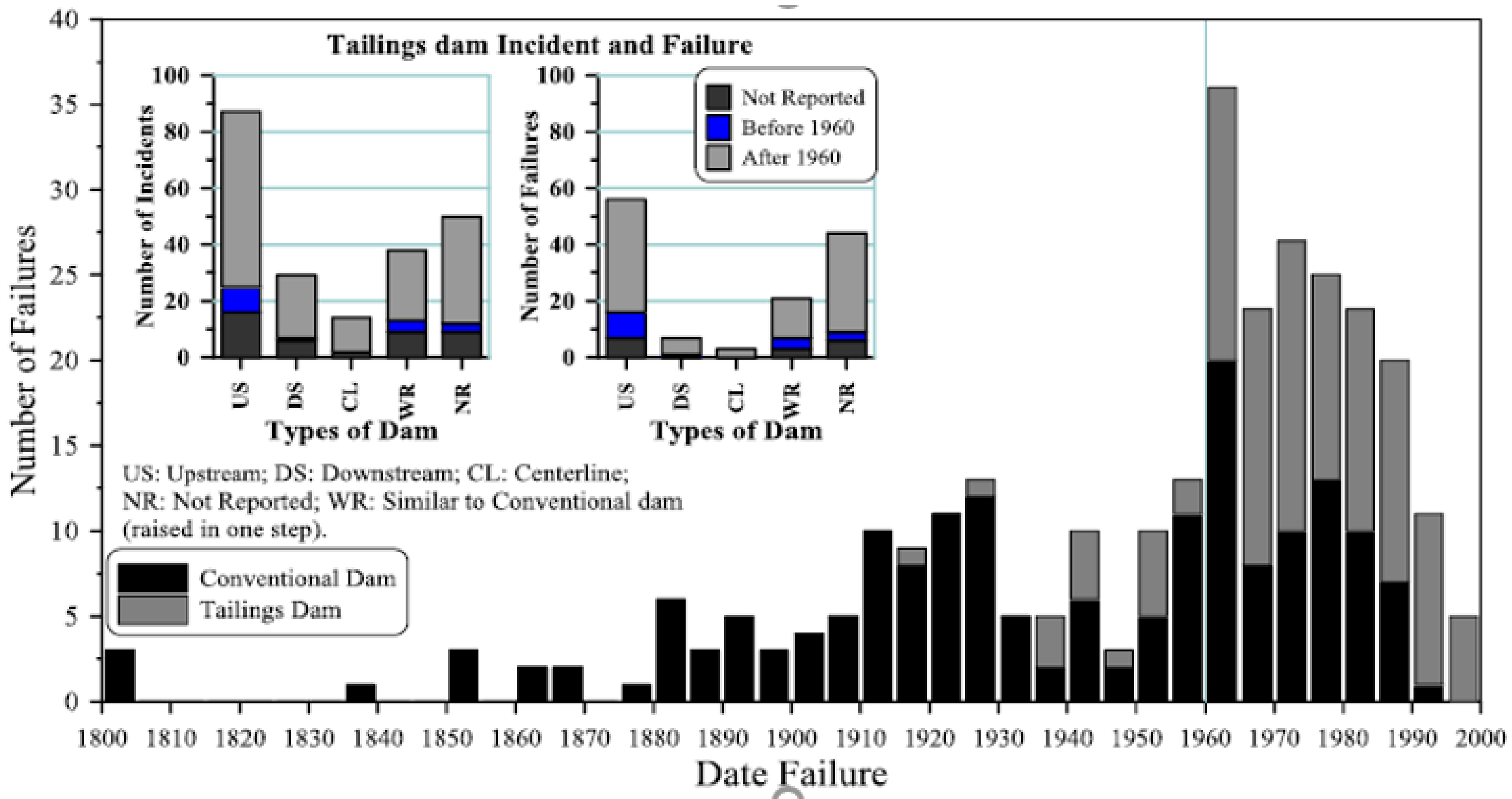
Bowker & Chambers (2015)

- In many metal mines – specially copper and iron – concentration is the main metallurgical process → thus **new and existing (expanded) large tailings deposits are required.**

Challenges involved in the safety of tailings deposits

- These large **tailings deposits – new and existing ones – need to be safe** without presenting a high failure risk that could be considered not tolerable by the industry and by the society and their institutions.
- Despite serious efforts from some institutions such ICMM, ICOLD and CDA in providing guidelines to proper design and operation of **tailings deposits and dams, major failures have continued to occur.**
- These failures have produced a negative perception from communities and government agencies making **increasingly more difficult to obtain approval for new tailings deposits.**
- Risk of failure of "civil" water dams is in the order of 1:10.000 or even lower (1:100.000 ?). **Probability of failure in tailings dams is around 1:1.000 (meaning "lesser quality" than hydro dams).**

Mining: poor record on tailing dams safety



ICOLD (1995, 2001)

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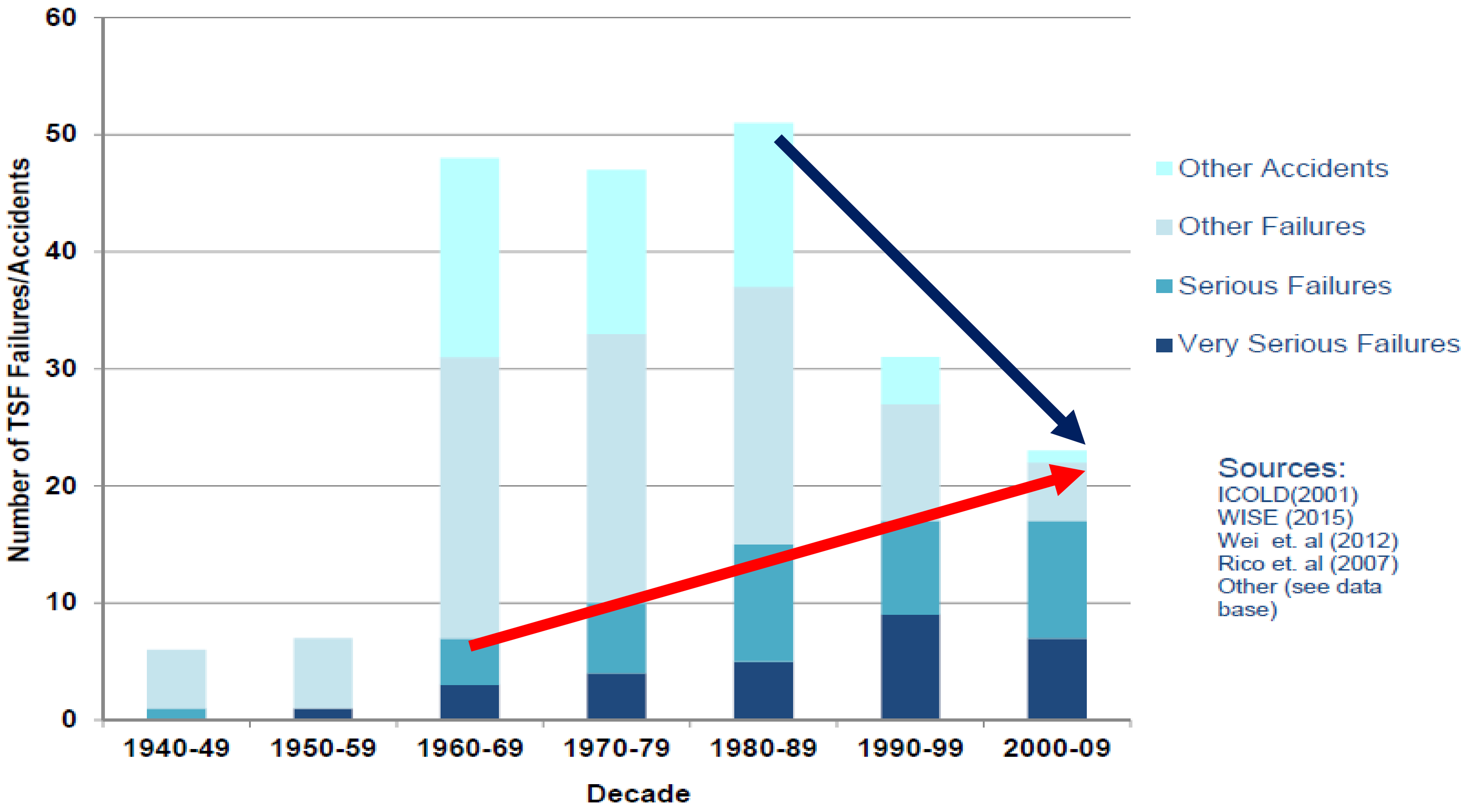
Tailings dams failure probability (1980 -2000 approx.)

Where	When (decade)	p_f	Approx p_f
World-wide	Around '79	44/(3,500*10)	10^{-3}
World-wide	Around '99	7/35,000	$2*10^{-4}$
US	Around '79 & Around '99	7 or 8/(1,000*10)	7 or $8*10^{-4}$

Ref. Oboni & Oboni, 2013

Tailings dams failures have decreased, but….



Bowker & Chambers (2015)

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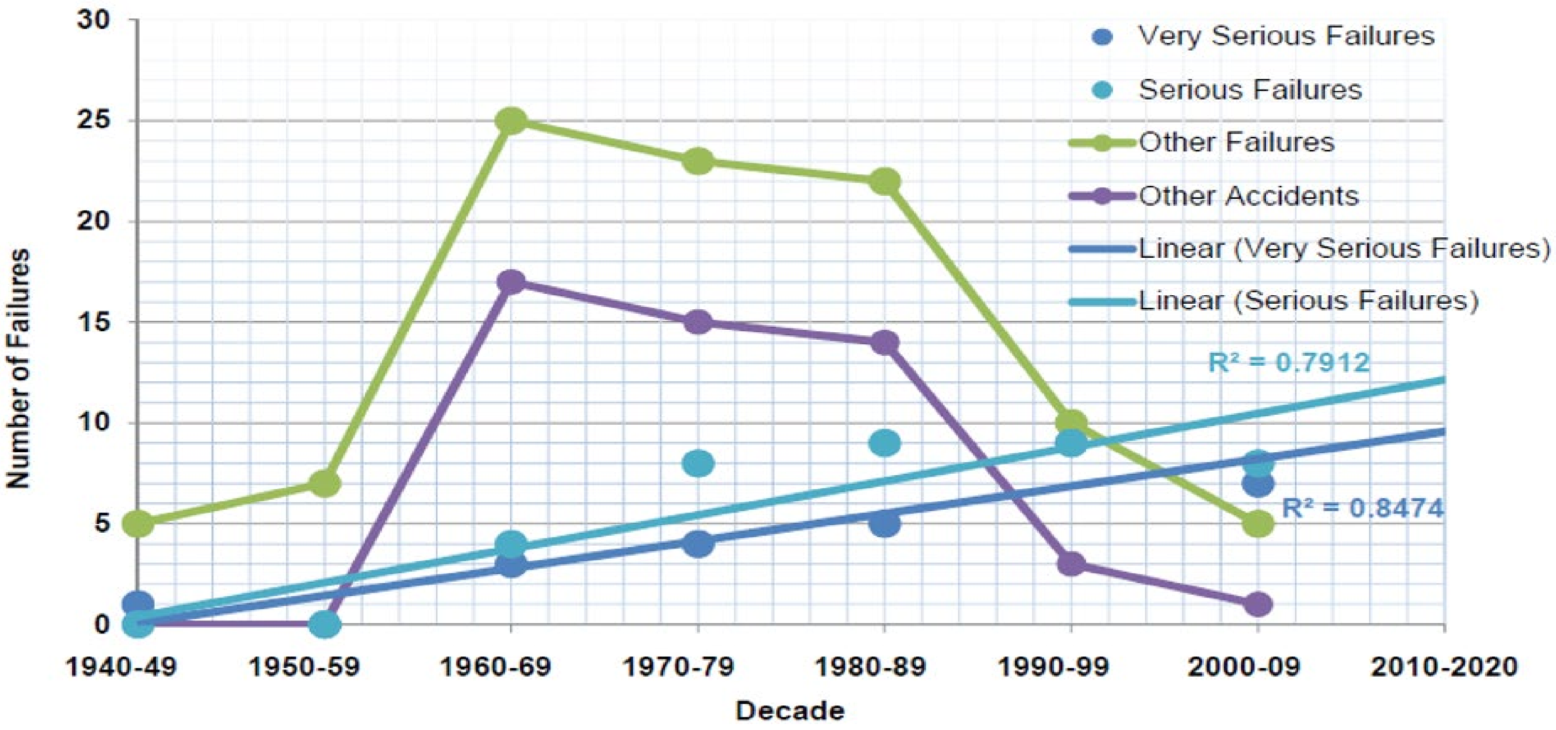
Number of serious failures increased !



Bowker & Chambers (2015)

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Major tailings dams failures after 2012

- **Padcal Mine, Itogon, Benguet province, Philippines (2012).** 20.6 Mton release after strong rainstorm.
- **Obed Mountain Coal Mine, North East of Hinton, AB, Canada. (2013).** 0,67 Mm3 of coal tailings water released and 90.000 ton of sediments.
- **Mount Polley, Canada (2014).** 24.4 Mm3 of tailings and contacted water released.
- **Hpakant, Kachin state, Myanmar (2015).** At least 113 people dead, no further information.
- **Fundao, Brazil (2015).** 45 Mm3. 19 fatalities and extensive contamination
- **New Wales Plant, Mulberry, Polk County, FL, USA. (2016).** 0,84 Mm3 of waste fluids contacted an aquifer source of drinking water.
- **Kokoya Gold Mine, Bong County, Liberia (2017).** Gold tailings with cyanide and arsenic content released to a river source of drinking water.
- **Mishor Rotem, Israel (2017).** 0,10 Mm3 of tailings and contacted water released.
- **Ronglvsham Mine, Hubei Province , China (2017).** 0,20 Mm3 of tailings released.
- **Cieneguita Mine, Chiguagua, Mexico (2018).** 0,45 Mm3 of tailings released leaving 3 dead, 2 wounded and 4 missing.
- **Cadia, New South wales, Australia (2018).** Upper basin containment dam collapsed over the lower basin, minor consequences.
- **Brumadinho, Brazil (2019).** 12 Mm3 total tailings released. 197 people dead and 111 missing. Extensive environmental damage.

http://www.wise-uranium.org/mdaf.html

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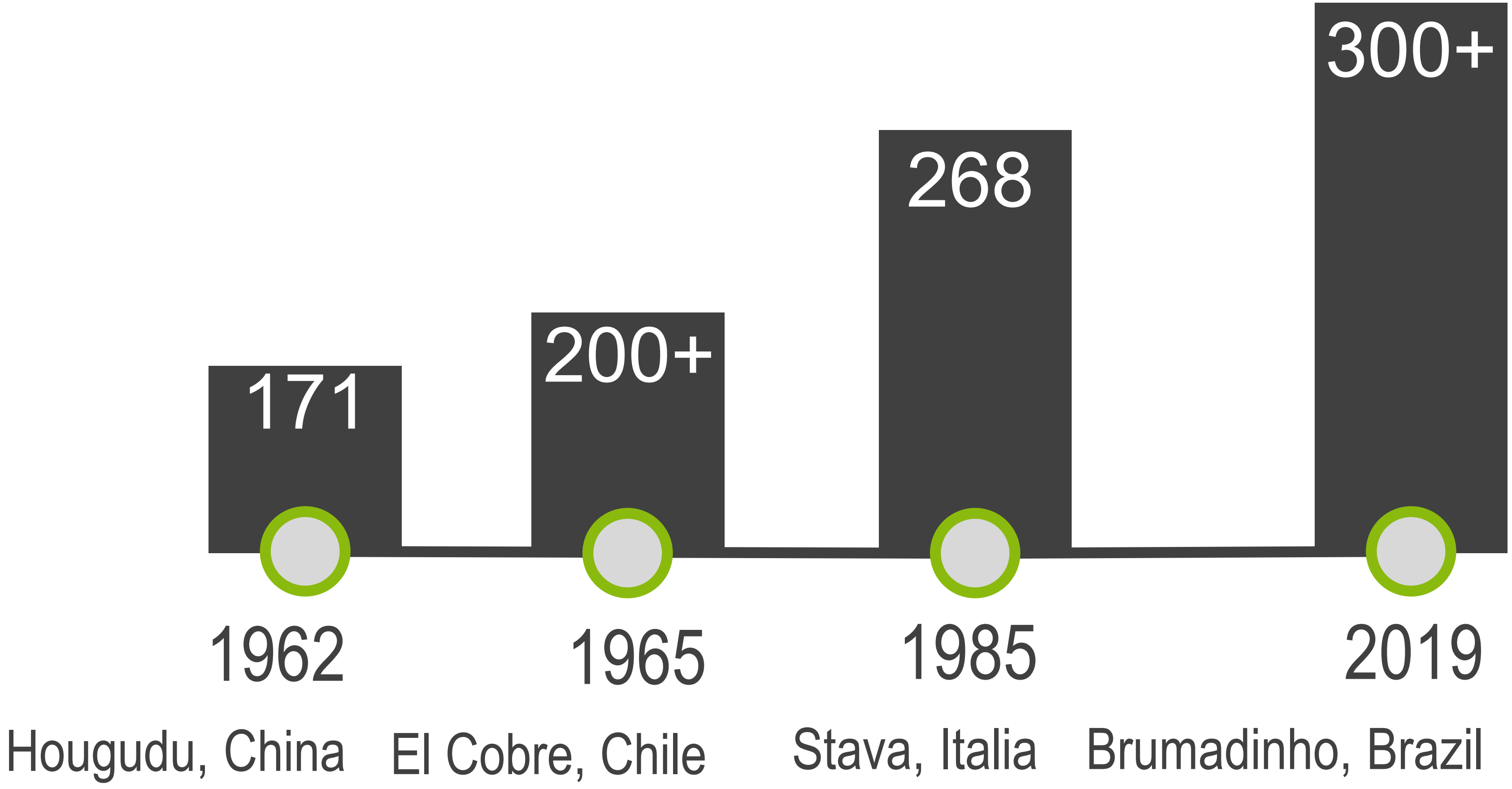
Number of fatalities has also increased



* Mir Mine Sgorigrad, Bulgaria (1966). 188 – 488 ? fatalities

This situation is not sustainable → there is a lack of proper and efficient risk management of tailings deposits and dams

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Mining countries also facing serious challenges

- Mining industry is a key economic activity for many countries like Australia, Canada, Chile, China, Peru and South Africa. Therefore **limiting and jeopardizing the growth of mining will impact on the economic growth of these countries.**
- On the other hand these countries are holding an **increasing volume of mining waste** that represents for them an **important environmental liability**.
- There is a clear **need of interaction and collaboration between government agencies, research groups and the mining industry** in terms of innovation and safety control of tailings deposits, a collaboration which is not present in several of the countries mentioned above.

What can be done to diminish TFS* failure risk?

- **Proper engineering design** following not only local legal requirements but also **the best practice** and recommendations from technical organizations such ICMM, ICOLD, CDA, Bureau of Reclamation and others.
- **Proper construction and operation** procedures according to design through all life of the TFS.
- **Comprehensive, robust and redundant monitoring** system, ideally on-line.
- **Proper closure design and post closure adequate supervision and monitoring.** Abandonment or "walk away" concept → difficult to guarantee adequate safety.
- **Adequate governance and stewardship structure**, with appropriate designation of roles and responsibilities.
- **Risk management procedures and organization** to allow risk based information and decisions.

***TSF:** Tailings Storage Facilities

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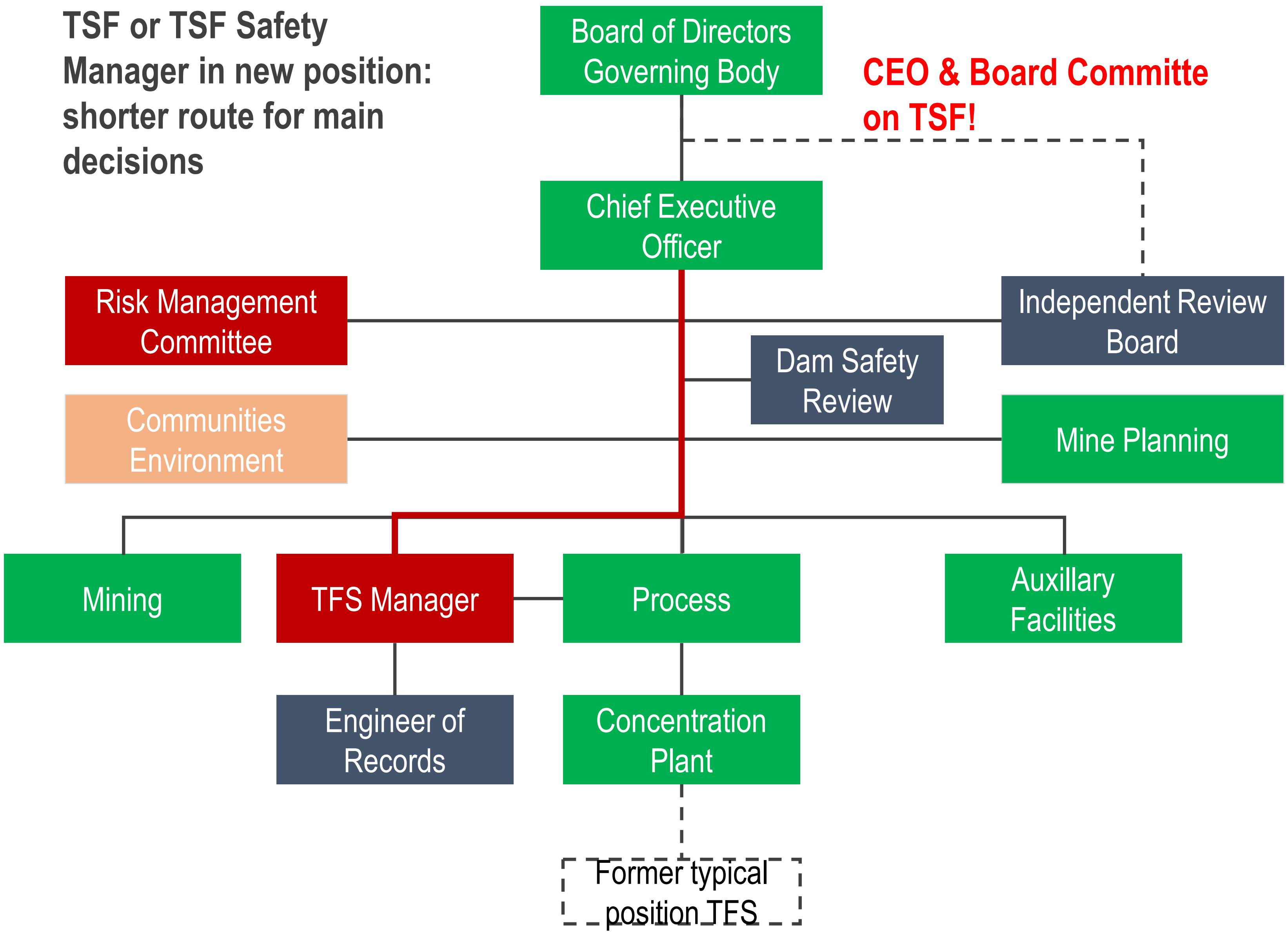
Adequate governance & stewardship structure

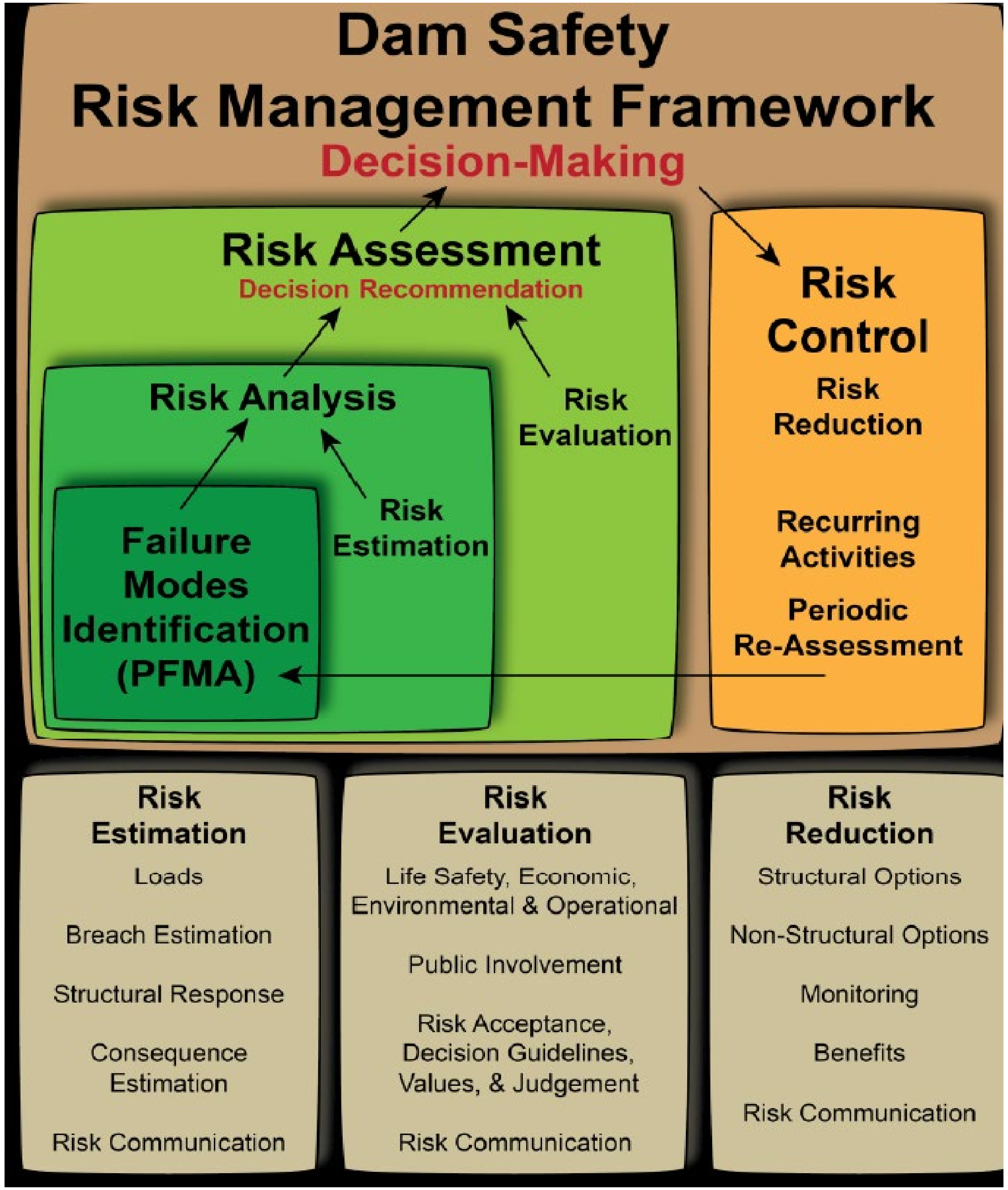
- Analysis of failures has shown that until few years ago **governance structure of most mining companies was not adequate** to guarantee safe tailings deposits and dams.
- ICMM, CAD, ICOLD among other institutions have made strong recommendations **to improve governance for tailings management**.
- Basic requirements for an adequate governance in tailings management:
  - Tailings management at a **higher level** in the organization.
  - Technically **Competent Person** as Tailings Manager
  - **Engineer of Records** to guarantee continuity in design and operation.
  - Periodic **Dam Safety Review** by independent engineering companies.
  - **Independent Review Panel** reporting to CEO and company Board;
- **Risk management procedures** supporting risk based decisions are also part of an adequate governance. More **involvement of CEO and company Board.**

Present trend on TFS management position and governance

TSF or TSF Safety Manager in new position: shorter route for main decisions



Risk management framework for dam safety



Bureau of Reclamation, 2015

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Risk management requires a probabilistic focus

- Risk management is a **fundamental part of dam safety** programs for dams (Bureau of Reclamation,MAC, ICMM, CDA, ICOLD).
- Quite commonly, **non quantitative risk analysis** are only associated to deterministic estimates of dam safety (FS stability).
- **Risk assessment require quantitative risk evaluation** associating values (cost/numbers) to the different consequences of a potential failure, **especially** in those cases **when the consequences of failure could be significative**.
- Risk assesment is required to evaluate whether identified risks associated to a potential failure mode and hazard **are tolerable or not.**
- A risk analysis of dam safety requires to determine **probability of failure** (from each mode of failure); **consequences of failure** and **tolerable risk limits.**

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Simplified dam classification criteria (CDA 2013)

Dam Class	Population at Risk [note 1]	Incremental Losses		
		Loss of Life [note 2]	Environmental and Cultural Values	Infrastructure and Economics
Low	None	0	Minimal short-term loss No long-term loss	Low economic losses; area contains limited infrastructure or services
Significant	Temporary only	Unspecified	No significant loss or only deterioration of fish or wildlife habitat Loss of marginal habitat only Restoration or compensation in kind highly possible	Losses to recreational facilities, seasonal workplaces, and infrequently used transportation routes
High	Permanent	10 or fewer	Significant loss or deterioration of *important* fish or wildlife habitat Restoration or compensation in kind highly possible	High economic losses affecting infrastructure, public transportation and commercial facilities
Very High	Permanent	100 or fewer	Significant loss or deterioration of *critical* fish or wildlife habitat Restoration or compensation in kind possible but impractical	Very high economic losses affecting important infrastructure or services (e.g. highway, industrial facilities, storage facilities for dangerous substances)
Extreme	Permanent	More than 100	Major loss of *critical* fish or wildlife habitat Restoration or compensation in kind impossible	Extreme losses affecting critical infrastructure or services (e.g. hospital, major industrial complex, major storage facilities for dangerous substances)

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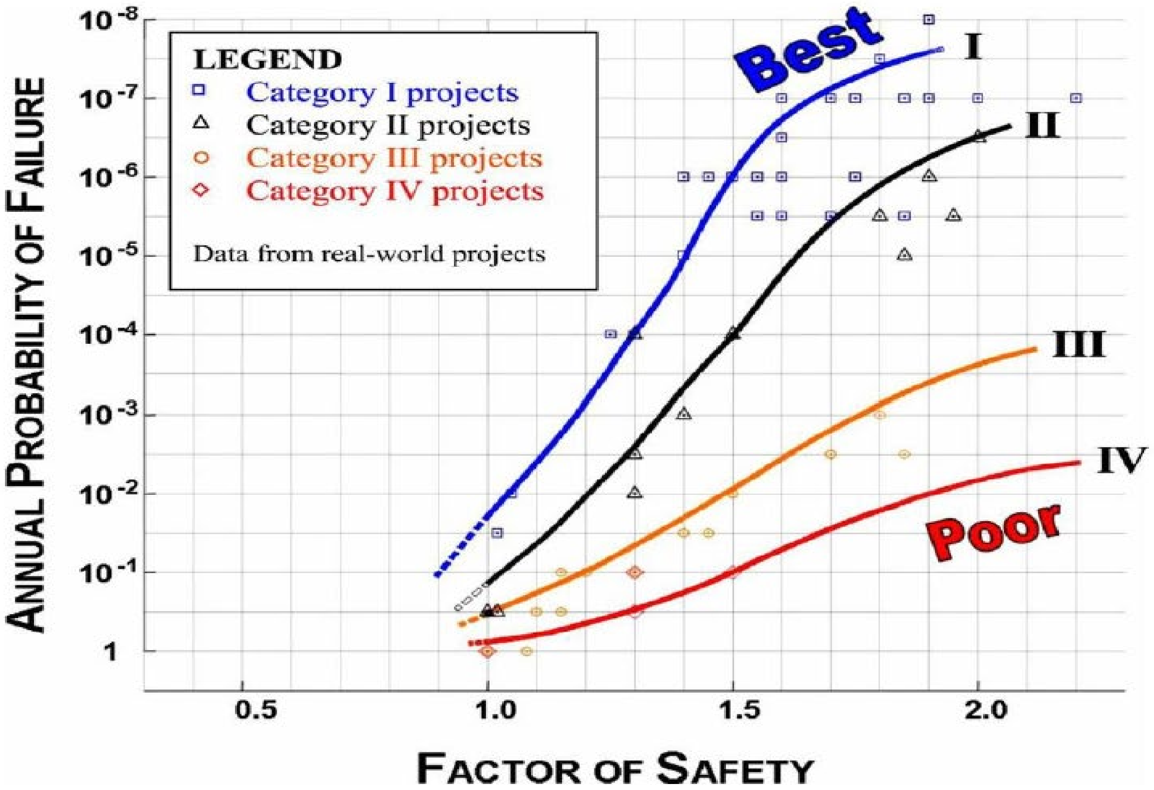
Important: best engineering & operation practice



Annual Probability of Failure vs. Factor of Safety following Silva, Lambe, Marr (SLM) (F. Silva, W. Lambe, W.A. Marr, 2008) methodology.

Ref. Oboni & Oboni, 2013

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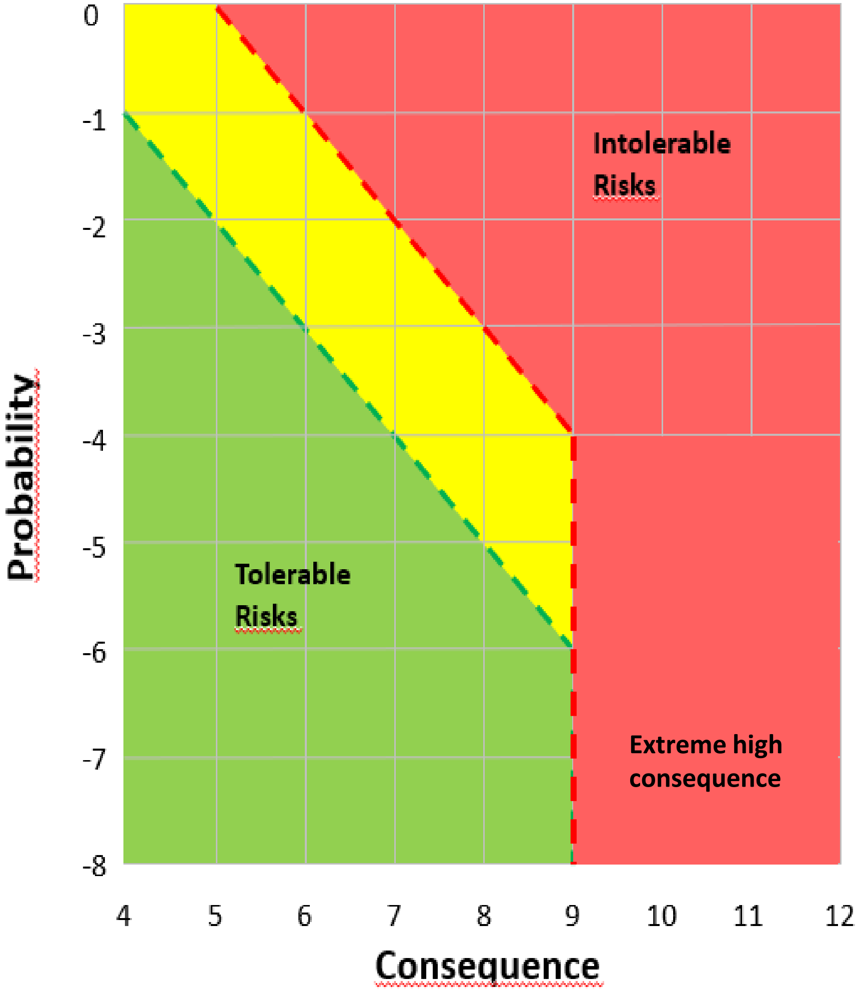
Risks and consequences of a TSF failure



- Low probability failures could have very high consequences in direct and indirect costs plus prestige and legal consequences that could be not tolerated by the company.
- Consequences on human fatalities and serious environmental damage could not be tolerated by the society.
- It is not possible to monetize all consequences so separate analysis could be necessary.

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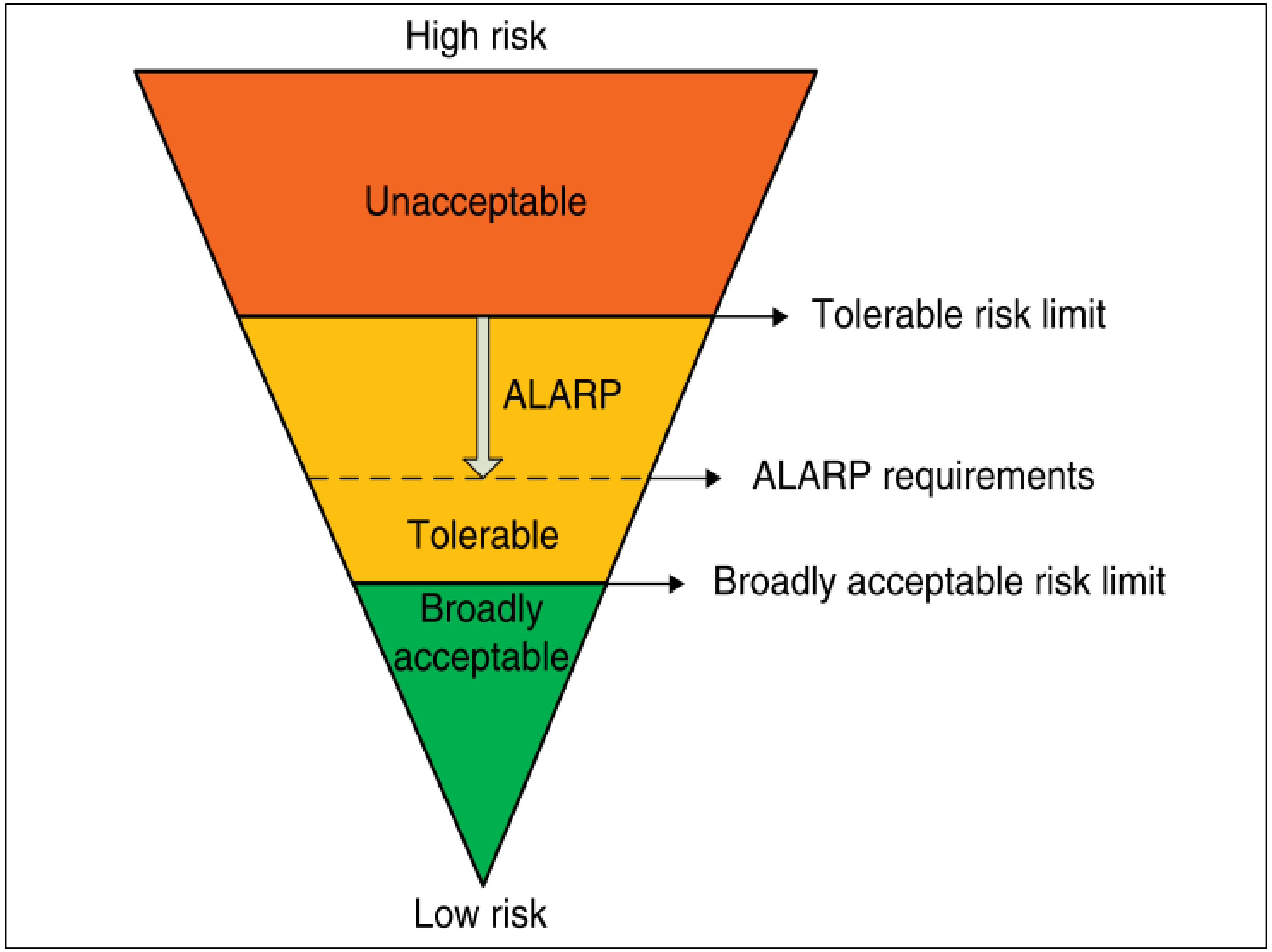
ALARP: As low as reasonably possible

Important challange: to define tolerabble risk limits



Zhang et al, 2016

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Definition of different tolerable risk limits

- **Consequences of dam breaching** (serious failures) could affect the mining company ("individual" risk) and/or the society (societal risk) → consequences should be assessed according to a multi tolerable criteria (i.e. human life, environmental damage, other social impacts, economic losses,).
- Most studies of societal tolerable risk associated to dam safety focus on **loss of human life**, which in general is the **most significant concern**. Other is the potential environment damage.
- **To define societal tolerable risk limits is a key aspect** to be considered in a country. If not available, international reference could/should be used. Industry, community and national/international institutions should participate in the definition.
- **Individual (mining company) tolerable risk limits:** New aspects in consideration beside societal risks and economic impact → legal risk for executives; loss of prestige; loss of license to operate; difficulties in permitting expansions or new projects.

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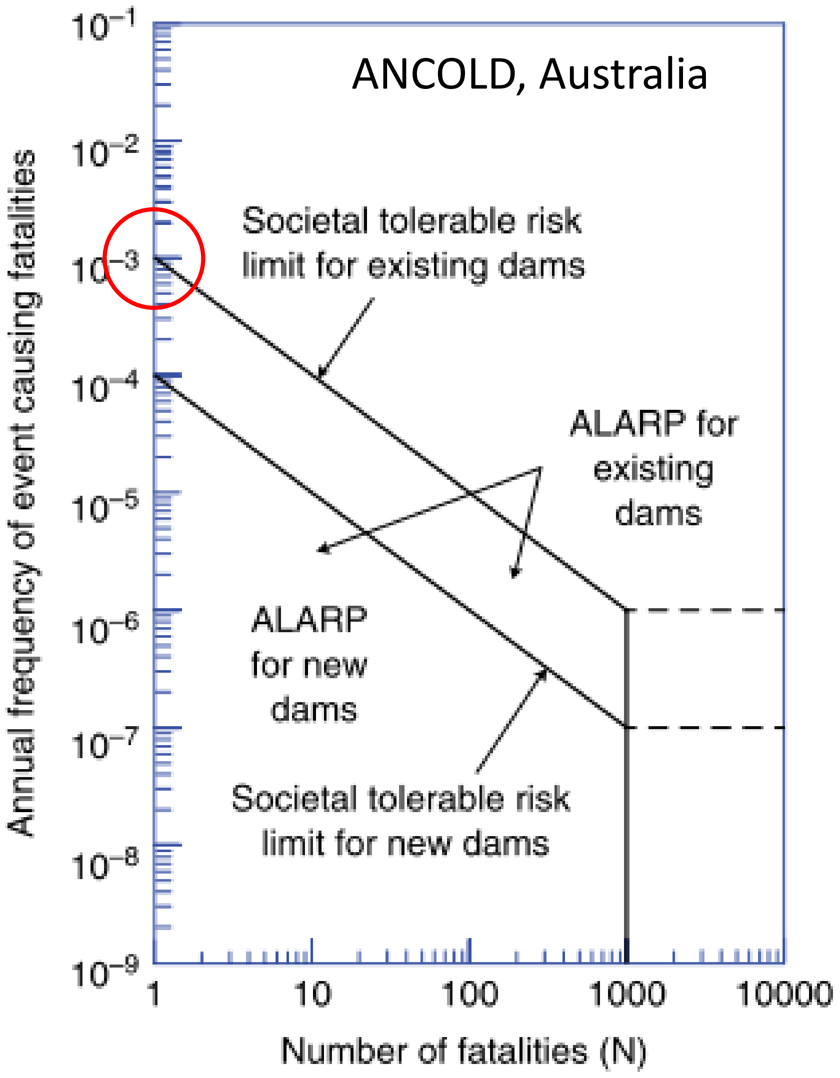
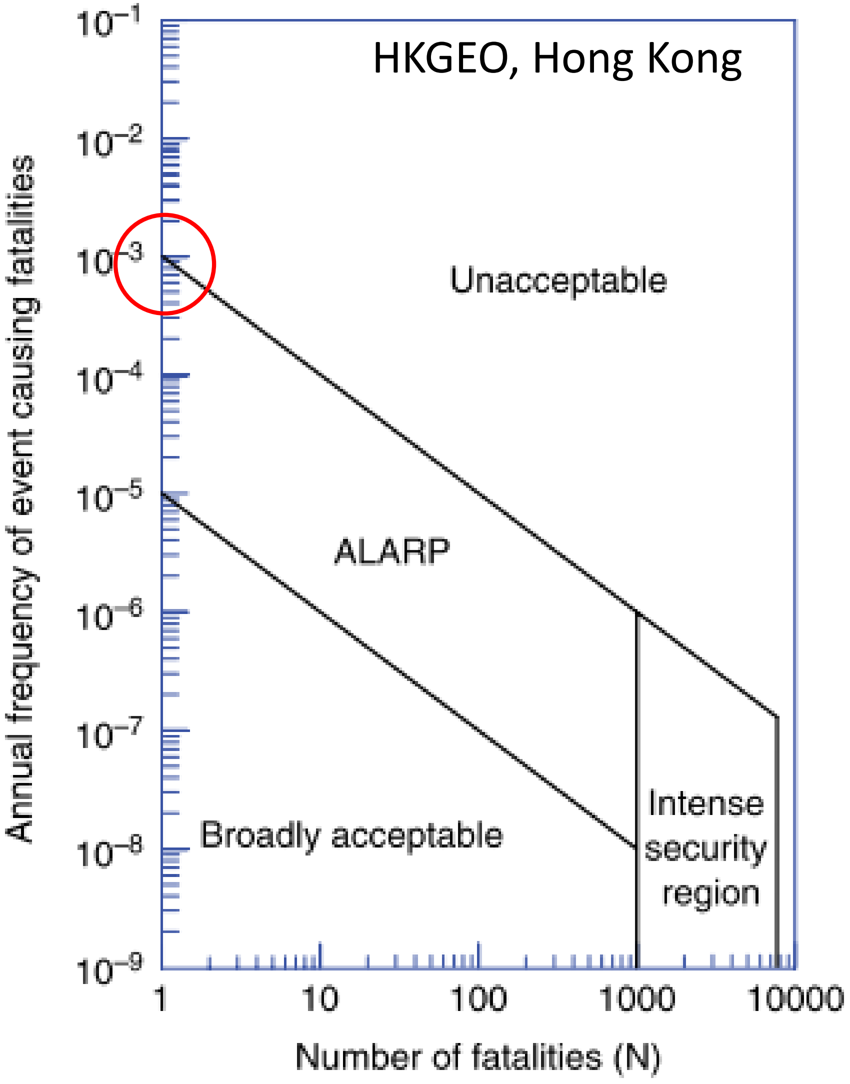
Probability – number of fatalities charts



ANCOLD, 2003

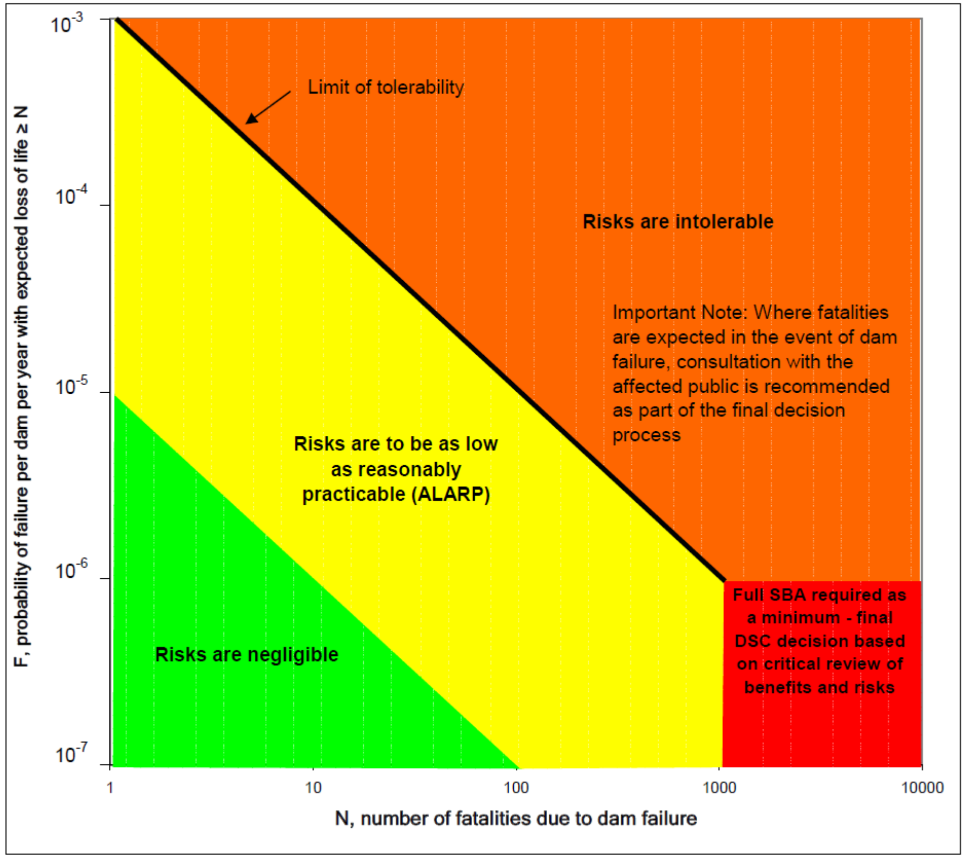


Wong et al, 1997

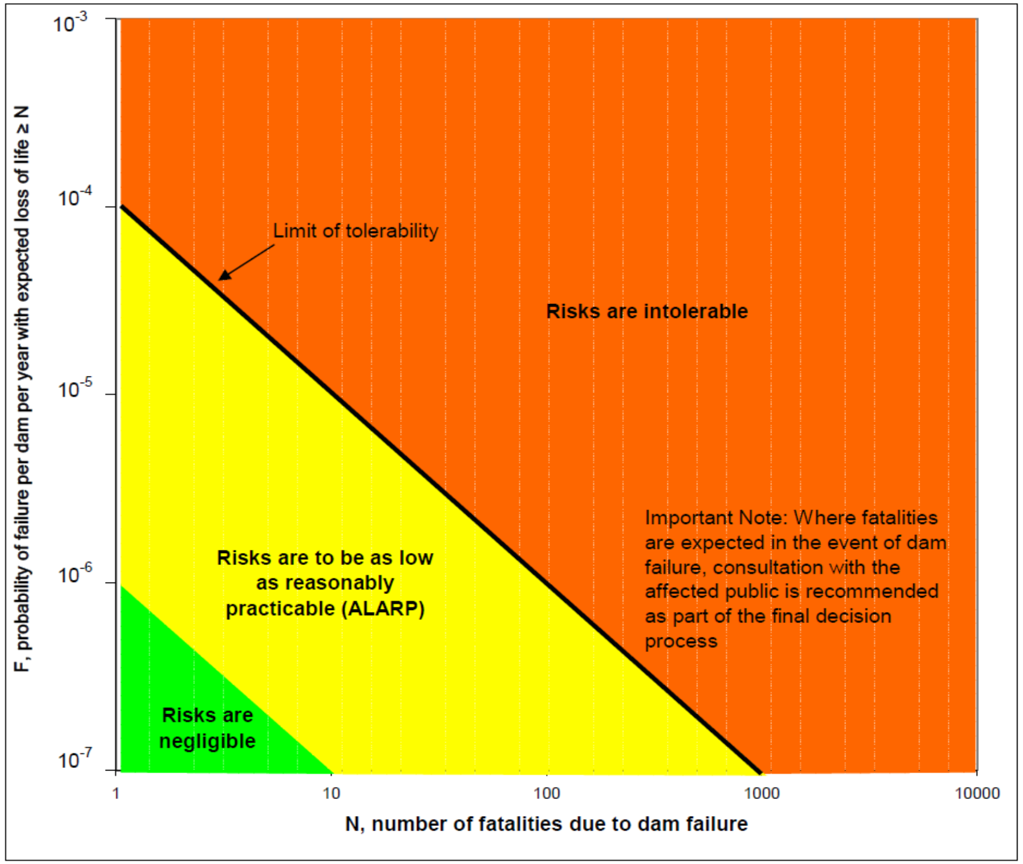
Societal tolerable risks - fatalities - TSF failure

- The statistics of dam failures corresponds approximately to 1:10.000 – or even lower - for water dams and **higher than 1:1.000 for tailings dams** (a figure of 1:700 has been mentioned in some publications).
- The **1:10.000 has been mentioned as the highest acceptable probability for the failure of a new dam** when there are possible consequences with fatalities. This number seemed somehow consistent with the present design practice that considers a maximum credible flood or earthquake corresponding to a 1:10.000 event (but only in these aspects).
- The present trend in the definition of societal tolerable risk limit when fatalities could be produced in a potential failure, **a much lower acceptable failure probability is suggested** (as proposed by NSW DSC).

Proposed NSW DSC societal risk requirements



Existing Dams



New Dams

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Risk of number of fatalities of a TSF failure

- **To determine the level of tolerable risks is not a trivial exercise** but it has to be done and to reviewed from time to time. Societal tolerable risk limits should be establish by the society as a whole. Individual (company or industry) should establish the individual tolerable risk limits considering the most strict recommendations of the industry if available.
- At the level of individual company, monetization of the cost of fatalities in risk analysis should be limited to potential direct economic consequences (such as indemnity), but **the potential number of fatalities in risk has to be considered separately taking in account the societal tolerable risk limits.**
- **Many countries and mining industry have not define the tolerable risk limits** → It is a pending task. An example to consider is the one of water dams agencies in USA, Canada and Australia (example NSW DCS proposal). Other industries, as the transport industry, has done much more progress to this respect

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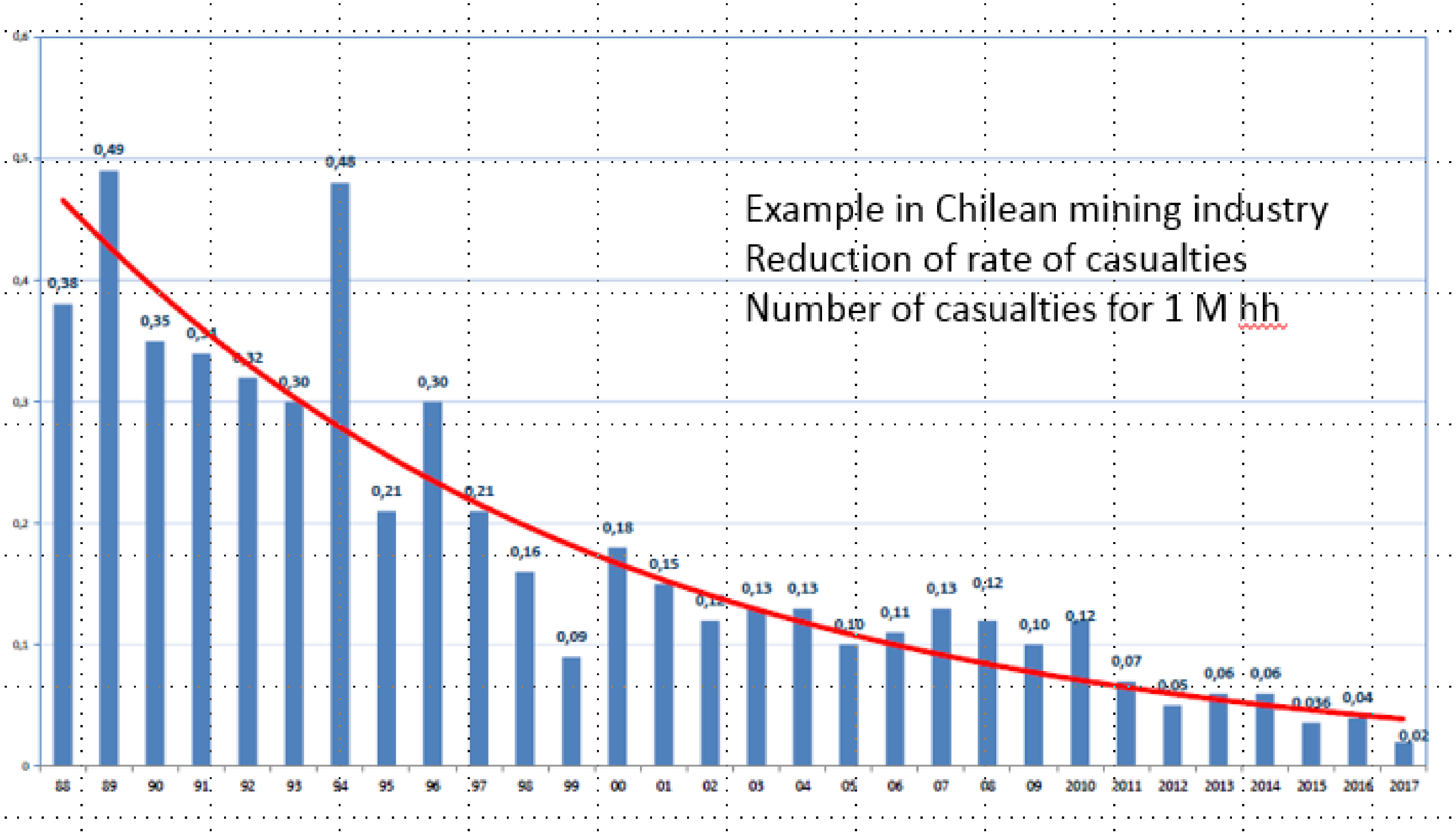
Human and cultural factors in risk assesment process

- The degree of acceptability of dam safety can be established after a **proper** risk assessment and risks control procedures to deal with identified **serious and important** risks.
- Vick (2017) recognizes the problem of "normalization of deviance" in which robust and even sophisticated risk assessment methods could be neutralized, **mainly due to human factors**:
  - "Repeated deviations from intended performance became accepted as normal"
  - "Deviations were rationalized"
  - "Warning signs and near-misses were ignored"
  - "Accepted deviations allowed failure triggers to go unrecognized".
- **Risk reduction measures could involve a large scale of organizational values and culture to achieve effectiveness in dam safety.**

How difficult is to implement risk management ?

- To implement a complete and reliable risk management organization and associated procedures is certainly not a easy task. **Just to define a Potential Failure Mode could be a complex exercise.**
- The possibility to diminish serious risks of tailings dams failures depends on the implementation of a **complete and efficient risk management** that will allow **risk informed decisions** by top management and owners.
- Mining industry has already proved that it is possible to implement a safety policy for their workers that required an important organizational effort and cultural change in the industry → **now it should be done with dam safety**

Successful implementation of a policy



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A recent failure example:

Brumadinho tailings dam N°1, Brazil

- The tailings dam N°1 of “Corrego do Feijao” mine is located in the Brumadinho area in the state of Minas Gerais in Brazil.
- Built in 1976 it was purchased by VALE on 2001 and ended its the operations in July 2016.
- Multiple raises were perfomed in the dam between 1982 to 2013, by different contractors.
- The construction method was upstream. The dam reached 87 m height and a crest length of 720 m.
- The total storage capacity at the end of the operation was 12,6 Mm^3, covering an area of about 250.000 m^2.

Ref: https://g1.globo.com/mg/minas-gerais/noticia/2019/01/25/veja-o-que-se-sabe-ate-agora-sobre-o-rompimento-da-barragem-da-vale-em-brumadinho.ghtml

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Brumadinho tailings dam N°1, Brazil

- On Friday 25th of January 2019 dam N°1 suddenly failed at mid day releasing of the order of 12 Mm^3.
- Tailings flow velocity was estimated in 120 km/h, impacting the toe of the N°6 dam. The flow continued towards the mine loading station and other Vale installations and facilities. 7 km downhill, the flow reached the Parapeba river.
- Total number of fatalities is on the order of 200 with more than 100 still missed (end of February 2019).

Ref: http://www.wise-uranium.org/mdafbr.html

Ref: https://g1.globo.com/mg/minas-gerais/noticia/2019/01/25/veja-o-que-se-sabe-ate-agora-sobre-o-rompimento-da-barragem-da-vale-em-brumadinho.ghtml

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Alternatives to conventional tailings deposit systems?

- Mining industry and research centers have been working in several **tailings disposal methods as** alternative to the conventional solution with tailings disposed by hydraulic methods contained by dams.
- Methods like **thickened tailings, paste and filtered** tailings have been used mainly on operations with low to medium productions rates. Other tailings dewatering techniques are also under development.
- The concepts are clear, technology is improving but logistic **problems are complex mainly with filtered tailings**.
- There is an international **interest in developing new techniques** → see for instance the X-Prize (Mining without Waste), COSIA (dewatering techniques), potential use of bacterias in Chile.

The present risks are related to the existing as well as the recently proposed conventional tailings dams. This is the case discussed today.

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