**WRITTEN EVIDENCE OF THE CITY OF VANCOUVER** **APPENDIX 22**
**Written Evidence of David Etkin**

# National Energy Board Hearing into Trans Mountain Expansion Project

**Written Direct Evidence of**
**David Etkin**

**8 May 2015**

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**INTRODUCTION AND SUMMARY OF QUALIFICATIONS**

**Q.1 Please state your name, occupation and business address**

A.1 My name is David Etkin. I am an Associate Professor of Disaster and Emergency Management at York University and have held this position since 2005. My primary areas of research are risk analysis, risk perception, natural hazards, disaster risk reduction, disaster ethics and climate change.

Prior to York University, I worked for Environment Canada from 1977 through to 2005. I worked on applied research in the Arctic and Industrial Climatology Divisions of the Canadian Climate Centre and, in 1993, I joined the Adaptation and Impacts Research Group of the Meteorological Service of Canada, specializing in the interdisciplinary study of natural hazards and disasters. From 1996-2005 I also worked at the University of Toronto with the Institute for Environmental Studies doing research on natural hazards and disasters. I have contributed research to several national and international natural hazard projects including the 2nd U.S. National Assessment of Research on Natural Hazards[1] and the Intergovernmental Panel on Climate Change[2]. I was the Principal Investigator of the Canadian National Assessment of Natural Hazards and I am the Past President of the Canadian Risk and Hazards Network.

**Q.2 What is your academic background?**

A.2 B.A Physics and Mathematics, York University 1972; B.Ed., University of Toronto, 1974; MSc Physics, York University, 1991.

**Q.3 Please outline your principal areas of research**

A.3 My primary areas of research are risk analysis, risk perception, natural hazards, disaster risk reduction, disaster ethics and climate change[3].

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[1] http://www.colorado.edu/hazards/publications/disastersbydesign.html

[2] http://www.ipcc.ch/

[3] For example:

- Etkin, D. (2015). *Disaster Theory: An Interdisciplinary Approach to Concepts and Causes*. Butterworth-Heineman. Etkin, D., Ivanova, J., MacGregor, S. and Spektor, A. (2014). Risk Perception and Belief in Guardian Spirits. *SAGE Open*, *4*(3), 2158244014549741.
- Etkin, D. and Timmerman, P. (2013). Emergency Management and Ethics. International Journal of Emergency Management, 9(4), 277-297.
- Nirupama, N., & Etkin, D. (2012). Institutional perception and support in emergency management in Ontario, Canada. Disaster Prevention and Management, Vol. 21 Iss:5

**Q.4 What is the purpose of your evidence in this proceeding?**

A.4 Trans Mountain Pipeline ULC ("Trans Mountain") has applied to the National Energy Board (the "NEB") pursuant to section 52 of the *National Energy Board Act* for a certificate of public convenience and necessity in respect of the proposed Trans Mountain Expansion Project (the "TMEP"). The proposed expansion would increase capacity of the current pipeline from 300,000 barrels per day (bbl/day) to 890,000 bbl/day, expand the tank farm and Marine Terminal facilities, and increase tanker traffic to and from the Westridge Maine Terminal from 5 tankers per month to 34 tankers per month.

4.2 The City of Vancouver is an Intervenor in the hearing of the TMEP application and has retained me to evaluate the risk assessment methodology used by Det Norske Veritas (DNV) in the report filed by Trans Mountain in support of its application and to provide my opinion on whether the exclusion of Segment 2 and Segment 3 from the risk assessment was reasonable. A copy of my report dated April 21, 2015 is attached at Appendix A.

4.3 The City of Vancouver subsequently requested that I review Trans Mountain's Response to City of Vancouver IR No. 2, 2.08.01.a through 2.08.01.d. and a copy of my report is attached as Appendix B.

## SUMMARY OF CONCLUSIONS

**Q.5 Please summarize your conclusions**

A.5 My conclusions are summarized in the following paragraphs:

- The most commonly used definition of risk in disaster studies presents risk as a function of hazard (including probability & severity) and consequences (a result of exposure & vulnerability). It is usually framed as **Risk = Hazard x Consequences**.
- Any risk assessment must incorporate consequence, no matter how risk is specifically defined.
- The Trans Mountain/DNV risk assessment excludes a large range of high magnitude spills and potential spills in Segments 2, 3 &4 based upon probability alone. Risk can only be evaluated using both (1) hazard (probability & severity) and (2) consequence (exposure & vulnerability).
- The Trans Mountain/DNV risk assessment incorrectly uses hazard probability in lieu of risk and this has resulted in an improper exclusion of a large range of low probability, high consequence (LPHC) events from the risk assessment.

- There are both quantitative and qualitative aspects to risk; it is not only a function of objective and measurable quantities, but is also culturally framed. This is important because values play a large role in determining costs and benefits, and acceptable levels of risk.
- The Trans Mountain/DNV risk analysis does not include perceived risks of populations, and therefore does not meet TERMPOL standards as setout out in section 3.15 of the TERMPOL report. This error is particularly evident in the exclusion of Segment 2 adjacent to the City of Vancouver.
- There are other reasons to support the inclusion of a spill in Segments 2 and 3 in the risk assessment. One is based upon observational evidence, which is that rare, very large spills have happened historically and represent a significant proportion of total spill amounts. The other reason is theoretical, and relates to the nature of the probability distribution that describes tanker spill frequencies. Oil spill impacts, as well as frequencies, follow a power law distribution, which means that LPHC events account for a significant amount of total impacts, and must be included in a risk analysis.
- The problem with relying exclusively upon historical data for risk analyses (particularly data that are only a few decades in length) is that it excludes events that just haven't happened yet. For example, a tsunami risk analysis based upon data extending over a few decades, if done prior to 2004, would not have captured the Indonesian catastrophe of December 2004 or the Japan one of 2011.
- The DNV credible worst case scenario is based upon a 16% spill of an Aframax tanker, which holds about 637,500 barrels (85% of capacity). Historical data do show much greater losses, of between 74% and 100% of cargo, than the DNV 16% scenario, though none that large have occurred since 1997.
- The effects of an aging fleet are not incorporated into the DNV risk analysis. Empirical data shows increasing failures as fleets age.
- The risk assessment by DNV/TMPEP only addresses the individual impact of spills, not cumulative impacts. This is not best practice within the risk assessment community and represents a serious omission.

**SUMMARY OF ANALYSIS CONDUCTED**

**Q.6 Please provide a summary of the analysis that you conducted in addressing the above questions above.**

Definition of Risk

A.6 The most commonly used definition of risk in disaster studies presents risk as a function of hazard (including probability & severity) and consequences (a result of exposure & vulnerability). It is usually framed as **Risk = Hazard x Consequences**. An example of a matrix that is typically used by emergency management professionals to illustrate how risk is a function of these two variables is shown in Table 1. It can be seen from this table that even low to very low probability events can be associated with high to very high risk, if consequences are major or extreme. It should be kept in mind that this table represents averages over long periods of time. An individual event that is very low probability can be catastrophic when it actually happens.

*Table 1: Example of a Risk Matrix based upon Risk = Hazard x Consequence*

| | **Consequence to People, Communities and the Environment** | | | | |
|---|---|---|---|---|---|
| | Low | Minor | Moderate | Major | Extreme |
| **Hazard Probability** | | | | | |
| Very high | High | High | Very High | Extreme | Extreme |
| High | Moderate | High | High | Very High | Extreme |
| Medium | Low | Moderate | High | Very High | Very High |
| Low | Low | Low | Moderate | High | Very High |
| Very Low | Very Low | Low | Moderate | High | High |

Risk can only be evaluated using both (1) hazard (probability & severity) and (2) consequence (exposure & vulnerability). This is illustrated in Table 1 where the level of risk is assessed by the vertical variable "Hazard Frequency" combined with the horizontal variable "Consequence".

Observational Evidence

Figure 1 shows tanker spill data from the International Tanker Owners Pollution Federation Limited (ITOPC)[4] for ships of all capacities. In this graph spills are ranked from largest (rank 1) to smallest

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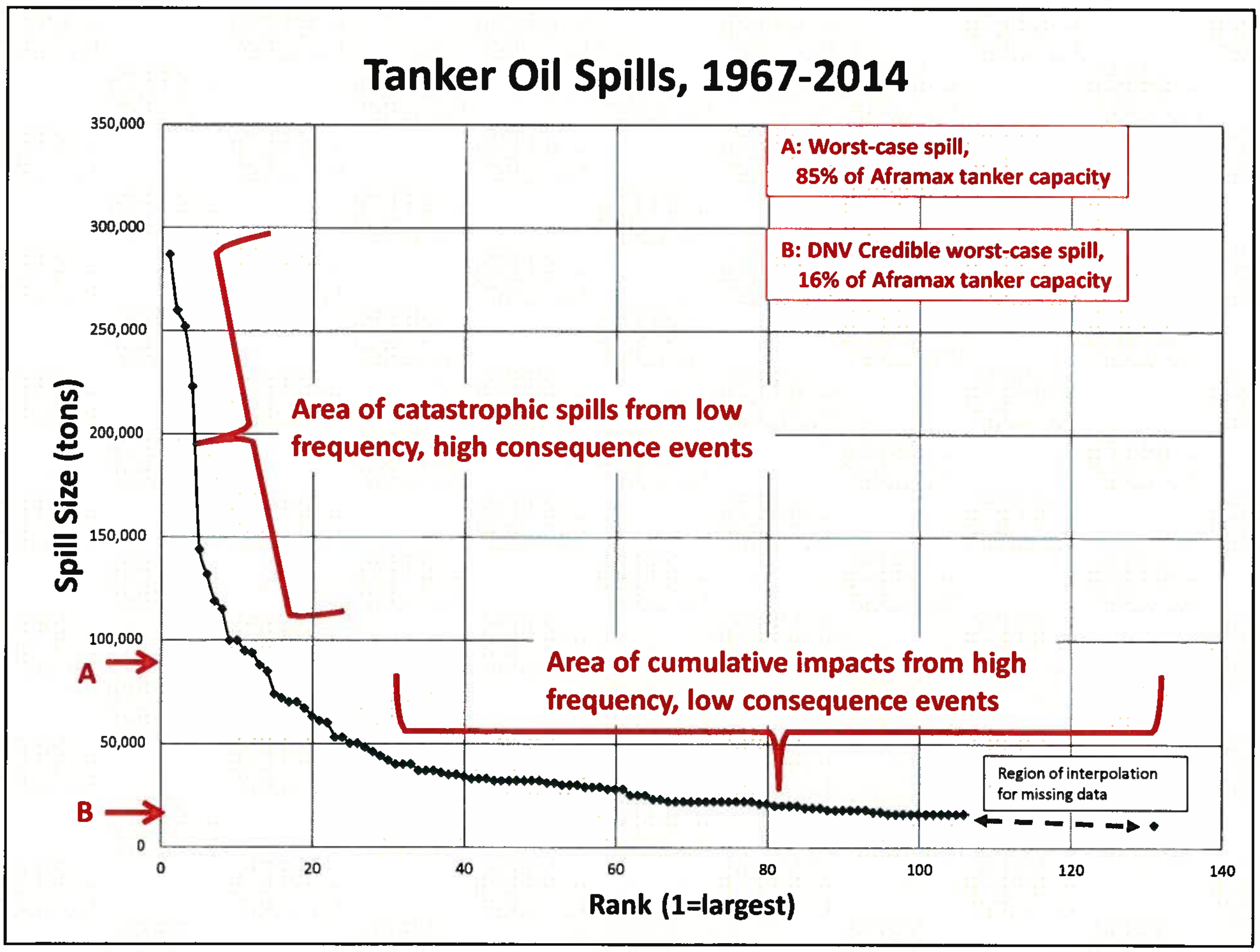
[4] The International Tanker Owners Pollution Federation Limited. http://www.itopf.com/

(rank 131), with the Y axis showing spill size (as yet I have no data for ranks107 to 130 and have therefore interpolated values). Note the relative importance of the largest spills; the top 4 spills account for 20% of the total amount spilt from the 131 events. For context, the theoretical worst case spill (A) and DMV credible worst-case spill (B) are shown by red arrows at the bottom left of the graph. The DNV credible worst case scenario is based upon a 16% spill of an Aframax tanker, which holds about 637,500 barrels (85% of capacity). Historical data do show much greater losses, of between 74% and 100% of cargo, than the DNV 16% scenario, though none that large have occurred since 1997.

*Figure 1: Global tanker spills from tankers of all capacities, rank ordered. Note the relative importance of low probability high consequence events in terms of total amount of oil spilt, shown by ranks 1-8 on the left side of the curve. High frequency events have much smaller spill sizes, but are so common that a risk analysis should consider the cumulative impact of these spills. Data Source: International Tanker Owners Pollution Federation Limited (ITOPF)*[5]

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[5] The International Tanker Owners Pollution Federation Limited. http://www.itopf.com/

There are obvious problems with using this data to infer probabilities, the most important of which is that over the past few decades there have been significant decreases in spill frequencies due to the use of double hulled ships and improved technology. This trend may also partly result from the use of newer tankers. As fleets age, empirical data shows increasing failures[6], so the documented trend towards fewer spills may shift in the future (I note that the effects of an aging fleet are not incorporated into the DNV risk analysis). Figure 1 alone should not discount the premise of DNV that a 14,000 ton (equivalent to a spill of 16% of tanker capacity) spill represents a credible worst case scenario, though it does make it more challenging to accept. The intent of Figure 1 is to demonstrate that spills conform to a power law distribution[7], discussed below.

## Theoretical Considerations – The Power Law and Hazard

### *A. Probability Distribution of the Hazard*

The nature of the hazard probability distribution plays an important role in whether or not exclusions of Segments 2, 3 & 4 and exclusion of LPHC spills larger than 16% of tanker capacity are reasonable. For example, a normal or Gaussian distribution (the well-known 'bell curve') behaves very differently from one represented by a power law (Figure 3). The issue of LPHC events is less important for hazards represented by normal distributions, and more important if they are represented by power laws. The reason is that rare events are a greater proportion of overall risk in the latter. *"Compared to many statistical distributions, power laws drop off more gradually, i.e. they have "fat tails"... This problem is intuitive. Power laws have fat tails so high casualty events are fairly common."*[8]

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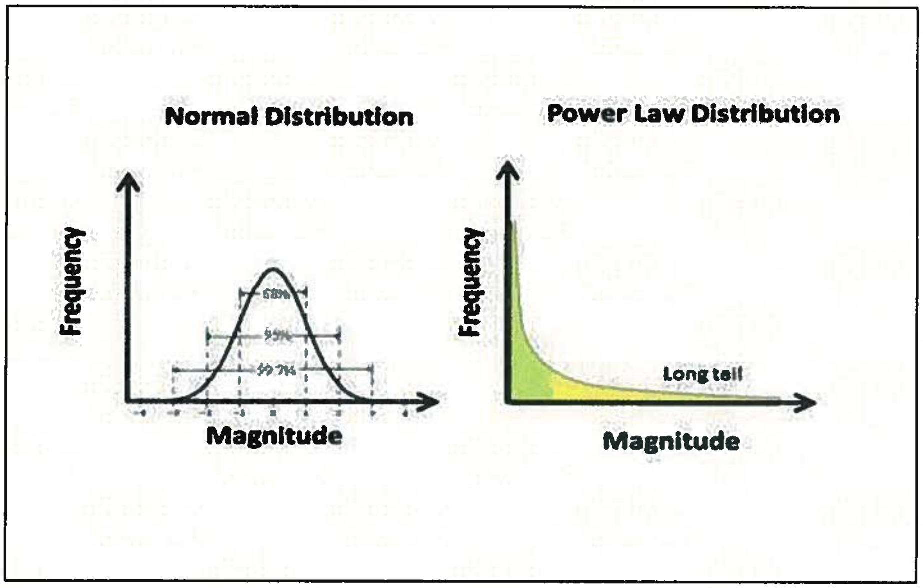
[6] Eliopoulou, E., Papanikolaou, A., Diamantis, P., & Hamann, R. (2012). Analysis of tanker casualties after the Oil Pollution Act (USA, 1990). *Proceedings of the Institution of Mechanical Engineers, Part M: Journal of Engineering for the Maritime Environment, 226(4)*, 301-312.

[7] Eckle, P., Burgherr, P., & Michaux, E. (2012). Risk of large oil spills: a statistical analysis in the aftermath of deepwater horizon. *Environmental science & technology, 46(23)*, 13002-13008.

[8] Becerra, Ó., Johnson, N., Meier, P., Restrepo, J., & Spagat, M. (2012). *Natural disasters, casualties and power laws: A comparative analysis with armed conflict.* In Proceedings of the Annual Meeting of the American Political Science Association.

*Figure 3: Comparison of Normal and Power Law Distributions. Note that in normal distribution (left), variables spend "most" of their time near some average or mean magnitude. Where distributions are power laws (right), the notion of average is not useful. There are a huge number of small magnitude events with a few medium ones, and rarer extreme ones.*




The probability distribution of disaster data are generally best represented by a power law. Mathematically a power law is represented by the equation $f(x) = ax^k$. The tendency of people to think in terms of averages is not helpful for variables that follow power laws (Box 1).

> Box 1: *"One consequence is that events with power laws are scale-free; there is no characteristic size that is typical of the system. What power laws challenge us to do then is give up the view of the world as consisting of typical events with infrequent random variations. Instead, we must accept that there is no "average" event. There are simply many small ones, a few larger ones, and occasionally extremely large ones."*[9]

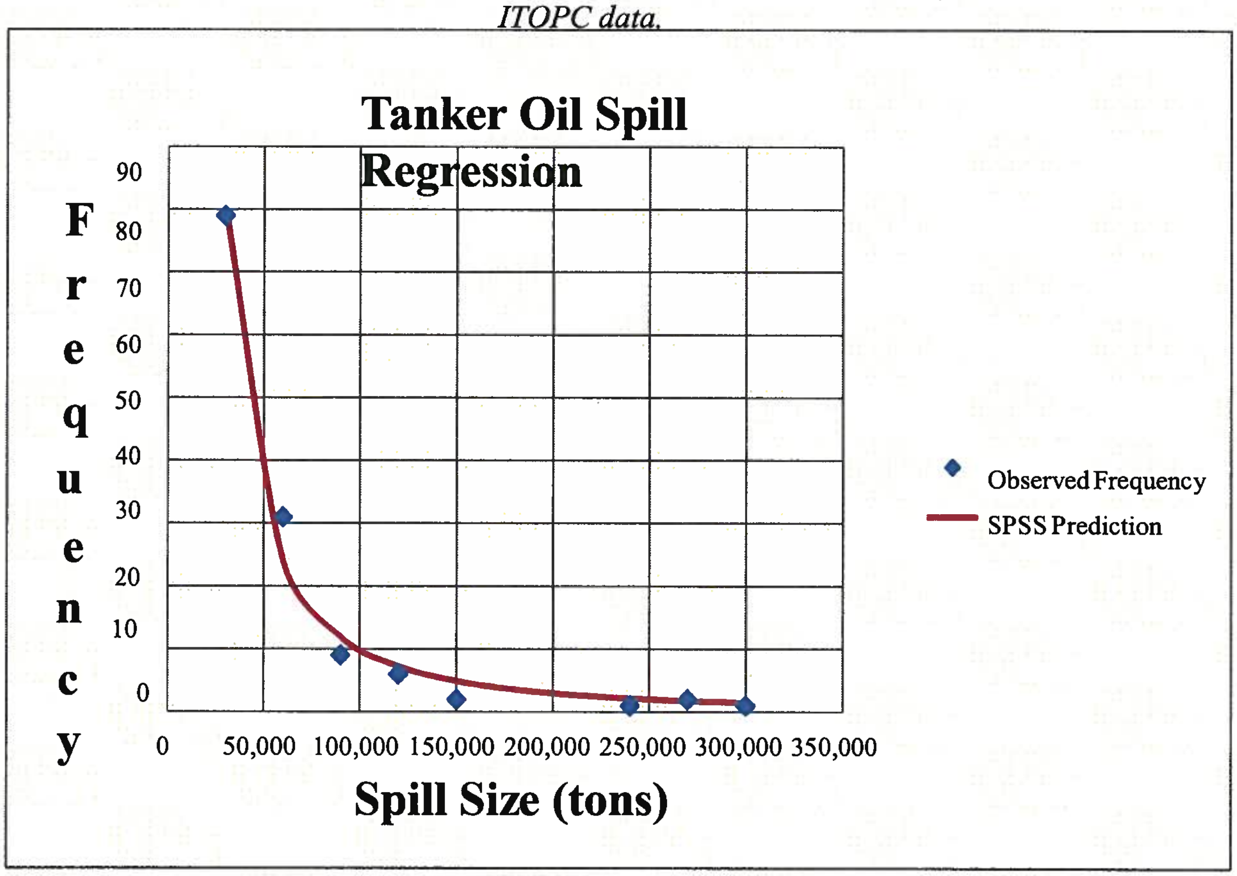
Using data for the worst 131 tanker spills obtained from International Tanker Owners Pollution Federation Limited (ITOPC), a statistical analysis using SPSS resulted in the following relationship:

$$P(x) = 47 \times 10^{9} x^{-17}$$

[9] Farber, D. A. (2003). *Probabilities Behaving Badly: Complexity Theory and Environmental Uncertainty*. UC Davis L. Rev., 37, 145. Retrieved from http://scholarship.law.berkeley.edu/facpubs/614

Where P = probability and x = size of tanker oil spill. Figure 6 shows the fitted power law curve to the data. Note that the $R^2$ value (a measure of goodness of fit where 1.0 is a perfect fit) for this curve is 0.98, which is very high. The X axis is bins of spill size using ranges of 30,000 tons (e.g., the first bin is <30,000 tons, the second bin is 30,000-60,000 tons, and so on). The Y axis is the number of spills within that bin. The blue diamonds are the observed ITOPC data and the red line is the power law curve. The spill data clearly shows a power law distribution, meaning that the low probability events are significant and should be included in the risk analysis.

*Figure 6: Frequency distribution of tanker oil spills using ITOPC data.*

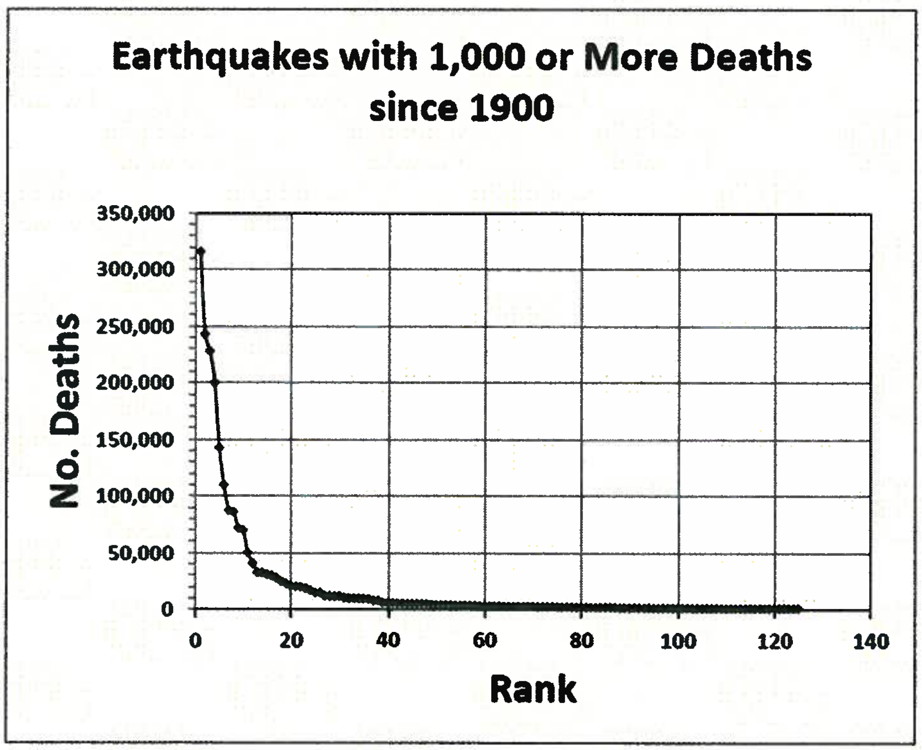


If tanker spills conformed to a normal distribution it might be reasonable to exclude some LPHC events, but given that they follow a power law, the weight of evidence means that they should be included. If it can be shown that consequences or impacts also follow power laws, then the conclusion that the full range of LPHC events must be included is not in question.

*B. Probability Distribution of the Consequences or Impacts of the Hazard*

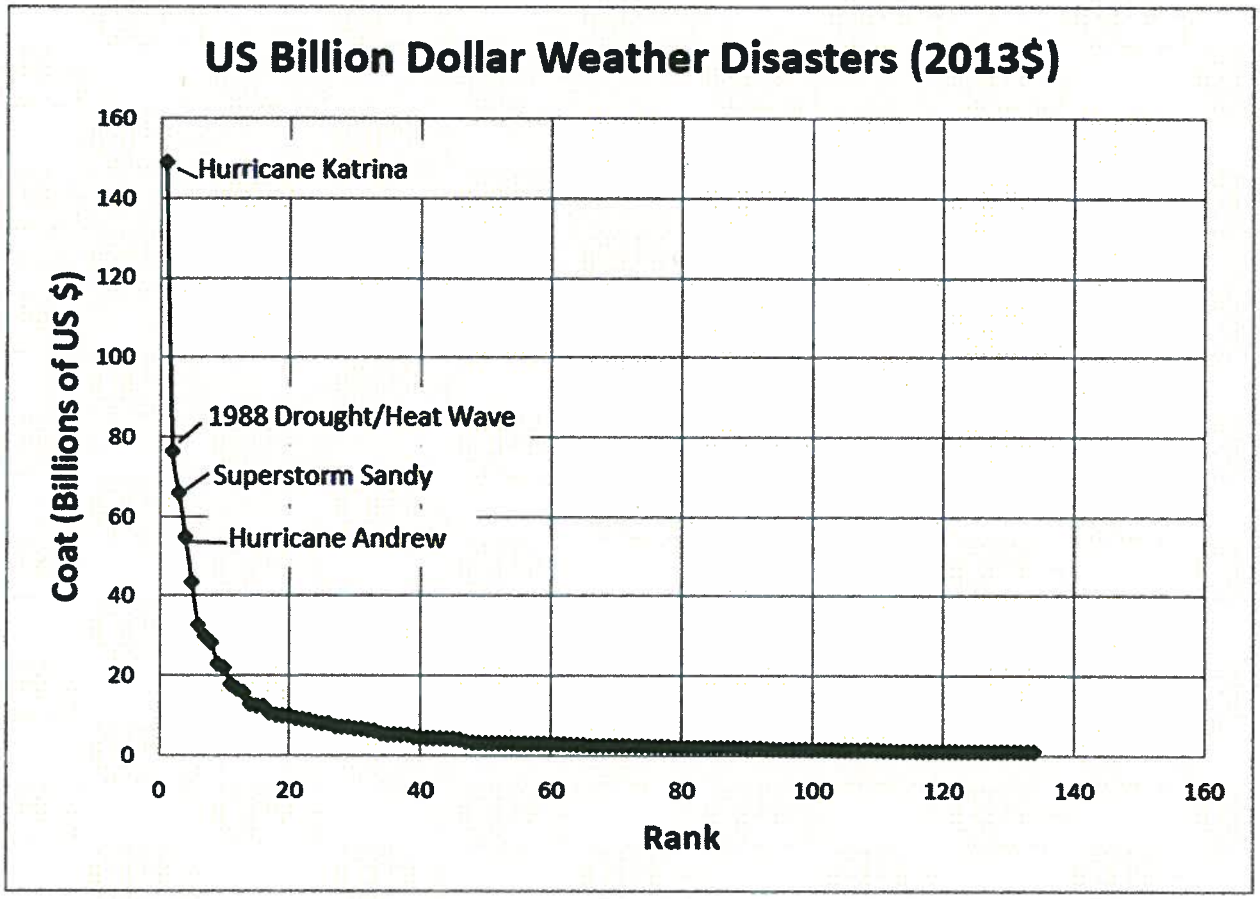
Disaster impacts generally follow power laws, no matter what the source. For example, Figures 6a and 6b show deaths from earthquakes and the cost of weather disasters in the United States. Earthquakes represent a useful comparison to tanker accidents, since deaths happen when the buildings people live and work in collapse on them; in this sense they are more of a technological disaster than a natural one. Additional examples for mining, explosions, industrial disasters, maritime disasters, stampedes & panics, structural collapses and structural fires are included in Appendix B to my report, and show similar patterns.

*Figure 6a: Global deaths from earthquakes, rank ordered. The top 10 of the 125 events account for about 2/3 of the total deaths*[10].




[10] Source: US Geological Survey. http://earthquake.usgs.gov/earthquakes/world/world_deaths.php

*Figure 6b: Relative costs of weather related disasters in the US exceeding $1 billion, CPI adjusted to 2013.The top 6 of the 134 events account for 43% of the total cumulative damage in the list.*



Both examples in Figures 6a&b and the examples in Appendix A to my report provide strong empirical evidence that support the importance of including LPHC events as part of a risk analysis. The mathematics of risk calculations also support this conclusion. There are compelling reasons to believe that oil spill impacts, as well as frequencies, follow power law distributions, which means that LPHC events account for a significant amount of total impacts, and must be included in a risk analysis.

**Q.7 Do you submit the contents of this document and the Appendices as your written evidence?**

A.7 Yes, this is my written evidence.

# APPENDIX A TO THE WRITTEN EVIDENCE OF DAVID ETKIN

*Report of David Etkin dated April 21, 2015*
*Low Probability High Consequence Events and*
*The Risk of Oil Spills:*
*An Evaluation of the Trans Mountain - Det Norske Veritas*
*Risk Analysis*

April 21, 2015

# LOW PROBABILITY HIGH CONSEQUENCE EVENTS AND THE RISK OF OIL SPILLS:

# AN EVALUATION OF THE TRANS MOUNTAIN-DET NORSKE VERITAS RISK ANALYSIS

BY

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# 1. EXECUTIVE SUMMARY:

1. This report is an evaluation of the methodology used in the Trans Mountain-Det Norske Veritas (TM/DNV) risk analysis of oil spills from tankers in support of the Trans Mountain Pipeline ULC application to the National Energy Board in respect of the TM Expansion Project (TMEP); specifically, (a) the methodology for risk assessment involving low probability/high consequence events, and (b) whether or not the exclusion of either or both of Segment 2 and Segment 3 from the spill modeling and impacts assessment is consistent with that risk assessment methodology.
2. In order to answer this question I considered both observational evidence of historical spills and theoretical issues related to the probability distributions of tanker oil spills.
3. My conclusion is that the methodology used by TM/DNV Risk Assessment is flawed and significantly underestimates the real risk of an oil spill. I reach this conclusion because of the following reasons:
    a. A flaw of logic: by using only hazard probability, instead of risk (which includes both hazard and consequences), to exclude Segments 2, 3 &4 and to exclude scenarios greater than 16% of cargo loss, the TM/DNV methodology failed to properly use their own definition of risk in their risk assessment.
    b. Observational evidence shows that the full range of Low Probability / High Consequence should be included in the oil spill risk analysis.
    c. Theoretical considerations show that the full range of Low Probability High Consequence should be included in the oil spill risk analysis.
4. There is no doubt that the full range of Low Probability / High Consequence events form a significant component of overall impacts, and should be explicitly included beyond the low threshold used in the TM/DNV risk analysis.
5. I also note that the TM/DNV risk analysis does not meet TERMPOL standards to include consequences, especially the risk perception of local communities.
6. Additionally, the cumulative impact of lesser spills is of potential significance, and should also form a part of the risk analysis. This is considered "best practice" within the risk assessment community.
7. I certify that I, David Etkin, am solely responsible for the production of this report and have no conflict of interest regarding the TM/DNV risk assessment.

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## 2. SCOPE OF WORK:

8. I have been retained by the City of Vancouver to evaluate the risk assessment methodology used by Det Norske Veritas (DNV) in their report to Trans Mountain Pipeline ULC (TM), in support of TM's application to the National Energy Board for a certificate of public convenience and necessity in respect of the TMEP. Specifically, (a) the methodology for risk assessment involving low probability/high consequence events; and (b) whether or not the exclusion of either or both of Segment 2 and Segment 3 from the spill modeling and impacts assessment is consistent with that risk assessment methodology.

9. The methodological issue underlying both 8(a) and (b) above relates to the incorporation of low probability, high consequence (LPHC) events into a risk assessment. Specifically, the risk assessment of oil spills from tankers associated with the Trans Mountain Pipeline Expansion Project (TMPEP) is being considered.

10. *Summary of the Issue:* The inclusion of LPHC events in risk analyses is an interesting and important issue. **It is obvious that excluding any range of events from a risk assessment will bias it towards a low estimation of risk; the important question to be asked is whether or not the exclusion is significant and the remaining hazard ranges being considered can provide a reasonable estimate of overall risk.**
    a. The answer is not obvious and will vary depending upon the hazard being considered and the vulnerability of exposed elements. It is common in the physical sciences to make simplifying assumptions in order to clarify complex systems and make their analysis more tractable. Examples include the flat earth assumption for aerodynamics and Newton's Law for forces. Such simplifications are justified by sensitivity analyses showing insignificant errors within defined ranges, but fail when extrapolated beyond certain bounds.

11. *Excluded Segments:* TM has stated in its application that there is no need for the inclusion of specific areas[1] in their risk assessment on the basis that the rarity of spills excludes the need for consideration. Thus, oil spill scenarios were not considered for study segments 3 (English Bay) and 4 (Roberts Bank). I also note the exclusion of study segment 2 (Vancouver Harbour Area) from their analysis, though in Appendix 2 of the Navigational HAZID Workshop it was stated in section 4 (HAZID Conclusion) that the route hazard and navigation complexity is *"Above average due to draft and tidal restriction obstructions from the first and second narrows and the high density of traffic within the harbour area."* Segment 2 is adjacent to the highly populated area of the City of Vancouver and other communities, and is of particular interest because of their exposure to oil spills.

12. *Excluded Scenarios:* As well as excluding study segments 2, 3 &4, a range of large oil spill scenarios were excluded from the TM/DNV risk analysis, specifically large spills exceeding 16% of tanker capacity. Again, the reason given is that they are very low probability events.

[1] Study Segments 3 and 4 *"Not considered as viable spill location due to relatively low frequency for an accidental oil cargo spill."* Source: TERMPOL 3.25 General Risk Analysis and Intended Methods of Reducing Risks, Ch. 10.1 Table 31.

13. *Report Topics:* In this report I examine (a) the TM/DNV risk assessment methodology as it relates to the above excluded areas and spill ranges, (b) the degree to which the TM/DNV risk assessment methodology is reasonable, and (c) consider if the methodology meets industry best practices and TERMPOL requirements. Ultimately, it is reasonable if a risk assessment excluding rare events is not substantially biased relative to a more complete estimation. My assessment will consider observational evidence, theoretical considerations, and published literature describing best practice risk assessments.

14. *Short Biography:* David Etkin is an Associate Professor of Disaster and Emergency Management at York University. His primary areas of expertise are: risk analysis, risk perception, natural hazards, disaster risk reduction, disaster ethics and climate change. Prior to being at York he worked for Environment Canada (1977-2005). During his career, he has done applied research in the Arctic and Industrial Climatology Divisions of the Canadian Climate Centre. In 1993 he joined the Adaptation and Impacts Research Group of the Meteorological Service of Canada, specializing in the interdisciplinary study of natural hazards and disasters. From 1996-2005 he worked at the University of Toronto with the Institute for Environmental Studies doing research on natural hazards and disasters. He has contributed to several national and international natural hazard projects including the 2nd U.S. national assessment, the Intergovernmental Panel on Climate Change, was Principal Investigator of the Canadian National Assessment of Natural Hazards and is Past President of the Canadian Risk and Hazards Network. He has 80 publications to his credit.

## 3. THE IMPORTANCE OF DEFINING RISK

15. In this section I will explain why the **definition of risk** is critical to evaluating the TM/DNV risk assessment. In their risk assessment the incorrect use of hazard probability in lieu of risk has resulted in an improper exclusion of a large range of LPHC events from the risk analysis. This is called an "unwarranted assumption fallacy"[2]. I also note that DNV has not sufficiently included consequence in their risk estimations.[3]

16. *Definition of Risk:* There are various definitions of risk within the academic and professional communities. The one most commonly used in disaster studies presents risk as a function of hazard (including probability & severity) and consequences (a result of exposure & vulnerability). It is usually framed as **Risk = Hazard x Consequences**[4]. An example of a matrix that is typically used by emergency management professionals[5] to illustrate how risk is a function of these two variables is shown in Table 1. It can be seen from this table that even low to very low probability events can be associated with high to very high risk, if

[2] It is often true that low probability events are not important to consider, but this is not generalizable to all events. The logical error made was that DNV applied this "rule" to a situation and context for which it is not applicable.

[3] Any risk assessment must incorporate consequence, no matter how risk is specifically defined by a user.

[4] Blaikie, P., Cannon, T., Davis, I., & Wisner, B. (2004). *At risk: natural hazards, people's vulnerability and disasters.* Routledge.

[5] For example, Emergency Management BC uses it as part of their Hazard, Risk and Vulnerability Analysis Tool Kit, http://www.embc.gov.bc.ca/em/hrva/toolkit.html

consequences are major or extreme. It should be kept in mind that this table represents averages over long periods of time. An individual event that is very low probability can be catastrophic when it actually happens.

*Table 1: Example of a Risk Matrix based upon Risk = Hazard x Consequence*

| | **Consequence to People, Communities and the Environment** | | | | |
|---|---|---|---|---|---|
| | Low | Minor | Moderate | Major | Extreme |
| **Hazard Probability** | | | | | |
| Very high | High | High | Very High | Extreme | Extreme |
| High | Moderate | High | High | Very High | Extreme |
| Medium | Low | Moderate | High | Very High | Very High |
| Low | Low | Low | Moderate | High | Very High |
| Very Low | Very Low | Low | Moderate | High | High |

17. *Cultural Framing:* There are both quantitative and qualitative aspects to risk; it is not only a function of objective and measurable quantities, but is also culturally framed. This is important because values play a large role in determining costs and benefits, and acceptable levels of risk. For example, a developer would estimate the relative value of an old growth forest as compared to a retail development very differently than an environmentalist would. When consequences are being considered, one must address the issue of who is affected, and the voices and values of potentially affected people and communities must be part of the assessment. This is why in section 3.15 of the TERMPOL report[6] where they discuss risk analysis, the following statement is made: "*Analysis should not be limited to a mathematical index (probability of an incident) but should also include perceived risks to:*
    - *populations within coastal zones along the intended route;*
    - *the terminal berth and surrounding area; and*
    - *the marine environment, fish and wildlife habitat.*"

The TM/DNV risk analysis does not include perceived risks of populations, and therefore does not meet TERMPOL standards. This is particularly evident in their exclusion of Segment 2 adjacent to the City of Vancouver.

[6] Transport Canada (2001). *TERMPOL Review Process 2001*, Marine Safety, Transport Canada TP742E.

18. *Logical Flaw in the TM/DNV Methodology:* There is a serious logical flaw in the DNV/TM risk assessment methodology[7]. The error is that their analysis excludes a large range of high magnitude spills and potential spills in Segments 2, 3 &4 based upon probability alone[8]. But it is risk, not probability, which is of primary interest, and risk can only be evaluated using both (1) hazard (probability & severity) and (2) consequence (exposure & vulnerability). This is illustrated in Table 1 where the level of risk is assessed by the vertical variable "Hazard Frequency" combined with the horizontal variable "Consequence".

19. *Summary:* Excluding LPHC events on the basis of probability alone is a logical fallacy. This represents a serious error in the DNV/TM risk assessment methodology. The potential consequences of a LPHC spill on the City of Vancouver and other communities should be calculated and be an explicit component of the risk analysis.

## 4. HAZARD PROBABILITY PROFILE

20. *Three Types of Evidence (Definitional, Observational & Theoretical):* The previous section identified a logical error in the TM/DNV risk assessment methodology, which related to the actual definition of risk and their exclusion from their risk assessment of (a) segments 2, 3 and 4 and (b) a range of high magnitude spills beyond 16% of tanker capacity. There are other reasons to support the inclusion of the missing segments and high magnitude spills. One is based upon observational evidence, which is that rare, very large spills have happened historically and represent a significant proportion of total spill amounts. The other reason is theoretical, and relates to the nature of the probability distribution that describes tanker spill frequencies.

21. *Observational Evidence*: Figure 1 shows tanker spill data from the International Tanker Owners Pollution Federation Limited (ITOPC)[9] for ships of all capacities. In this graph spills are ranked from largest (rank 1) to smallest (rank 131), with the Y axis showing spill size (as yet I have no data for ranks107 to 130 and have therefore interpolated values). Note the relative importance of the largest spills; the top 4 spills account for 20% of the total amount spilt from the 131 events. For context, the theoretical worst case spill (A) and DMV credible worst-case spill (B) are shown by red arrows at the bottom left of the graph. The DNV credible worst case scenario is based upon a 16% spill of an Aframax tanker, which holds about 637,500 barrels (85% of capacity). Historical data do show much greater losses, of between 74% and 100% of cargo[10], than the DNV 16% scenario, though none that large have occurred since 1997.

*Figure 1: Global tanker spills from tankers of all capacities, rank ordered. Note the relative importance of low probability high consequence events in terms of total amount of oil spilt, shown by ranks 1-8 on the left side of the curve. High frequency events have much smaller spill sizes, but are so common that a risk*

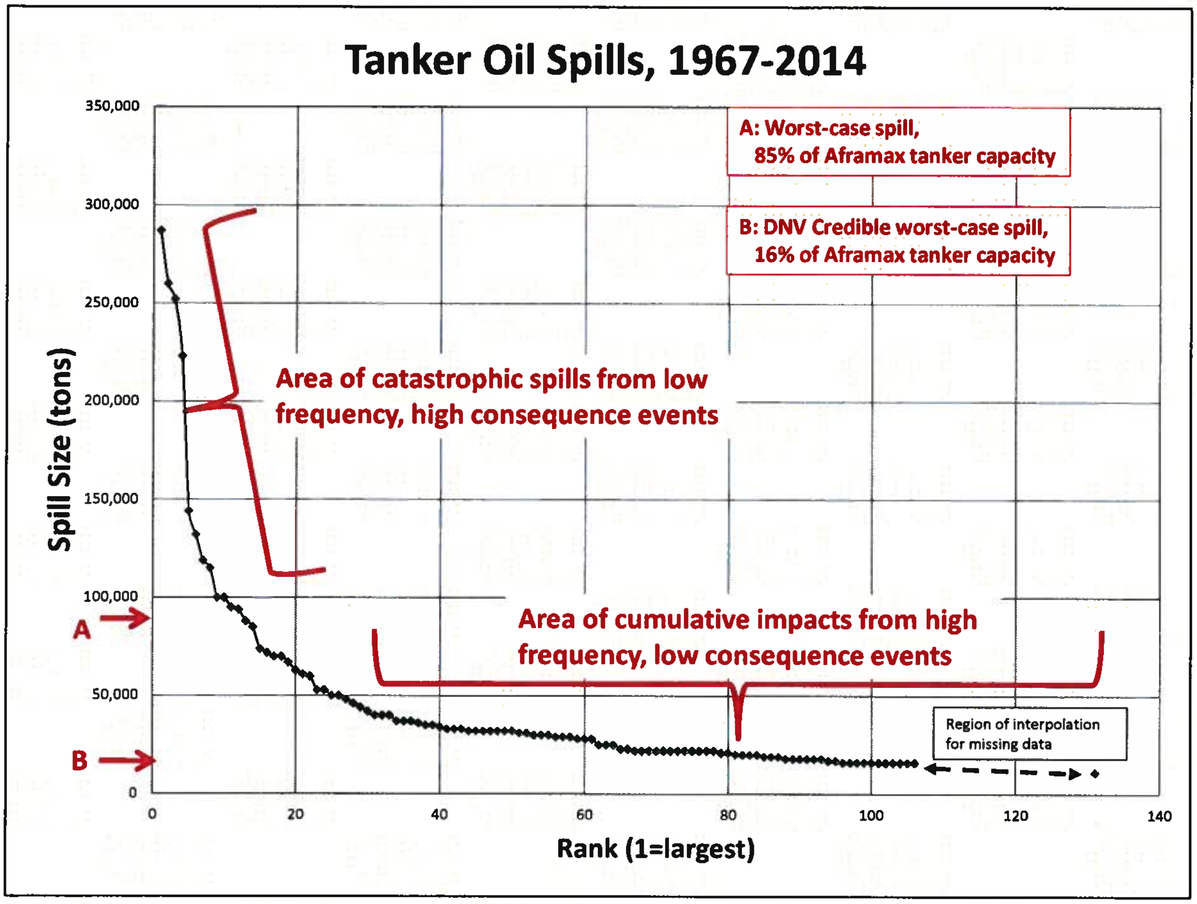
[7] Det Norske Veritas (U.S.A.), Inc. (2013). TERMPOL 3.15 – *GENERAL RISK ANALYSIS AND INTENDED METHODS OF REDUCING RISKS,* Trans Mountain Expansion Project. DNV Doc. No./Report No.: 167ITKV-9/PP061115

[8] TERMPOL 3.25 General Risk Analysis and Intended Methods of Reducing Risks, Ch. 10.1 Table 31.

[9] The International Tanker Owners Pollution Federation Limited. http://www.itopf.com/

[10] Etkin, D. S. (2001, March). *Analysis of oil spill trends in the United States and worldwide.* In International Oil Spill Conference (Vol. 2001, No. 2, pp. 1291-1300). American Petroleum Institute.

*analysis should consider the cumulative impact of these spills. Data Source: International Tanker Owners Pollution Federation Limited (ITOPC)*[11]




22. The following quote from ITOPF supports the importance of these rare events - "*... it should be noted that a few very large spills are responsible for a high percentage of oil spilt.*" [12] International Tanker Owners Pollution Federation Limited.

23. *Limitations to Figure 1:* There are obvious problems with using this data to infer probabilities, the most important of which is that over the past few decades there have been significant decreases in spill frequencies due to the use of double hulled ships and improved technology (Figure 2[13]). This trend may also partly result from the use of newer tankers. As

[11] The International Tanker Owners Pollution Federation Limited. http://www.itopf.com/
[12] ITOPF: Oil Tanker Spill Statistics 2013. The International Tanker Owners Pollution Federation Limited.
[13] At first glance the curves of Figure 5 appear to be different from the following Figures 3 and 4, but this is only because the x-axis and y-axis are logarithmic scales. If they were linear scales the curves would look the same since they are all power laws.

fleets age, empirical data shows increasing failures[14], so the documented trend towards fewer spills may shift in the future (I note that the effects of an aging fleet are not incorporated into the DNV risk analysis). Figure 1 alone should not discount the premise of DNV that a 14,000 ton (equivalent to a spill of 16% of tanker capacity) spill represents a credible worst case scenario, though it does make it more challenging to accept. The intent of Figure 1 is to demonstrate that spills conform to a power law distribution.

*Figure 2: Tends in Oil Spill Frequencies. Note the trend towards fewer spills. The distribution of spills however, follows a power law distribution (discussed below).[15] Both axes are logarithmic, unlike the following graphs. This is why the curves appear different; on linear graph paper they would appear similar.*

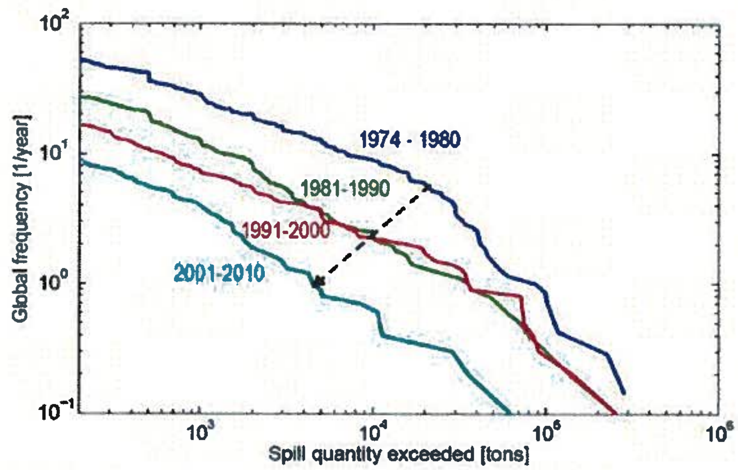



**Figure 5.** Empirical frequency consequence curves (1-ECDF) × frequency constructed from global historical ship spills exceeding 200 tons. The data set was split into four time intervals as the frequency of spills is found to decrease over time.

24. *Theoretical Considerations (A) – The Power Law and Hazard:* The nature of the hazard probability distribution plays an important role in whether or not exclusions of Segments 2, 3 & 4 and exclusion of LPHC spills larger than 16% of tanker capacity is reasonable. For example, a normal or Gaussian[16] distribution (the well-known 'bell curve') behaves very differently from one represented by a power law (Figure 3). The issue of LPHC events is less important for hazards represented by normal distributions, and more important if they are represented by power laws. The reason is that rare events are a greater proportion of overall risk in the latter. "*Compared to many statistical distributions, power laws drop off*

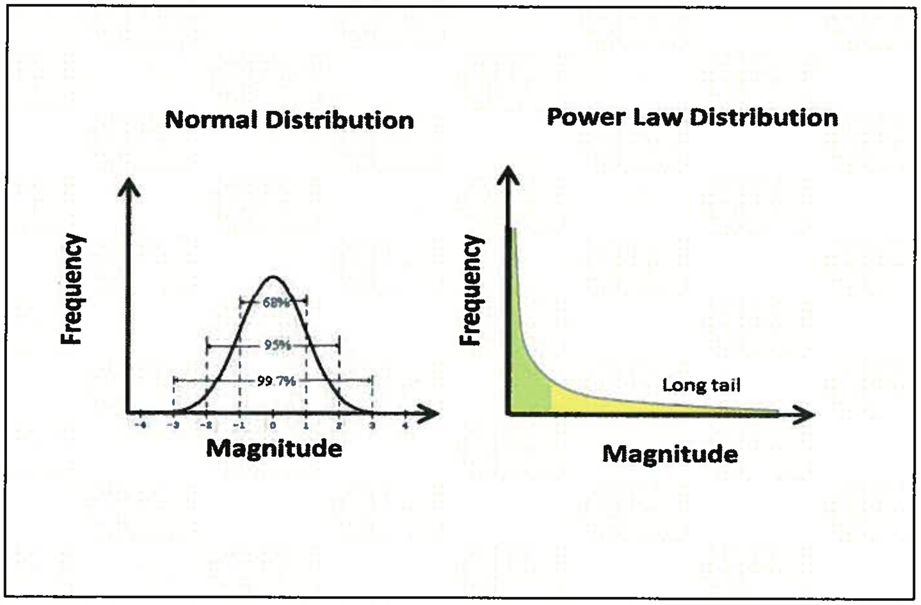
[14] Eliopoulou, E., Papanikolaou, A., Diamantis, P., & Hamann, R. (2012). Analysis of tanker casualties after the Oil Pollution Act (USA, 1990). *Proceedings of the Institution of Mechanical Engineers, Part M: Journal of Engineering for the Maritime Environment, 226(4)*, 301-312.

[15] Eckle, P., Burgherr, P., & Michaux, E. (2012). Risk of large oil spills: a statistical analysis in the aftermath of deepwater horizon. *Environmental science & technology, 46(23)*, 13002-13008.

[16] The Gaussian distribution is represented by the equation $F(x) = a \exp(-(x-b)^2)/2c^2) + d$

*more gradually, i.e. they have "fat tails"... This problem is intuitive. Power laws have fat tails so high casualty events are fairly common."*[17]

*Figure 3: Comparison of Normal and Power Law Distributions. Note that in normal distribution (left), variables spend "most" of their time near some average or mean magnitude. Where distributions are power laws (right), the notion of average is not useful. There are a huge number of small magnitude events with a few medium ones, and rarer extreme ones.*




25. *Normal Distributions:* To illustrate by example, Figures 4a & b shows July mean maximum temperatures (approximately normally distributed) at Vancouver Airport for the period 1950-2012.

*Figure 4a: Histogram of July average maximum temperatures at Vancouver Airport. This is an example of a probability distribution that is approximately normal. Rare events are important, but not necessarily overwhelmingly so compared to the rest of the distribution. Data from NOAA, http://www.ncdc.noaa.gov/data-access/land-based-station-data.*

[17] Becerra, Ó., Johnson, N., Meier, P., Restrepo, J., & Spagat, M. (2012). *Natural disasters, casualties and power laws: A comparative analysis with armed conflict.* In Proceedings of the Annual Meeting of the American Political Science Association.

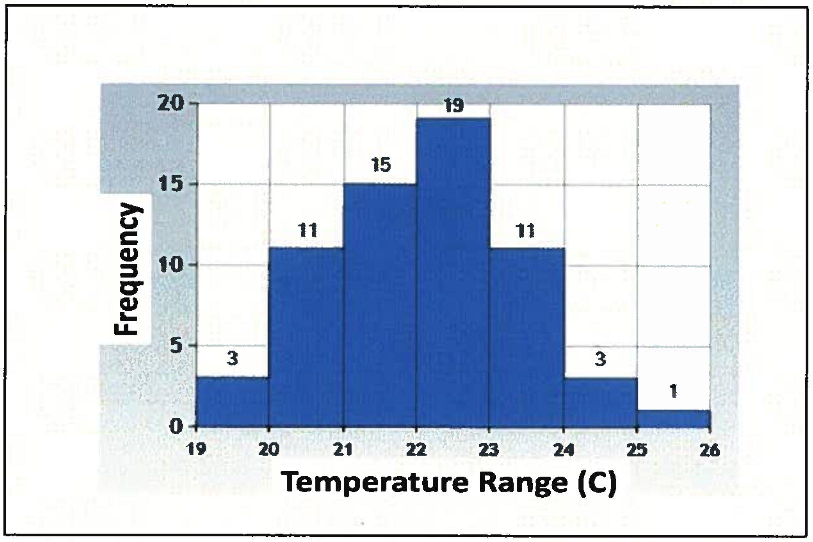
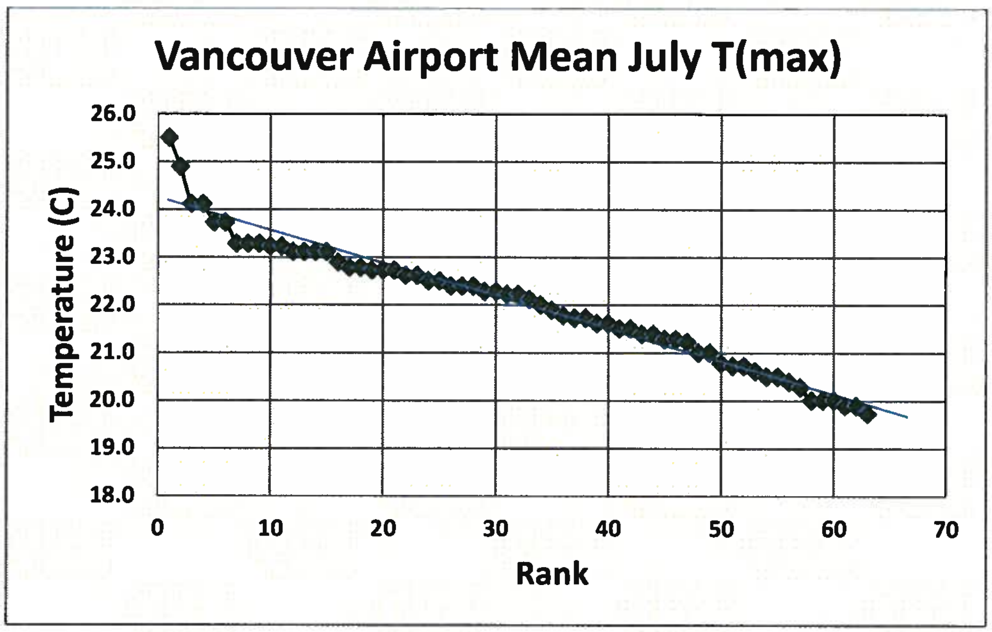



*Figure 4b: Data from Figure 4a was rank plotted, and is approximately linear, as is the case for normal distributions. Rank 1 is the warmest month, and is at the extreme left of the x-axis.*




26. Note that in Figure 4b, where the data are rank ordered, the relationship is linear except for two years (1958 and 1985), which at ranks 1 & 2 are somewhat higher than a linear fit would suggest. This may be because of an unusual weather pattern, instrument error, or a change in the physical environment at the weather station (such as nearby construction). Statistical averages and variances are useful for normal distributions, since they indicate a region where variables exist most of the time.

27. *Disaster Data Fit a Power Law, Not a Normal Distribution:* The probability distribution of disaster data are very different from Figures 4 and are generally best represented by a

power law. Mathematically a power law is represented by the equation $f(x) = ax^k$. An example of this is earthquake frequencies (Figure 5a). The tendency of people to think in terms of averages is not helpful for variables that follow power laws (Box 1). Recall that earthquake magnitude (MM) is logarithmic, such that a MM=8 is one-tenth as strong as a MM=9. Figure 5b shows the 100 largest recorded earthquakes, rank ordered; note the non-linear curve.

28. Box 1: ***"One consequence is that events with power laws are scale-free; there is no characteristic size that is typical of the system. What power laws challenge us to do then is give up the view of the world as consisting of typical events with infrequent random variations. Instead, we must accept that there is no "average" event. There are simply many small ones, a few larger ones, and occasionally extremely large ones. "***[18]

[18] Farber, D. A. (2003). *Probabilities Behaving Badly: Complexity Theory and Environmental Uncertainty*. UC Davis L. Rev., 37, 145. Retrieved from http://scholarship.law.berkeley.edu/facpubs/614

*Figure 5a: Frequency of earthquakes by magnitude[19]. Note the rarity of high magnitude events compared to small ones. This curve is best represented by a power law. The X-axis of this curve has low magnitude events to the right and high magnitude events to the left, which is the opposite of Figure 3. This is why the curve is a mirror image of the right side of Figure 3.*

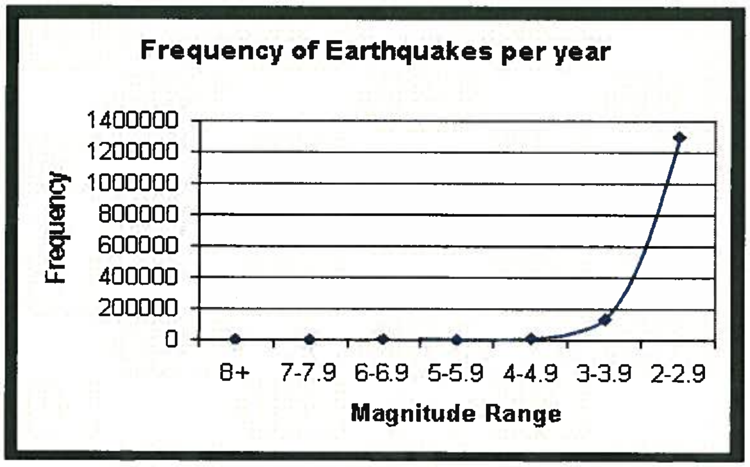
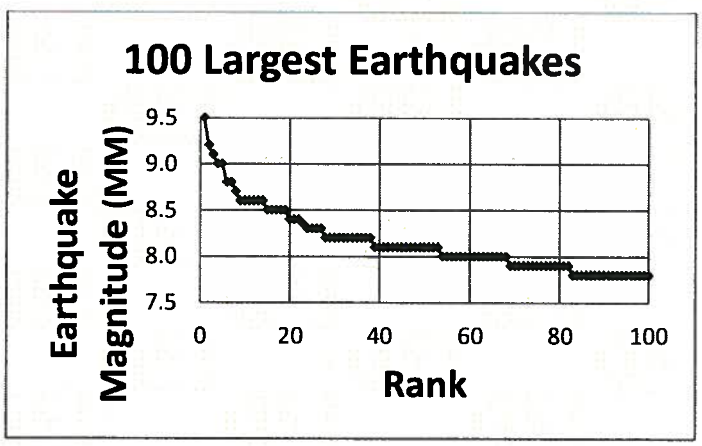



*Figure 5b: Example of a power law. 100 largest recorded earthquakes, rank ordered (rank 1 = largest recorded quake). Note how the curve grows exponentially upward to the left, as events become rarer and of higher magnitude20. The Y-axis (MM) has a logarithmic definition, such that a 9.0 earthquake is ten times as strong as an 8.0.*




[19] Source: Teaching Quantitative Skills in the Geosciences. Carleton University. http://serc.carleton.edu/quantskills/methods/quantlit/logarithms.html
[20] Data Source: US Geological Survey, http://earthquake.usgs.gov/earthquakes/world/world_deaths.php

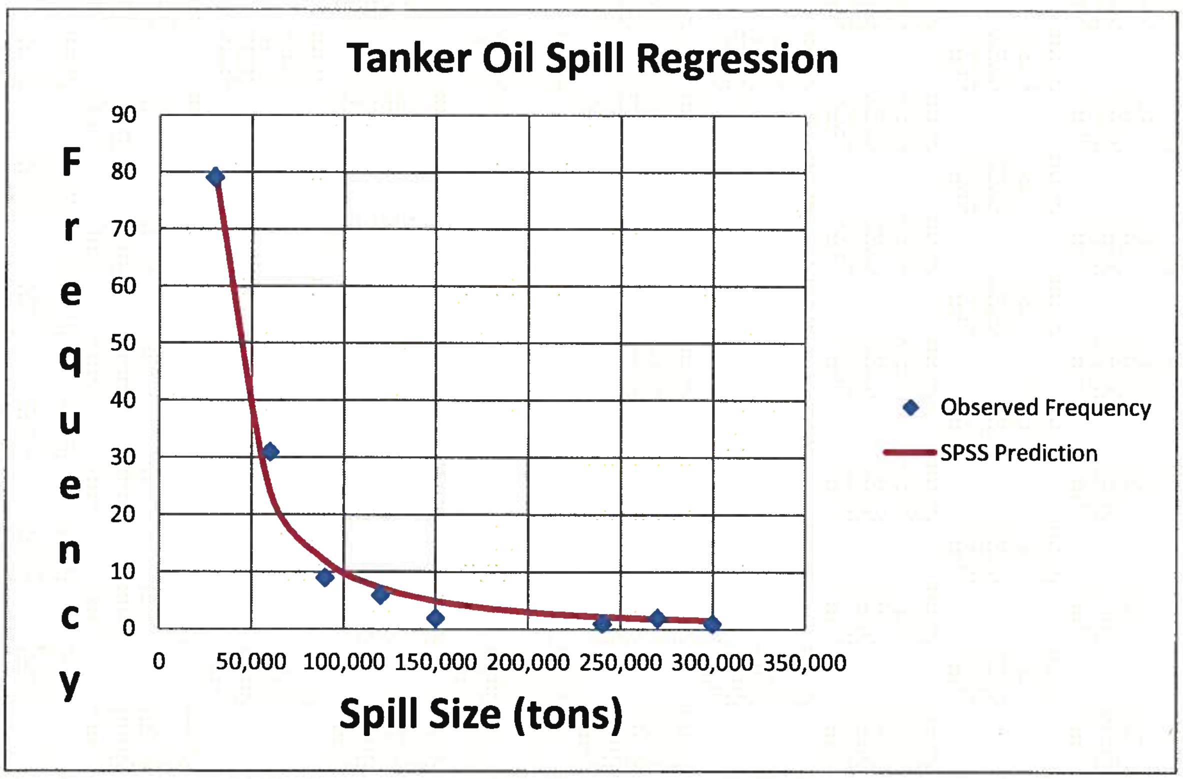
29. *When are LPHC Events Important to a Risk Analysis?:* The importance of including LPHC events in the TM/DNV risk assessment will depend upon what kind of probability distribution best fit tanker spills. If spills fit a power law distribution, then, in my opinion, they should be included.

30. *Do Tanker Oil Spills Follow Power Laws?* Using data for the worst 131 tanker spills obtained from *International* Tanker Owners Pollution Federation Limited (ITOPC)[21], a statistical analysis using SPSS resulted in the following relationship:

$$P(x) = 4.7x10^{9}x^{-1.7}$$

Where P = probability and x = size of tanker oil spill. Figure 6 shows the fitted power law curve to the data. Note that the $R^2$ value (a measure of goodness of fit where 1.0 is a perfect fit) for this curve is 0.98, which is very high. The X axis is bins of spill size using ranges of 30,000 tons (e.g., the first bin is <30,000 tons, the second bin is 30,000-60,000 tons, and so on). The Y axis is the number of spills within that bin. The blue diamonds are the observed ITOPC data and the red line is the power law curve. The spill data clearly shows a power law distribution, meaning that the low probability events are significant and should be included in the risk analysis.

*Figure 6: Frequency distribution of tanker oil spills using ITOPC data.*

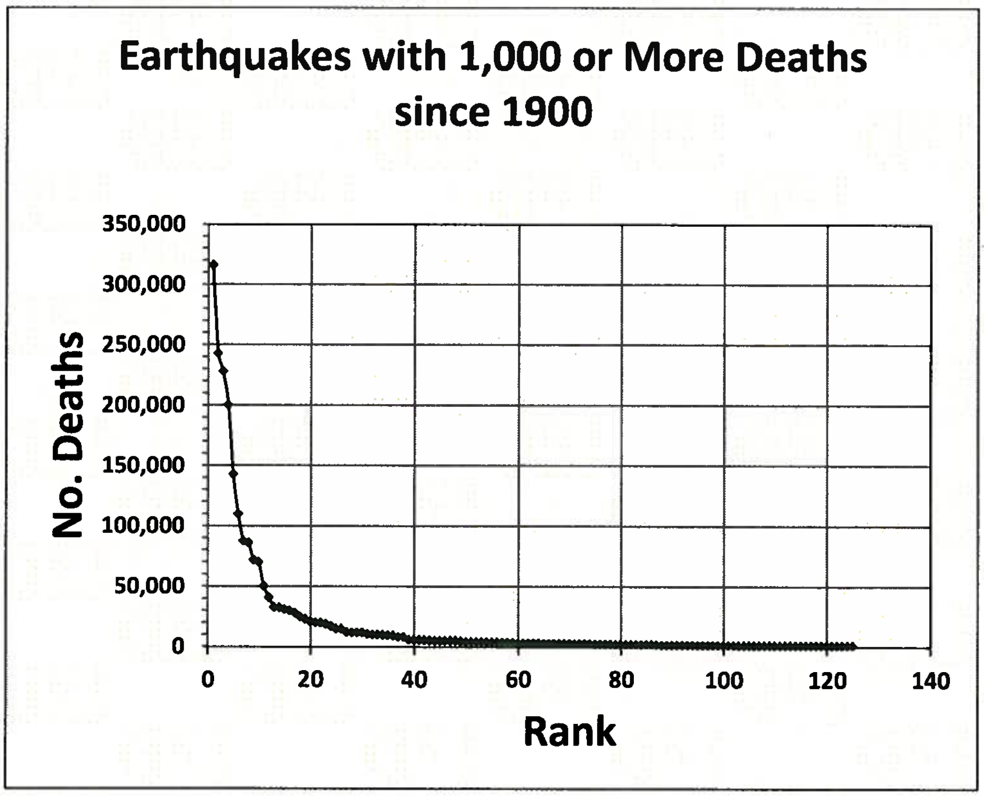



[21] The International Tanker Owners Pollution Federation Limited. http://www.itopf.com/

31. *Summary:* This section has explored the importance of power laws for hazard profiles. If tanker spills conformed to a normal distribution it might be reasonable to exclude some LPHC events, but given that they follow a power law, the weight of evidence means that they should be included. If it can be shown that consequences or impacts also follow power laws, then the conclusion that the full range of LPHC events must be included is not in question.

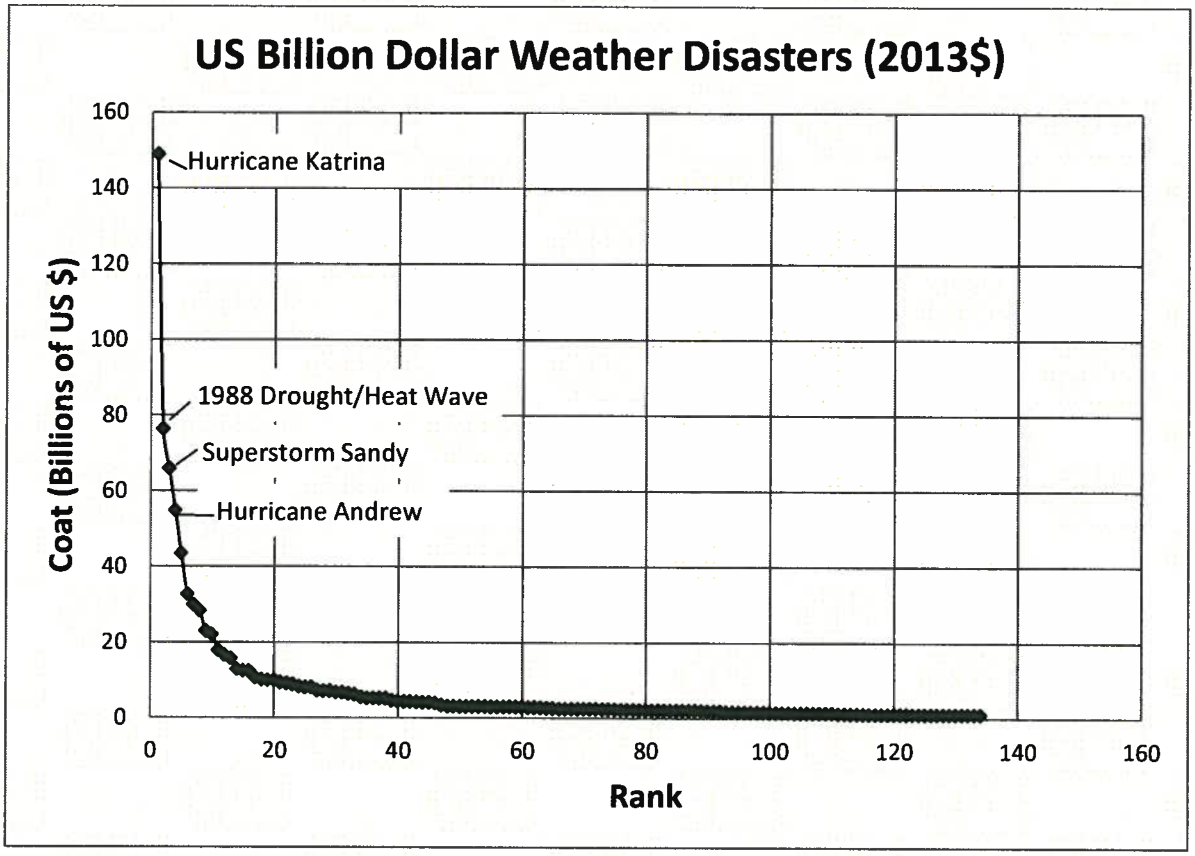
32. *Theoretical Considerations (B) – the Power Law and Consequences or Impacts:* The previous section considers the probability distribution of hazard. This section focuses on impacts. Disaster impacts generally follow power laws, no matter what the source. For example, Figures 6a and 6b show deaths from earthquakes and the cost of weather disasters in the United States. Earthquakes represent a useful comparison to tanker accidents, since deaths happen when the buildings people live and work in collapse on them; in this sense they are more of a technological disaster than a natural one. Additional examples for mining, explosions, industrial disasters, maritime disasters, stampedes & panics, structural collapses and structural fires are included in Appendix A, and show similar patterns.

*Figure 6a: Global deaths from earthquakes, rank ordered. The top 10 of the 125 events account for about 2/3 of the total deaths*[22].




[22] Source: US Geological Survey. http://earthquake.usgs.gov/earthquakes/world/world_deaths.php

*Figure 6b: Relative costs of weather related disasters in the US exceeding $1 billion, CPI adjusted to 2013. The top 6 of the 134 events account for 43% of the total cumulative damage in the list*[23].




33. *Will Oil Spill Impacts Follow Power Laws?:* Both examples in Figures 6a&b and the examples in Appendix B provide strong empirical evidence that support the importance of including LPHC events as part of a risk analysis. The mathematics of risk calculations also support this conclusion. There are compelling reasons to believe that oil spill impacts, as well as frequencies, follow power law distributions, which means that **LPHC events account for a significant amount of total impacts, and must be included in a risk analysis.**

34. *Conclusion:* Evidence indicates that oil spill impacts follow power law distributions. LPHC events should, therefore, be included in a risk analysis.

[23] Data Source: National Oceanic and Atmospheric Administration, http://www.ncdc.noaa.gov/billions/events

# 5. LPHC EVENTS & THE TITANIC MENTALITY

35. *Titanic Mentality:* Unfortunately, there is a long history of catastrophes that were considered to be so implausible that they were not properly planned for. Examples include the Titanic, nuclear power plant failures at Three Mile Island, Chernobyl and Fukishima, and others. The mentality is that failure is not possible because the system/ship/etc. has been designed so well. There is even a phrase for it in popular culture, called the "Titanic Mentality".

36. Box 3: The Titanic Mentality mindset is noted in various papers and After Action Reports, for example:
    a. The Executive Summary of the Final Report-Investigation Committee on the Accident at Fukushima Nuclear Power Stations of Tokyo Electric Power Company noted: "*...a lack of ... imagination toward a major tsunami*".[24]
    b. The 9/11 Commission Report found: "*...a failure of imagination and a mindset that dismissed possibilities' as a key underlying factor*"[25].
    c. "*Prior to the Three Mile Island-2 accident, a "Titanic mentality"... existed in many minds about nuclear reactor plant robustness*"[26]

37. *DNV/TM and the Titanic Mentality:* DNV notes that "*Based upon the fact that there has not been any total loss of containment scenarios involving a double hull tanker, ever, to date a credible worst case scenario does not include total loss of tanker with complete loss of cargo.*"[27] This is a mindset that is fundamentally flawed. The problem with relying exclusively upon historical data for risk analyses (particularly data that are only a few decades in length) is that it excludes events that just haven't happened yet. For example, a tsunami risk analysis based upon data extending over a few decades, if done prior to 2004, would not have captured the Indonesian catastrophe of December 2004 or the Japan one of 2011. Using such data as a basis for a credible worst case scenario can easily lead to a deeply flawed risk estimation. If risk assessments are to be robust, they must go beyond a historical lessons learned approach and include scenarios of possibilities. To do otherwise is to be caught in a cognitive trap where risk estimations are bounded too narrowly.

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[24] Investigation Committee on the Accident at Fukushima Nuclear Power Stations of Tokyo Electric Power Company (2012). Executive Summary of the Final Report http://www.cas.go.jp/jp/seisaku/icanps/eng/finalgaiyou.pdf

[25] The 9/11 Commission Report (2004). http://www.9-11commission.gov/report/911Report.pdf

[26] Rempe, J., Farmer, M., Corradini, M., Ott, L., Gauntt, R., & Powers, D. (2012). Revisiting Insights from Three Mile Island Unit 2 Postaccident Examinations and Evaluations in View of the Fukushima Daiichi Accident. *Nuclear Science and Engineering, 172(3)*, 223-248.

[27] TERMPOL 3.15 – General Risk Analysis and Intended Methods of Reducing Risks: Trans Mountain Expansion Project, Section 9.1.5, Det Norske Veritas (U.S.A.), Inc., DNV Doc. No./Report No.: 167ITKV-9/PP061115

## 6. CUMULATIVE EFFECT ASSESSMENT

38. There is a large literature on the importance of assessing the cumulative effects or impacts of projects, and cumulative assessments are often required by legislation and/or policy, such as the Canadian Environmental Assessment Act. It is beyond the scope of this report to discuss this issue, but I feel compelled to observe that the risk assessment by DNV/TMPEP only addresses the individual impact of spills, not cumulative impacts. This is not best practice within the risk assessment community and represents a serious omission.

## 7. GENERAL CONCLUSIONS

39. *Methodological Error:* The DNV/TM risk analysis has a serious methodological flaw related to their exclusion of a range of LPHC events. Though they define risk properly in their risk analysis (Risk = Hazard x Consequences), they only use probability of hazard to eliminate Segments 2, 3 &4, and LPHC scenarios larger than 16% of tanker capacity. **They should be included.** This error, in my opinion, leads to a serious underestimation of risk.

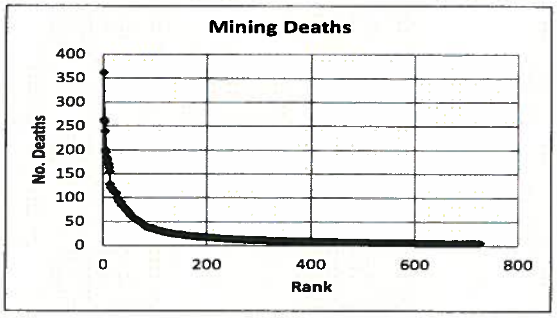
    a. The DNV/TM risk analysis excludes specific Segments (2, 3 & 4) on the basis of their low probability. This exclusion, in my opinion, leads to a serious underestimation of risk. The potential consequences of a LPHC spill on the City of Vancouver and other communities should be calculated and be an explicit component of the risk analysis.

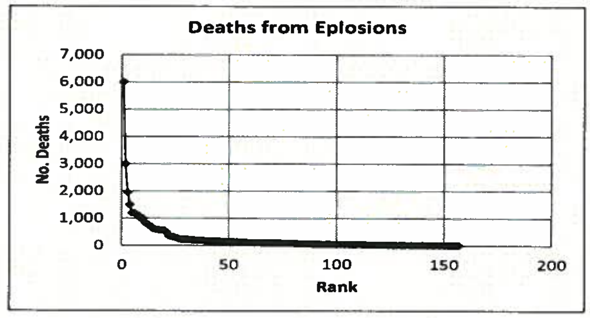
    b. The DNV/TM risk analysis excludes tanker spills in excess of 16% of tanker capacity on the basis of their low probability. This exclusion, in my opinion, leads to a serious underestimation of risk.

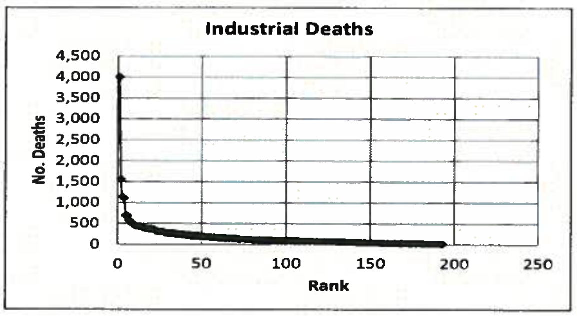
40. *Cumulative Impacts:* Doing a risk assessment of a hazard such as tanker oil spills, which is represented by a power law distribution, requires an evaluation of both (a) specific impacts from LFHC disastrous events, and also (b) the cumulative impact from high probability / low consequence (HPLC) events. The latter has not been done and may represent a serious omission.

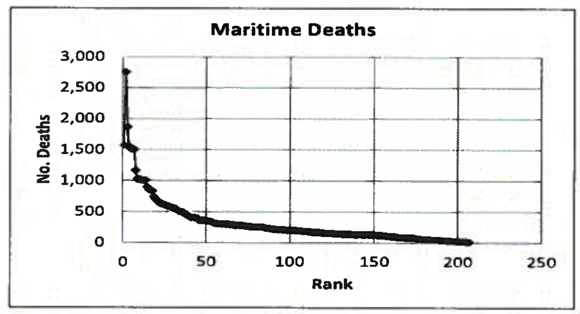
41. *Cultural Framing of Risk:* Additionally, because risk is culturally framed, input from potentially affected communities plays an important role in determining acceptable level of risk. Such input is not included in the DNV risk assessment, and should be added. This is particularly true for Segment 2 near the City of Vancouver.

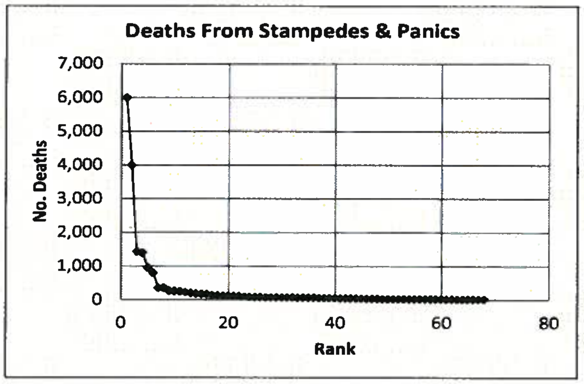
# APPENDIX A: EXAMPLES OF DISASTERS & POWER LAWS

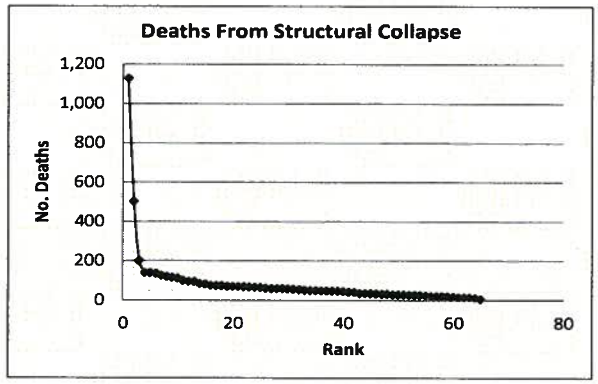


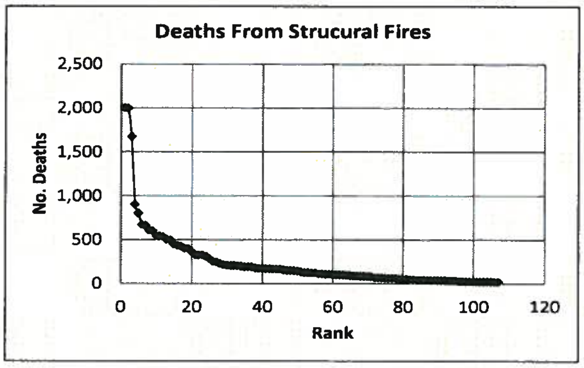



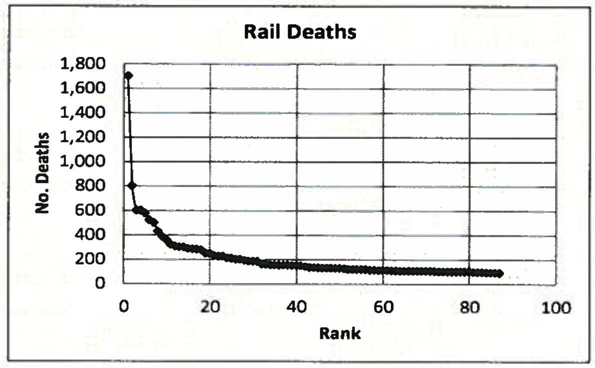






42. *Data:* Mining Disasters (USA): 1839-2019. Explosions (not including bombings, aviation incidents or mining disasters): 1597-2013. Industrial Disasters: 1860-2013. Maritime Disasters (peacetime only): 1622-2012. Stampedes & Panics: 1809-2010. Structural Collapses: 1907-2013 (with one event in 1627). Structural Fires: 1863-2012. Rail Disasters (more than 90 Deaths): 1876-2010. Sources: Centre for Disease Control for mining disasters[28] and Wikipedia[29] for other disasters. Wikipedia data do not include deaths by natural disasters, war or violent acts.

43. *Chart Descriptions:* Each chart is rank ordered along the x-axis with the largest event as rank 1. Number of deaths is along the y-axis; where a range of values were given the lesser value was used in order to provide conservative estimates. These graphs, like Figures 6, illustrate the pattern typical of disasters following power laws - that a few extreme events account for a relatively large proportion of the total losses.

[28] Centre for Disease Control, http://www.cdc.gov/niosh/mining/statistics/content/allminingdisasters.html
[29] Wikipedia. Missing data is likely due to the unreviewed nature of the data sources, but does not affect the shape of the curve.
http://en.m.wikipedia.org/wiki/List_of_accidents_and_disasters_by_death_toll#Rail_accidents_and_disasters

# APPENDIX B: ABBREVIATED CV

A. PERSONAL

1. NAME: David A. Etkin, Associate Professor, York University;
   Associate Faculty, Royal Roads University.

2. DEGREES:
   B.Sc., York University, Faculty of Science (1972)
   B.Ed., University of Toronto, Faculty of Education (1974)
   M.Sc., York University, Faculty of Science (1991)

3. EMPLOYMENT HISTORY:

| EMPLOYER | TIME PERIOD | POSITION |
|---|---|---|
| York University | 2005-present:<br>Faculty of Liberal and Professional Studies | CLA 2005-2008<br>Assistant Professor 2008-2011<br>Associate Professor 2011-present |
| Environment Canada | 1976-94 | Weather Forecaster & Instructor, Research Meteorologist |
| | 1994-2005:<br>Institute for Environmental Studies, U. of T. | Natural Hazards and Risk Analyst, Associate Member of the School of Graduate Studies |
| Etobicoke Board of Education | 1974-76 | Teacher of math and science |

4. HONOURS AND AWARDS:
   Environment Canada Award for Excellence (2003)
   York University Merit Award (2011 & 2012)

B. SCHOLARLY AND PROFESSIONAL CONTRIBUTIONS:

1. SUMMARY OF PUBLICATIONS AND PROFESSIONAL CONTRIBUTIONS

- 1 textbook on disaster theory and 6 edited volumes
- 11 book chapters
- 37 refereed publications:
- 23 publications in peer reviewed journals. Two of these publications have over 100 citations.
- 2 publications in peer reviewed conference proceedings
- 12 other refereed publications

- Co-editor of 1 online textbook
- 29 non-refereed articles
- 2 works in progress
- PI or Contributor to several national and international projects, including the IPCC (co-recipient of the 2007 Nobel Peace Prize)
- Frequent reviewer of manuscripts submitted to peer review journals

Summary of Citation indices from Google Scholar, as of December 6, 2014.

| | **All** | **Since 2009** |
|---|---|---|
| **Citations** | 856 | 438 |
| **h-index** | 14 | 11 |
| **i10-index** | 19 | 13 |

h-index is the largest number h such that h publications have at least h citations. The second column has the "recent" version of this metric which is the largest number h such that h publications have at least h new citations in the last 5 years.
i10-index is the largest number h such that h publications have at least h citations. The second column has the "recent" version of this metric which is the largest number h such that h publications have at least h new citations in the last 5 years.

2. SELECTED PUBLICATIONS:

1. Etkin, D. (2015). Disaster Theory: An Interdisciplinary Approach to Concepts and Causes. Butterworth- Heineman.
2. Etkin, D., Ivanova, J., MacGregor, S., & Serota, T. (2014). Risk Perception and Belief in Guardian Spirits. *SAGE Open, 4(3),* 2158244014549741.
3. Etkin, D. (2014). What is Your Dangerous Idea? Newsletter of the Canadian Risk & Hazards Network, Vol. 6(1) Fall, 2014, pp. 37-38.
4. Etkin, D., Buchanan, A., Cheung, G., Lee-Bun, C., Macdonald, K., Marcon, H., Musten, M. and Ristic, M. (2013). A Dangerous Idea. *World Conference on Disaster Management: The Power of Global Networking.* http://www.wcdm.org/blog/york-university-presents-a-dangerous-idea.html
5. Etkin, D. (2013). Reflections on Modeling Disaster. Encyclopedia of Natural Hazards, Springer, Netherlands, pp. 827-835.
6. Etkin, D. and Timmerman, P. (2013). Emergency Management and Ethics. *International Journal of Emergency Management,* 9(4), 277-297.
7. Haque, C.E. and Etkin. D. (Editors) (2012). Disaster Risk and Vulnerability: Mitigation Through Mobilizing Communities and Partnerships. McGill-Queens University Press, 300 pgs.
8. Haque, C.E. and Etkin, D. (2012). Dealing with Disaster Risk and Vulnerability: People, Community and Resilience Perspectives. In 'Haque, C.E. and Etkin. D. (Editors) (2012).

Disaster Risk and Vulnerability: Mitigation through Mobilizing Communities and Partnerships. McGill-Queens University Press, pp. 3-23.

9. Nirupama, N., & Etkin, D. (2012). Institutional perception and support in emergency management in Ontario, Canada. *Disaster Prevention and Management*, Vol. 21 Iss:5
10. Etkin, D., Higuchi, K. and Medayle, J. (2012). *Climate Change and Natural Disasters: An Exploration of the Issues.* Journal of Climate Change, June 2012, Volume 112, Issue 3-4, pp. 585-599.
11. Editor and Author: Textbook on "*Disaster & Emergency Management: The Canadian Context*". A Canadian Risk and Hazards Network Project (www.crhnet.ca). In Progress, at http://www.yorku.ca/etkin/dem_book/

# APPENDIX B TO THE WRITTEN EVIDENCE OF DAVID ETKIN

## *Review of Trans Mountain Response to City of Vancouver IR No. 2*

# Review of Trans Mountain (TM) Response to City of Vancouver IR No. 2

**By**

**Professor David Etkin[1], York University**

1. TM has responded to the following City of Vancouver Information Requests (ID A4H819, PDF page 174):
    a. Trans Mountain Response to City of Vancouver IR No. 2, 2.08.01.a
    b. Trans Mountain Response to City of Vancouver IR No. 2, 2.08.01.b
    c. Trans Mountain Response to City of Vancouver IR No. 2, 2.08.01.c
    d. Trans Mountain Response to City of Vancouver IR No. 2, 2.08.01.d

    The purpose of this note is to comment on the relevance and validity of their responses.

2. **City of Vancouver IR2.08.01a:** Please confirm that DNV did not take into consideration low probability, high consequence events when performing its risk analysis for the Trans Mountain Expansion Pipeline.
3. **TM Response:** DNV undertook a quantitative marine risk assessment for the Trans Mountain Expansion Project. Guidelines from Transport Canada on the TERMPOL Review Process, 2001 were followed. TERMPOL requires the proponent to assess risk, in terms of "the probabilities of credible incidents which result in the breaching of the ship's cargo containment system". A credible worst case oil spill from a project tanker (as calculated in the updated risk assessment) is 16,500 m3 of oil cargo and occurs once every 2,840 years. Please refer to Table A-8 in Trans Mountain's Response to NEB IR regarding TERMPOL report and Outstanding Filings (Filing ID A4G3U5). DNV considers such an event a low probability, high consequence event. Figure 34 and Figure 35 in the report show all modelled oil spill volumes and probabilities, this is again paired with incident frequencies in Figure 41 to show the total risk picture. Trans Mountain is confident that the evaluation of potential environmental effects applying this methodology fulfills NEB requirements (Filing ID A3V6I2) and describes the range of environmental effects that could result from an oil spill along the marine shipping route.
4. **Comments by Etkin:**
    a. In the DNV risk analysis they accounted for some, but by no means all, Low Probability High Consequence (LPHC) events. This is the crux of the problem with their analysis. They should have included all the possible events. This applies both to spills larger than 16% of tanker capacity, and segments 2, 3 & 4 that are excluded from their risk analysis.
    b. DNV indicates that they accept the need for the evaluation of LPHC events, but this statement must be placed in context, particularly with respect to their assumptions. Their methodology limits these worst case events to those that are considered 'credible' (as per to the TERMPOL Review Process 2001), and so to a large degree the issue revolves around the meaning of that word. Their judgement is that tanker spills can be analyzed using a cutoff of 16% of tanker capacity (this is very different from an absolute

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worst case scenario, which is over 6 times that volume) and that some segments need not be included, simply because of low probability. Excluding scenarios on the basis of probability alone, without including consequence, is an error in logic. But also the question must be asked - What is the meaning of 'credible', in this context?

c. The meaning of the word credible is "capable of being believed", "plausible" or "worthy of belief". My first response to the notion that the tanker shipping system could operate for almost 3 thousand years (according to their calculations) without a spill of greater than 16% of tanker capacity is one of incredulity. However it is beyond my mandate to review in detail the mathematics of how probabilities were calculated. I note though, that the level of safety assumed is based upon the use of double hulled tankers, which replaced the more vulnerable single hulled ones. A factor not considered is the age of the fleet. The new double hulled fleet replaced an older one, and research shows that older ships are more likely to have spills[2]. As the current fleet ages, gains in safety that have been observed over the past few decades may not be maintained. No analysis of this aging tanker issue exists in the DNV report. It is also worth commenting on uncertainties associated with extrapolating a few decades of data to return periods of thousands of years. Doing this should generate large error bars, an analysis that is missing from their report, but which is essential to understanding the probability analysis.

*d.* There is another important issue that DNV avoids. In section 3.15 of the TERMPOL report[3] where they discuss the risk analysis, the following statement is made: "*Analysis should not be limited to a mathematical index (probability of an incident) but should also include perceived risks to:*

*i. populations within coastal zones along the intended route;*

*ii. the terminal berth and surrounding area; and*

iii. *the marine environment, fish and wildlife habitat.*"

This clearly indicates that the TERMPOL notion of risk includes both hazard probability and the impact of a spill on exposed social and ecosystems. The DNV report uses only hazard probability as delimiter of risk, and therefore fails to meet the TERMPOL standards, as well as best practice within the risk assessment industry, which would include a comprehensive assessment of impacts.

e. Since tanker oil spills follow a power law distribution, the inclusion of all LPHC events (that is, those existing within the 'fat tail' of the probability distribution), not just a small subset of them, is important, especially when the exponent in the defining equation is small. Power laws (or as they are also know, Pareto distributions) are represented by the equation

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[2] Eliopoulou, E., Papanikolaou, A., Diamantis, P., & Hamann, R. (2012). Analysis of tanker casualties after the Oil Pollution Act (USA, 1990). *Proceedings of the Institution of Mechanical Engineers, Part M: Journal of Engineering for the Maritime Environment, 226(4)*, 301-312.

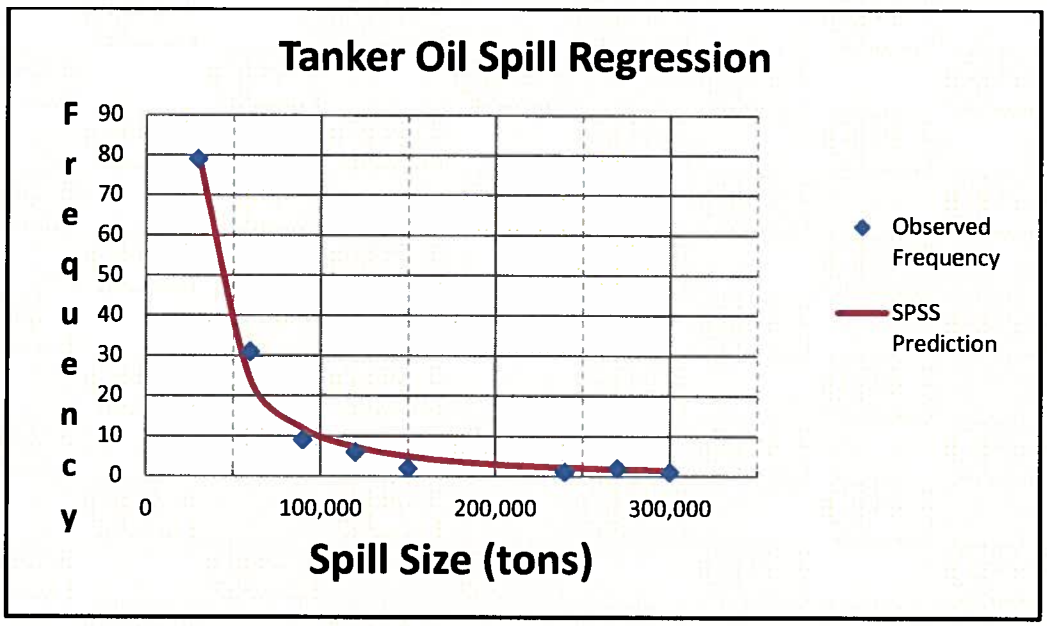
[3] Transport Canada (2001). *TERMPOL Review Process 2001*, Marine Safety, Transport Canada TP742E.

$$P(x) = kx^{-\alpha}$$

where P is probability, x is some variable, k is a constant, and α is the exponent or scaling parameter. The smaller the scaling parameter α, the fatter the tail and the more important are rare events. Using data for the worst 131 tanker spills obtained from International Tanker Owners Pollution Federation Limited (ITOPF)[4], a statistical analysis using SPSS resulted in the following relationship:

$$P(x) = 4.7x10^{9}x^{-1.7}$$

Where x = size of tanker oil spill in tons. Figure 1 shows the fit of the curve to the data. Note that the $R^2$ value for this curve is 0.98, which is very high. The X axis is bins of spill size using ranges of 30,000 tons (e.g., the first bin is <30,000 tons, the second bin is 30,000-60,000 tons, and so on). The Y axis is the number of spills within that bin. The blue diamonds are the observed ITOPF data and the red line is the power law curve.




f. Where α is small, the LPHC events become relatively more important. For comparison purposes fatality datasets for the following disaster types were similarly analyzed with the following results forα: U.S. mining disasters (α=-3.8), structural fires (α=-2.4), U.S. tornadoes (α=-1.5), earthquakes (α=-2.7), explosions (α=-2.6), structural collapses (α=-2.8), railway (α=-2.1); and U.S. billion dollar weather disasters (α=-2.5). The scaling parameter for tanker oil spills of α=-1.7, with the exception of tornadoes, is smaller than

[4] The International Tanker Owners Pollution Federation Limited. http://www.itopf.com/

the other disaster types analyzed, suggesting that it is even more important to include all rare events.

g. It is axiomatic that excluding a range of scenarios from a risk analysis will bias risk estimation to a lower value. In science, simplifying assumptions are often made in order to make problems tractable. Examples include Newton's Law and the Flat Earth Assumption. The issue is, to what extent are the assumptions valid. If errors generated are small or do not matter to a particular application, then they are justifiable. Is this the case for tanker oil spills?

h. Because disasters have power law distributions, the exclusion of rare events is, in general, difficult to justify. There is a large body of literature demonstrating the importance of including events in a risk analysis when they lie within the fat tail of a power law (for example Jo and Ko, 2014[5]). Consider, for example, the Haiti earthquake of 2011, the Indonesian tsunami of 2004, Hurricane Katrina of 2004 or the earthquake disaster at Fukushima in 2011. Each of these events was rare, but the exclusion of them in a risk assessment would result in one that was deeply flawed and much too optimistic. Given the relatively small value of the exponent of $\alpha$=-1.7, one should conclude that a risk analysis should include all events.

5. **City of Vancouver IR2.08.01b:** Does DNV agree with the statement in Reference i that "it is time for us to focus our attention, technical skill and research and development on the low probability, high consequence, events"? If not, explain why.
6. **TM Response:** DNV does agree with this statement. Therefore, DNV together with Trans Mountain focused on identifying current and extraordinary risk-reducing measures so that the frequency of a credible worst case oil spill event remains low. Please refer to the risk-reducing measures in Section 13 of Volume 8C TERMPOL 3.15 (Filing ID A3S5F6).
7. **Comments by Etkin:** I cannot comment on the accuracy of this answer since I am not an expert in oil spill risk reduction methods. I note, though, that their answer addresses risk-reducing measures only, and not the risk analysis, in which a large range of LPHC events were excluded.

8. **City of Vancouver IR2.08.01c:** Does DNV agree with the statement in Reference ii that "Understanding the risk of a major oil leak or a blowout gives half the oil spill risk picture. The probability of impacting personnel and the environment and the potential consequences of this must also be included in the overall risk picture"? If not, explain why.
9. **TM Response:** Risk is widely considered as a combination of probability and consequence. The probability of impacts on personnel and the environment and the potential consequences are components of the overall consequences of major failures. DNV is very aware of this; therefore, DNV together with Trans Mountain focused on identifying current and extraordinary risk-reducing measures so that the frequency of a credible worst case oil spill event remains low. Please refer to the risk-reducing measures in Section 13 of Volume 8C TERMPOL 3.15 (Filing ID

[5] Jo, H. H., & Ko, Y. L. (2014). Large Variance and Fat Tail of Damage by Natural Disaster. *arXiv preprint arXiv:1407.6209.*

A3S5F6). DNV GL's risk assessment has been the basis for the oil drift modelling, which in turn has been the basis for assessment of environmental impact risk. Trans Mountain believes that sufficient information has been provided to address the National Energy Board's (NEB) List of Issues (Filing ID A3V6I2).

10. **Comments by Etkin:** It is unfortunate that the recognition of risk as being a function of probability and consequence, as acknowledged here by DNV, was not incorporated into their risk assessment. DNV did not answer the question asked regarding the actual risk assessment they did, but rather pivoted to answer a question not asked, regarding risk reduction measures. They did this for the simple reason that they, in fact, did not include consequence in their risk assessment.

11. **City of Vancouver IR2.08.01d:** Does a risk assessment which fails to take into consideration low probability, high consequence events meet DNV's standard for best practices? If yes, explain DNV's standard for risk assessment best practices and how it is met by an assessment that fails to take into consideration low probability, high consequence events.
12. **TM Response:** DNV GL is confident that this study meets the objectives of a state of the art risk assessment.
13. **Comments by Etkin**: DNV indicates that they are following best practice, but this is not an accurate statement. There are serious flaws in their risk assessment, as discussed above in my report dated April 21, 2015. The second part of the question was not answered.

# APPENDIX C TO THE WRITTEN EVIDENCE OF DAVID ETKIN

## *Certificate of Expert's Duty*

**Appendix "C": Certificate of Expert's Duty**

I, David Etkin, of Vancouver, British Columbia have been engaged on behalf of the City of Vancouver to provide evidence in relation to Trans Mountain Pipeline ULC's Trans Mountain Expansion Project application currently before the National Energy Board.

In providing evidence in relation to the above-noted proceeding, I acknowledge that it is my duty to provide evidence as follows:

1. to provide evidence that is fair, objective, and non-partisan;
2. to provide evidence that is related only to matters within my area of expertise; and
3. to provide such additional assistance as the tribunal may reasonably require to determine a matter in issue.

I acknowledge that my duty is to assist the tribunal, not act as an advocate for any particular party. This duty to the tribunal prevails over any obligation I may owe any other party, including the party on whose behalf I am engaged.

Date: __May 8, 2015____________ Signature: David Etkin