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DEFINING A WORST-CASE RELEASE SCENARIO FOR THE ENBRIDGE CRUDE OIL PIPELINES CROSSING THE STRAITS OF MACKINAC – LINE 5

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Background

The basic objectives of the MPSAB in commissioning the studies were to obtain: 1) an expert risk analysis on the Enbridge Line 5 pipeline crossing the Straits of Mackinac (Straits) and 2) an analysis of alternatives for NGL/crude oil transportation. The risk analysis was to include identification of worst-case and alternative scenarios based on different pipeline failures, materials being transported, seasons of the year and etc. The alternatives analysis was to include: construction of new pipelines, use of alternative pipelines and other transportation methods, replacement of the existing pipelines across the Straits, maintaining existing pipeline operations and decommissioning the Straits crossing with continued use of upstream and downstream segments.

The Risk Analysis - The State of Michigan (State) terminated the contract with Det Norske Veritas, Inc. (DNV GL), the contractor developing the risk analysis study on June 21, 2017, due to violation of conflict of interest prohibitions contained in the contract. The draft report was not received by the State and is not available for public review. The failure to deliver this report creates a huge void in identifying and understanding the risks of Line 5 operations in the Straits, especially the worst-case scenario (WCS).

The Alternatives Analysis – the "Draft Final Report - Alternatives Analysis for the Straits Crossing" developed by Dynamic Risk Assessment Systems, Inc. was submitted to the State on June 27, 2017 and then released for public review and comment. (1) Comments on this report are provided in a separate paper.

This report addresses the worst-case release scenario for a failure of Line 5 at the Straits, filling part of the void left by the DNV GL contract termination. This report provides an overview of the current confusion in understanding WCS's, alternative scenarios and conflicting risk management and regulatory definitions for "WCS". For the State of Michigan and communications to the citizens and stakeholders, it is important to use a common sense and professional risk management approach, not so-called worst cases reduced and restrained by numerous assumptions that can fail or not correctly defined for the issue under study. The release quantities in this report can be used to model spill dispersion and human health, environmental and economic impacts. The assumptions are also defined, transparent and can be debated and adjusted.

FLOW provides an analysis in this report on WCS releases and potential quantities that could be released in the Straits from a Line 5 failure. In other words, it answers the question; how big could the spill be? The report does not provide information on crude oil spill dispersion, fate and consequences after release to the waters of the Straits. Other organizations are working on fate and consequence assessments. It is vital that these assessments include realistic crude oil WCS release quantities; concentrations and dispersion ranges drive the magnitude of consequences.

Executive Summary

Identification of the worst-case and alternate scenarios is the key starting point in conducting a risk assessment. On June 21, 2017, the State terminated the contract with DNV GL, the consultant who was to provide the worst-case and risk analysis. The failure to deliver this report creates a huge void in identifying and understanding Line 5 risk in the Straits. This study provides a worst-case release scenario for consideration.

There is considerable confusion and misunderstanding on a worst-case release scenario for the Straits as different organizations use different definitions, leading to public misunderstanding. This report provides a credible worst-case release based on risk management principles that allow consideration of passive controls - fixed systems but not active controls (mechanical, electrical and control systems, procedures and emergency response) to identify the worst-case.

Department of Transportation Pipeline and Hazardous Materials Safety Administration (PHMSA) regulations require the calculation of a scenario for emergency response planning. Pipeline operators can assume credits in their scenarios for passive and active controls (alarms, SCADA / material balance systems, remote valves, water back pressure, emergency response) and 100% reliability. Although noted as a "worst-case discharge", in the regulations and application as the largest release that the Emergency Response Plan submitted to PHMSA for approval is theoretically able to handle; it is not **how big a spill could really be. In other words, the worst-case discharge submitted by Enbridge to meet PHMSA requirements is not a Worst-Case Scenario. (2,3,4)**

The scenario for a catastrophic release submitted to PHMSA by Enbridge is approximately 4,500 bbl. The WCS release calculated by FLOW is 61,000 bbl. for a catastrophic release. For a slow leak release scenario, 24,000 bbl. per week was calculated; however, a 20-day undetected leak could exceed the size of a catastrophic failure. Dispersion modeling to determine shoreline impact was beyond the scope of this report; however, for comparison, Dr. David Schwab at the University of Michigan modeled several release scenarios. The largest release modeled was 25,000 bbl. (1,050,000 gallons) which is approximately the quantity released in 2010 from the Enbridge Line 6B failure in the Kalamazoo River watershed. Dr. Schwab's model indicated that a 25,000 bbl. release in the Straits could impact approximately 720 miles of Lake Michigan and Lake Huron shorelines.

The report prepared by Dynamic Risk Assessment Systems, Inc. (Dynamic Risk) does not contain a worst-case scenario and impact analysis. It is a comparative analysis of possible alternatives. Do not interpret findings in this report as representative of a worst-case. The release quantities in the Dynamic Risk alternative scenarios are orders of magnitude lower than a possible WCS.

Overview

This report provides background information on risk management and worst-case scenario (WCS) information that should be communicated to stakeholders concerned with the risks posed by the Enbridge Line 5 pipeline at the Straits. This information is not available from the MPSAB consultant studies as the contract with DNV GL was terminated and the analysis by Dynamic Risk did not include a WCS, as it was not within the scope of their work.

The identification of a WCS in most cases does not require complex mathematical modeling. The most important aspects of WCS identification are proper definition of the system scope or boundaries and appropriate application of protective measures to prevent a release from occurring. Inappropriate assumptions that reduce release quantities can result in gross under estimations of potential consequences. There is a history of events in several industries where real events exceeded WCS's submitted to meet regulatory requirements. (9)

Hazardous Materials Risk Management (5,6,7,8)

Risk is a function of ***consequence*** and ***probability***. ***Probability*** is a function of ***vulnerability*** and ***threat***. It is important to define and understand basic definitions for risk management upfront as the terms are often used loosely resulting in confusion to stakeholders and leading to a misunderstanding of real risk.

Risk is a function of ***consequence*** and ***probability***.

Risk = Consequence X Probability

> ***Risk*** – a measure of human injury, environmental damage or economic loss in terms of incident likelihood (probability) and the magnitude of loss or injury (consequence).

Consequence – the direct undesirable result of an incident outcome, specifically the impacts resulting from the release of a hazardous material. Consequence is generally a function of the hazards of the material released, the extent of the release and the presence of receptors (people, ecosystems, property, etc.).

Probability – the expression for the likelihood of occurrence of an event or an event sequence during an interval of time or the likelihood of the success or failure of an event on test or demand.

Probability is considered to be a function of ***vulnerability*** of hazardous materials operations to various ***threats.***

Probability = Vulnerability X Threat

Vulnerability – any weakness in a system or asset that can be affected or exploited by accidental, natural or man-made causes resulting in harm.

Threat – any indication, circumstance, or event with the potential to cause the loss of, or damage to, a system or asset. Threats can be of natural or man-made origin.

For example, the risk posed by a crude oil pipeline is a function of consequences resulting from a crude oil release to the environment and the vulnerabilities of the pipeline to the various threats in its operating environment.

Worst–Case Scenario (WCS) and Alternative Release Scenarios (ARS)

In risk management for existing and proposed operations and transportation systems, a starting point is to identify the WCS and understand the possible consequences. For a WCS where the consequences are intolerable, even with an extremely low likelihood of occurrence, alternative options are required. Failure to identify the WCS misinforms the public and can lead to decisions that later lead to disaster. Unfortunately, the phrase "worst-case scenario" is used loosely with different definitions causing confusion and surprises when emergency response is inadequate.

Fundamentally, a WCS analysis in managing hazardous materials is the identification of the largest quantity release and consequences mitigated by permanent, fixed infrastructure and natural features. For example, a facility built in a natural basin or surrounded by permanent secondary containment (dike, basin) is considered to have "passive protective control measures" and these features can be counted upon to reduce release quantities to the environment. Other release scenarios that include valves, alarms, supervisory control and data acquisition (SCADA) systems and etc. that act to reduce release quantities are "active protective control measures" and the scenarios developed are called Alternate Release Scenarios (ARS). Release quantities from an ARS are less than a WCS. (10,11)

The overall risk management approach is to identify: the WCS for existing or proposed operations and ARS's and opportunities to eliminate entirely or reduce risks. In the case of an intolerable WCS, current operations are halted and an acceptable alternative implemented.

Risk management is trying to address failures of risk identification approaches to identify possible scenarios that are beyond worst-case. Disasters such as Deep Water Horizon, Enbridge Line 6B, the Fukishima nuclear reactor disaster and so on are often considered to be “Black Swan” or “Perfect Storm” scenarios. A key issue is that these types of incidents are continuing to occur as well as the reoccurrence of incidents that were to “never happen again.” (12, 13,14, 15)

> **Black Swan -** as outlined by N. Taleb (12), it is 1) an outlier, as it lies outside the realm of regular expectations, because nothing in the past can convincingly point to its possibility; 2) it carries an extreme impact; 3) in spite of its outlier status, human nature makes us concoct explanations for its occurrence after the fact, making it explainable and predictable.

> **Perfect Storm** – can be considered to be a sub-case of the Black Swan but importantly the events and possibilities are better known, in some cases well-known but decisions are made to not consider them because they lie outside regular expectations. (15)

Risk managers are working to improve assessment and auditing practices to root-out and prevent black swans and perfect storms. A controversy is the question; can these events really be identified? In practice, often the answer is yes but they were not considered due to incorrect system and scope definitions, incorrect assumptions, over-confidence in the functioning of protective systems, poor threat assessment, management failing to address an obvious issue and so on.

A WCS is a concept in risk management wherein the planner, in planning for potential disasters considers the most severe possible outcome that can reasonably be projected to occur in a given situation. For hazardous materials operations and transportation the definition is more refined.

Worst-Case Scenario (WCS) – also called a “credible worst-case scenario” is the potential release quantity based on system capacity <u>with</u> the consideration of mechanical, control system, operational and human factors <u>failures</u>. Credits for mitigation of potential release volume are allowed for ***passive controls*** that are permanently in place and in very limited cases for active controls.

> ***Passive controls*** are equipment, devices, or technologies that function without human, mechanical, or other energy input. Passive mitigation systems include dikes, containment walls and natural barriers such a valleys and berms.

> ***Active controls*** are measures such as remote shutdown valves, computer control and material balancing systems, alarms, operating procedures and training. Active controls require mechanical, energy or human input to function.

The scope of the <u>system</u> must also be correctly and consistently defined as changing simple assumptions can drastically change release quantities. A recognized definition is provided by the Occupational Health & Safety Administration (OSHA) Process Safety Management (PSM) Program and used by other regulatory agencies [x].

> ***Process and Interconnected System*** - Any activity involving a regulated substance, including any use, storage, manufacturing, handling, or on-site movement of such substances, or combination of these activities. For the purposes of this definition, any group of vessels that are interconnected, or separate vessels that are located such that a regulated substance could be involved in a potential release, shall be considered a single process."

Thus, to calculate a WCS, the system would be defined as connected tanks and pipes, connected storage tanks and credit given for the presence of passive control measures. In the case of crude oil pipelines and facilities, passive control measures are typically permanent secondary containment structures.

Common cause failures and ***cascading events*** are also important considerations in identifying the WCS. A "common cause" failure example would be a severe weather event that leads to power failures affecting equipment and delays response by operating personnel. A "cascading failure" example is a mechanical failure that triggers a "hydraulic hammer" to propagate down a pipeline and cause a rupture at a weak point.

Alternative Scenarios are calculated in addition to the WCS based on assumptions required in regulations or defined by the owner/operator. For example, company management or insurers may define an alternative or "most-likely accident scenario" or an "emergency response-planning scenario" required for insurance certification or regulatory permit approval. Planning scenarios have much lower release and consequence levels than the WCS.

The PHMSA WCS – PHMSA defines a WCS as shown below. This definition is used by owner/operators to develop emergency response plans for regulatory approval. ***The approach defined by PHMSA is does not follow the hazardous industry approach for WCS, but it is consistent with an ARS for emergency response planning. Unfortunately, government officials, 1st responders and the general public often assume that the PHMSA definition identifies the WCS; it does not. It is the largest spill that the Emergency Response Plan should be capable of handling.***

The PHMSA definition also leaves a lot of discretion to the pipeline owner/operator. An owner/operator must determine the quantity escaping based on release time, shutdown time plus the amount of material that drains from the pipeline after shutdown. Contrary to industry practices for WCS identification, pipeline owner/operators take credit for active controls, SCADA control and material balancing systems, operator training, management procedures and even emergency response measures, such as vacuuming materials calculated to be remaining in the pipeline. This approach is unacceptable in EPA, OSHA, DHS and NRC worst-case scenario determinations, but it is not for determining an ARS. The PHMSA Worst-Case Discharge is an alternate planning scenario and not a WCS as practiced by risk management professionals.

PHMSA WCS - Department of Transportation (DOT) and their Pipeline and Hazardous Materials Safety Administration (PHMSA)

Response Plans for Onshore Oil Pipelines 49 CFR 194 - Department of Transportation (DOT) and their Pipeline and Hazardous Materials Safety Administration (PHMSA) -

49 CFRR 194.105 Worst-Case Discharge

(a) Each operator shall determine the worst-case discharge for each of its response zones and provide the methodology, including calculations, used to arrive at the volume.

(b) The worst-case discharge is the largest volume, in barrels (cubic meters), of the following:

(1) The pipeline's maximum release time in hours, plus the maximum shut-down response time in hours (based on historic discharge data or in the absence of such historic data, **the operator's best estimate)**, multiplied by the maximum flow rate expressed in barrels per hour (based on the maximum daily capacity of the pipeline), plus the largest line drainage volume after shutdown of the line section(s) in the response zone expressed in barrels (cubic meters); or

(2) The largest foreseeable discharge for the line section(s) within a response zone, expressed in barrels (cubic meters), based on the maximum historic discharge, if one exists, **adjusted for any subsequent corrective or preventive action taken**; or

(3) If the response zone contains one or more breakout tanks, the capacity of the single largest tank or battery of tanks within a single secondary containment system, adjusted for the capacity or size of the secondary containment system, expressed in barrels (cubic meters).

(4) Operators may claim prevention credits for breakout tank secondary containment and other specific spill prevention measures as follows:

Prevention measure	Standard	Credit (percent)
Secondary containment > 100%	NFPA 30	50
Built/repaired to API standards	API STD 620/650/653.	10
Overfill protection standards	API RP 2350	5
Testing/cathodic protection	API STD 650/651/653.	5
Tertiary containment/drainage/treatment	NFPA 30	5
Maximum allowable credit		75

The Enbridge / PHMSA Scenario

The assumptions and approach used by Enbridge to calculate their scenario follows PHMSA regulatory requirements as outlined in the regulations, above and Enbridge's redacted emergency response plan (3). Details on the assumptions and calculations are not provided as Enbridge and PHMSA claim that the information is sensitive security information and protected from public disclosure. Under other regulatory regimes, this protection is normally not allowed for information that was publically available to the public prior to the 9-11 terrorist attack. For example, information submitted to the EPA by regulated owner/operators to meet the Clean Air Act Risk Management Rule requirements was removed from the Internet but the public can still review it by signing in at "EPA reading-rooms". This procedure maintains the citizen's right-to-know provisions and provides some level of security. However, Enbridge at public forums has disclosed enough information that the main elements of their scenario can be analyzed. (16)

Assumptions & Basis for the Enbridge Scenario – At a conference sponsored by the Tip of the Mitt Watershed Center in Petoskey Michigan on August 27, 2015 an Enbridge representative presented information on the scenario: (16).

- Size of the crude oil release 4,500 bbl

- Failure is a guillotine cut to one of the 20 inch pipelines
- Supervisory control and data acquisition (SCADA) control and material balancing systems alert control center personnel
- Personnel take action within the 10 minute procedure decision time
- Operator use remote control to close block valves
- The valves close in 3 minutes, slow to prevent hydraulic hammer
- Total operating flow time from discovery to shutdown is 13 minutes
- Amount of crude oil drain-down after shutdown per owner/operator judgment – by calculation method, the pipeline was divided into segments that would or would not leak based on the specific gravity of the crude oil being less than water and that the water pressure at depth in the Straits would prevent the crude oil from leaking from the ruptured pipeline.
- Then, emergency response crews would insert a tube from shore and pump the crude oil out of the underwater pipeline in the segments where it is held back by water pressure.

Back calculating from a release quantity or 4,500 bbl. (189,000 gal.) and assuming the pipeline is operating at capacity (540 bbl./day divided by 2 for one 20" pipeline), a 13-minute period would release 2,438 bbl. This leaves the expected drain-down to be 2062 bbl. For the scenario to achieve only a 4,500 bbl. release quantity, it assumes design performance of all active controls (alarms, SCADA, electrical, mechanical, procedural and training) and unbelievably, theoretical emergency response.

Assuming perfect performance of all systems is not allowed in other regulatory regimes for the WCS. For example, the Enbridge Line 6B failure events at their operations center in Calgary where the optimal "near instantaneous shutdown" as described in Congressional testimony by Enbridge 10 days prior to the rupture, turned out to be a PHMSA described Keystone Cops debacle of 17 hours. Similar events occurred with the Santa Barbara crude oil pipeline spill in 2015 and the Colonial gasoline pipeline leak in 2015.

Worst-Case Scenario, Are There 2, a Major Breach & Undetected Leak?

This report provides two credible WCS's: 1) a release based on a major failure that would be immediately detected and 2) a leak with a flow rate just below the detection threshold for the SCADA and material balancing systems.

Major failure – Alarms, the SCADA and material balancing systems, pump failure alarms immediately alert operating personnel to a major failure. The following assumptions are used to calculate the WCS scenario:

- Both 20" pipelines fail or are cut:

- There are identified threats that could cause a double breach
- In addition, as both lines are connected as one system, engineering principles and other regulatory regimes would count the quantity in both pipelines even if only one were breached.

- SCADA and material balancing systems immediately alert control center personnel.
- Remote operated valves and shutdown systems do not work as they are active control measures.
- Remote valves must be manually closed. A two (2) hour response time is used as noted by Enbridge represented in public information. This is an active measure; personnel live in the St. Ignace area. It can be argued that in bad weather conditions, the response time may be longer.
- Assume full flow for 2 hours.
- It can be argued that the pumps will go down. In this case if there are NGL's in the line upstream, the depressurization will result in the NGL's expanding and driving crude oil down the line to the failure point under 2-phase flow. The amount driven by this mechanism could far exceed a 2-hour shutdown flow.
- The quantity of crude oil released after manually closing the valves is the volume of both pipelines. Retention of a large quantity of crude oil within the pipelines for later recovery is not counted. This assumption is not allowed under other regulatory regimes and questionable in practice. Backpressure and specific gravity differences are NOT secondary containment - only permanent fixed structures are secondary containment.

Assuming operation at capacity (540 bbl./day), a 2-hour release is 45,000 bbl. The quantity that is contained in the pipelines in the Straits is 15.6 bbl. for a **WCS of 61,000 bbl.**

These assumptions can be debated and adjusted up or down but the result still is that the WCS calculated using risk management and other regulatory regime assumptions is greater than 10 times larger than the Enbridge/PHMSA approved Emergency Response Planning Scenario or worst-case discharge which is often mistakenly referred to as the WCS.

The "Black Swan" or "Perfect Storm" Scenario

Research and assessments continues to be done on the failures of traditional risk analysis approaches. (9) Major incidents in the nuclear, chemical, oil & gas, refining, and transportations industries have occurred and later deemed to be the result of a failure to properly identify and analyze risk (consequences, vulnerabilities, threats).

"Black Swan" and "Perfect Storm" scenarios are often discussed after a major incident and then critiques begin on how risk managers should have predicted the incident and taken action beyond the minimum regulatory requirements to protect human health, safety, the environment and economy. Too often studies quickly deep-dive into quantitative, mathematical exercises without getting the scope and assumptions correct at the start of the analysis. The results are a major failure possibly even a Black Swan or Perfect Storm event that could have been foreseen or at least considered. The State of Michigan in its request for comprehensive risk and alternatives analysis is not required to follow regulatory definitions but the public trust doctrine and the iconic nature of the Straits requires that they approach WCS analysis from recognized risk management and "black swan –perfect storm "perspectives.

A "perfect storm" for Line 5 is a major pipeline failure during a major weather event with the resultant power and system failures. It can be argued that emergency generators operate (active controls) and pumps shutdown or fail. However, the pipeline also transports large quantities of NGL's, which are liquids under transport conditions but a gas under atmospheric pressure or the pressure at the bottom of the Straits. A line failure would result in the pipeline de-pressuring and the NGL's expanding (phase transition from a liquid to a gas). The resulting expansion would push crude oil downstream to the rupture point through open or partially shut valves. Rapid two-phase (gas-liquid) flow would occur. This is analogous to shaking up a bottle of champagne and then popping the cork. Depending on the assumptions for the location of the NGL's in Line 5 and how many miles of crude oil are between the NGL's and the pipeline failure point; the amount of crude oil released could be orders of magnitude greater than the worst-case described above.

The Undetected Leak

SCADA and computer-based material balancing systems have limitations on accuracy. The limitations are the result of the inherent capabilities and the technologies and electronics of the system components. The typical accuracy for these systems in the chemical and refining industry is 1.0% to 1.5%. Enbridge has claimed that 3,350 bbl. could be leak undetected by their system which is 0.62% accuracy.[1] The lower detection limit is assumed to be "best-in-class"; however, the release quantity is still quite large.

Discovery by private citizens is historically the means of detecting slow leaks and even large ones where the SCADA and material balance systems fail to alert operators or when operators make wrong decisions. A release at the bottom of the Straits could run for many hours and days before being detected by a private citizen, for example walking on the beach. A one-week duration would result in a spill of 23,450 bbl. Spill durations of 30, 60 and even 90 days can be envisioned depending on the time of the year (winter ice cover), crude oil "weathering phenomena" (agglomeration with particulates and dispersion to Lakes Michigan and Huron in the water column, below the surface), shoreline impact in areas not frequented by the public and etc.

Dispersion Modeling

This study does not address the dispersion and shoreline impact of the WCS release quantities. However, Dr. David Schwab as the University of Michigan modeled several release scenarios.

[1] Correspondence from Enbridge (Brad Shamla) to Attorney General Bill Schuette and DEQ Director Dan Wyant, February 27, 2015, Item 14.
http://www.michigan.gov/documents/deq/Appendix_B.6_493994_7.pdf

The largest release was 25,000 bbl. (1,050,000 gallons) which is approximately the quantity released in 2010 from the Enbridge Line 6B failure in the Kalamazoo River watershed. This release impacted approximately 700 miles of lake shoreline. This report concludes that the potential release for a catastrophic failure of Line 5 could 2.5 times larger, shoreline impact is unknown and that for a slow leak potentially even larger depending on time to detection.

CONCLUSIONS

The State of Michigan does not have a worst-case release scenario in-hand to assess the consequences of a Line 5 failure.

The WCS must be based on risk analysis approaches that only allow release reduction credits for passive control measures. The WCS scenario and its communication to the citizens of the State of Michigan are vital to establish whether continued operation of Line 5 is acceptable. The Enbridge/PHMSA worst-case discharge scenario is not a true WCS analysis and should not be viewed as such.

There are two potential worst-cases, 1) catastrophic failure and release and 2) slow undetected leak for an extended period of time. For comparison:

> **Enbridge/PHSMA Worst-Case Discharge = 4,500 bbl**
>
> **FLOW Worst-Case Scenario = 61,000 bbl**
>
> **Flow Undetected Slow-Leak Scenario = would exceed the Flow WCS in 20 days**

Recommended Reading

Niklas Möller and Per Wikman-Svahn , "Black Elephants and Black Swans of Nuclear Safety", *Ethics, Policy & Environment*, 14:3, 273-278, DOI: 10.1080/21550085.2011.605853, 2011. http://dx.doi.org/10.1080/21550085.2011.605853

This article is recommended reading because it provides a broad outline on risk management failures that can be applied to all high hazard industries, including pipelines. It is a short and worthwhile read.

> *This leads us to highlight another concept that we believe is important in order to understand and to prevent hazards: the 'black elephant', which is similar to a black swan, but like the 'elephant in the room' is visible but largely ignored (Gupta, 2009). We define a black elephant as: (i) a high-impact event, that (ii) lies beyond the realm of regular expectations, but (iii) is ignored despite existing evidence.*

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