LINE 5 WISCONSIN SEGMENT RELOCATION PROJECT

Probability of Failure Analysis

For Enbridge Energy, Limited Partnership

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EXECUTIVE SUMMARY

DNV GL USA, Inc. (DNV) was tasked by Enbridge Energy, Limited Partnership (Enbridge) with examining the probability of a failure (POF) of the Line 5 Wisconsin Segment Relocation Project. Publicly available failure data, as well as DNV's proprietary probabilistic risk model, were utilized to estimate the POF of a failure along the mainline pipe for the proposed route, as well as various alternatives (RA-01, RA-02, and RA-03). The POF of a pipeline failure of horizontally directional drilled (HDD) water crossings as well as open cut water crossings were also calculated. For each failure estimation, the probability of various spill volumes was also calculated. Enbridge's construction standards and integrity management program preventive measures were considered in the analysis.

This report reaches the following conclusions:

It is estimated that the POF, considering all commodities transported, for the Line 5 Wisconsin Segment Relocation Project for the proposed route is 3.96x10-6 failures per mile per year for all release sizes, and the POF of a full-bore rupture is 6.34x10-8 per mile per year. This is equivalent to the extremely remote probability of a failure occurring somewhere on a given mile of pipe of 1 in 252,000 and a full-bore rupture of 1 in 15,700,000 for any given year.

It is estimated that the POF for a release of NGLs for the proposed route is 6.34x10-7 failures per mile per year for all release sizes and the POF of a full-bore rupture in NGL service is 1.01x10-8 per mile per year. This is equivalent to the extremely remote probability of a failure occurring somewhere on a given mile of pipe of 1 in 1,580,000 and a rupture of 1 in 99,000,000 in any given year.

The POF of any size release at the Bad River ranges from 1.25x10-7 to 4.59x10-7 depending on the route, and at the White River ranges from 2.92x10-7 to 8.34x10-7 depending on the route. The POF of any size release at any other water body crossed by the relocation using a shorter HDD is estimated to be lower than those predicted for these crossings. The POF of a release greater than 334 barrels at the Bad River Crossing ranges from 2.14x10-8 to 7.85x10-8 per year depending on route. The POF of a release greater than 334 barrels at the White River Crossing ranges from 4.99x10-8 to 1.43x10-7 per year depending on route. The overall POF for any release in a waterbody crossed by the relocation is extremely remote, in all cases less than 1 in 6,990,000 in any given year.

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1 INTRODUCTION

DNV was tasked by Enbridge with examining the POF of the Line 5 Wisconsin Segment Relocation Project (Line 5 Relocation Segment). The project is a relocation of approximately 41 miles of pipeline around the Bad River Reservation in Ashland, Bayfield, and Iron County, Wisconsin. DNV evaluated the POF of the mainline pipe along the proposed route, as well as for the three alternate routes (RA-01, RA-02, and RA-03). The POF of a pipeline failure of an HDD water crossing represented by the Bad River and White River crossings, as well as open cut water crossings, were also calculated. For each failure estimation, the probability of various spill volumes was also calculated.

2 BACKGROUND

Enbridge's Line 5 pipeline, in operation since 1953, runs from Superior, Wisconsin to Sarnia, Ontario as a single 30-inch nominal diameter pipeline. Line 5 transports light crude oil and natural gas liquids (NGL) in batches of various quantities. Crude oil is shipped in batches of similar products, while NGL batches transported through Line 5 are a combination from several sources that are blended within common storage at the Superior Terminal. The exact composition of the crude oil and NGL will vary from batch to batch. NGLs constitute approximately 16% of volumes shipped on Line 5.

The proposed route is approximately 41 miles in length. It is expected to require 13 locations of HDD crossings, and 10 miles where rock blasting may be required. The alternate route, RA-01, is 31.4 miles in length, alternate route, RA-02, is 58.0 miles in length, and alternate route, RA-03, is 101.6 miles in length with varying numbers of HDD crossings and rock ditch.

The Line 5 Relocation Segment is expected to be 30-inch nominal diameter, 0.500-inch wall thickness, grade X70 line pipe manufactured to American Petroleum Institute (API) specification API 5L X70 PSL2 and Enbridge specifications. The pipe is expected to have a double submerged arc weld (DSAW) long seam with a seam factor of 1.0. The overall design factor for the pipeline is 0.72 with a maximum operating pressure (MOP) of 1,440 psig. The pipeline will be coated with fusion bonded epoxy (FBE) and additional abrasion resistant overlay (ARO) coating in the HDD sections. The pipeline will be buried to a depth of four feet except in areas of rock ditch and where the pipe is installed via HDD.

Once completed, the Line 5 relocation will be operated and maintained in accordance with Enbridge's integrity management program, which is developed and administered in accordance with Pipeline and Hazardous Materials Safety Administration (PHMSA) regulations at 49 C.F.R. Part 195.

3 SCOPE OF WORK

DNV was tasked by Enbridge with examining the POF of the 30-inch Line 5 Wisconsin Segment Relocation Project. The POF of the mainline pipe was calculated for the proposed route, as well as for the alternate routes. DNV calculated the POF based on the threats identified in American Society of Mechanical Engineers (ASME) Standard B31.8S. Additionally, the probability of a pipeline failure occurring at specific water crossings was determined for each pipeline route. The probability of release for various spill sizes was also calculated.

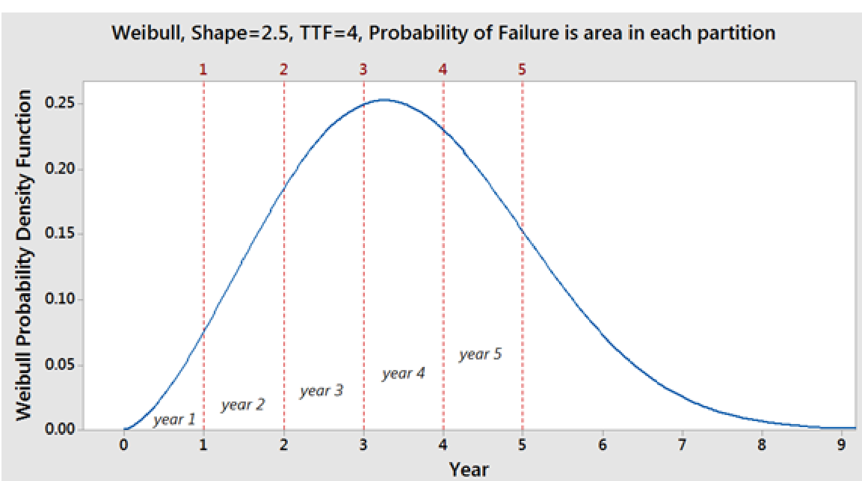
3.1 Probability of Failure Estimation

The probability of pipeline failure was calculated based on the pipeline threats identified in ASME B31.8S. The threats considered are as follows:

- External corrosion
- Internal corrosion
- Stress corrosion cracking (SCC)
- Manufacturing defects and pressure cycle fatigue
- Welding/fabrication defects
- Third party damage (mechanical damage)
- Incorrect operations
- Weather related and outside force
- Vandalism and theft

All threats were assigned a POF and no threat was assigned a POF of zero.

The probability of pipeline failure for all threats other than manufacturing defects and welding/fabrication defects were calculated based on DNV's proprietary pipeline probabilistic risk model. DNV's risk model takes into account the pipeline design (i.e., diameter, wall thickness, coating type, grade, etc.) and operating characteristics (i.e., operating pressure), as well as information regarding land use, crossings, etc. Various public data sources are used to populate threat variables such as earth movement, climatological impact, soil characteristics, and waterway characteristics. For time-based threats such as external corrosion, internal corrosion, and SCC a remaining life is calculated. A Weibull function analysis is then performed to convert expected remaining life to annual probabilities. The Weibull analysis incorporates a shape factor which creates the shape of the failure distribution based on historic industry failure patterns. This is commonly referred to as the "bathtub curve" affect associated with new or aging pipelines. For a hypothetical estimated remaining life of 4 years (TTF=4), the hypothetical plots below computes the Weibull probability of failure based on a shape factor (β=2.5). The current POF is the area under the curve between year 0 and 1. Note: The POF in the plots below has been assigned a random value for illustration purposes. Additionally, these curves can also be utilized to project risk into future years as illustrated by the year 1 through 5 designations.



For time independent threats such as mechanical damage, weather related and outside force, which can vary based on location and land use, the POF was calculated based on industry data and the estimated mileage of each land-use type.

DNV's risk model also takes into account preventive measures that are included in the pipeline design or planned in the Integrity Management Plan for each threat. These include but are not limited to additional pipe wall thickness, depth of cover, and coating selection.

For manufacturing defects (considering pressure cycle fatigue) and welding/fabrication defects, the POF was estimated using publicly available PHMSA reportable incident data[1] for hazardous liquid pipelines. The data was sorted for similar pipeline configurations, vintage, size, and operation as the Line 5 Relocation Segment project (e.g., sorted by modern, large diameter pipe). These data were utilized to establish a conservative or upper bound of a POF for modern pipeline construction. It must be noted that these POFs are not considered to be the actual failure rate as they do not necessarily account for all of the preventive measures that Enbridge may implement during the design, construction, and operation of the Line 5 Relocation Segment to prevent a failure, including measures taken under Enbridge's Integrity Management Plan. These measures include but are not limited to;

- Operational pressure cycle monitoring
- Oil temperature monitoring and mitigation
- Baseline ILI inspection within one year of commissioning
- Post construction in-situ coating condition survey
- Route geotechnical and aquifer surveys
- Construction quality management system implementation
- Traceability database for all installed pipe

A mitigation reduction factor of 10 (i.e., a reduction of one order of magnitude) was applied to the failure rates calculated from PHMSA data in order to account for these measures.

The results from both DNV's proprietary model and those calculated using PHSMA data were then aggregated to determine a POF per mile per year. The probability of a failure occurring during NGL service was also calculated as described in subsequent sections below.

[1] https://www.phmsa.dot.gov/data-and-statistics/pipeline/distribution-transmission-gathering-lng-and-liquid-accident-and-incident-data

3.2 Probability of Spill Volume

The probability for various spill volumes was calculated utilizing PHMSA data to calculate percentages of failures for different spill size ranges. These percentages were then applied to the calculated pipeline POF (as described in the previous section) in order to determine a probability for each range of spill volumes. The ranges of spill volumes considered correspond to Recent Average Release Volumes (RARV) and Historic Accident Release Volumes (HARV), and are as follows:

- Overall Releases
- >334-1911 barrels
- >1911 - <8517 barrels (less than rupture)
- Full bore rupture

3.3 Probability of Failure at Water Crossings

The in-service POF was calculated for HDD water crossings using the approach described in Section 4.1. The POFs for the Bad and White River HDD crossings were calculated to provide an upper bound for a release that directly enters a large waterway. The probability range associated with other HDD watercourse crossings is dependent on the direct impact length of the crossing and is expected to be less than the POF at the Bad and White rivers. The length of HDD that crosses the waterway valley and can directly impact the waterway is different for each of the Bad and White River crossing; therefore, the POF varies for each route.[2] Additionally, the POF was calculated for multiple lengths of an open cut waterbody crossing for comparison. The POF of individual crossings can be extrapolated from the HDD or open cut POF based on method of construction and relative length of each crossing.

The probability of a release was then determined by multiplying each probability of failure by the percentage distribution of spill volumes (as described in Section 4.2). The probability of release by crossing by spill size is summarized in Tables 1 through 3. The probability of a spill occurring decreases sharply with increased spill size.

Table 1. Bad River Crossing (probability of release per year)

	Proposed	RA-01	RA-02
Overall[3]	$1.53\text{x}20^{-7}$	$4.59\text{x}10^{-7}$	$1.25\text{x}10^{-7}$
>334 barrels	$2.62\text{x}10^{-8}$	$7.85\text{x}10^{-8}$	$2.14\text{x}10^{-8}$
>1911 barrels	$1.02\text{x}10^{-8}$	$3.07\text{x}10^{-8}$	$8.37\text{x}10^{-9}$
Full bore rupture	$2.45\text{x}10^{-9}$	$7.34\text{x}10^{-8}$	$2.00\text{x}10^{-9}$

[2] RA-03 contains no crossings of the Bad or White Rivers so no POF was calculated for this route.

[3] Overall results are the probabilities of failure considering all commodities transported and all spill volumes considered.

Table 2. White River Crossing (probability of release per year)

	Proposed	RA-01	RA-02
Overall	$8.34x10^{-7}$	$3.89x10^{-7}$	$2.92x10^{-7}$
>334 barrels	$1.43x10^{-7}$	$6.66x10^{-8}$	$4.99x10^{-8}$
>1911 barrels	$5.59x10^{-8}$	$2.61x10^{-8}$	$1.96x10^{-8}$
Full bore rupture	$1.33x10^{-9}$	$6.23x10^{-9}$	$4.67x10^{-9}$

Table 3. Generic Open Cut Crossing (probability of release per year)

	295 feet	1083 feet	1968 feet
Overall	$5.01x10^{-7}$	$8.35x10^{-7}$	$1.21x10^{-6}$
>334 barrels	$8.57x10^{-8}$	$1.43x10^{-7}$	$2.07x10^{-7}$
>1911 barrels	$3.36x10^{-8}$	$5.60x10^{-8}$	$8.11x10^{-8}$
Full bore rupture	$8.02x10^{-9}$	$1.34x10^{-8}$	$1.94x10^{-8}$

3.4 Probability of Failure for the Pipeline

The overall POF for each of the proposed pipeline routes was calculated for the entire route. The POF is then converted to a per mile basis for direct comparison. The POF for each route includes the total number and type of all pipeline crossings along the route. The POF of the overall route is greater than the POF of the worst-case water crossing which reflects the additional preventive measures incorporated into water crossing designs. The probability of failure overall as well the probability of release of larger volumes (>334 barrels) for each route are summarized in Table 4.

Table 4. Pipeline Route (probability of failure per mile per year)

	Proposed	RA-01	RA-02	RA-03
Overall[3]	$3.96x10^{-6}$	$1.02x10^{-5}$	$8.92x10^{-6}$	$3.85x10^{-6}$
>334 barrels	$6.78x10^{-7}$	$1.74x10^{-6}$	$1.53x10^{-6}$	$6.58x10^{-7}$
>1911 barrels	$2.66x10^{-7}$	$6.83x10^{-7}$	$5.98x10^{-7}$	$2.58x10^{-7}$
Full bore rupture	$6.34x10^{-8}$	$1.63x10^{-7}$	$1.43x10^{-7}$	$6.16x10^{-8}$

3.5 Probability of Pipeline Failure in NGL Service

The POF in NGL service for the proposed pipeline routes were calculated on a per mile basis for direct comparison. The difference in threats associated with NGL service would be expected to vary with changes in operating conditions such as pressure, pressure cycles, and corrosivity of the product. However, a review of PHMSA accident data for pipelines that transport multiple batched products including NGLs and refined products was inconclusive. No correlation between failure frequency and the transportation of NGLs versus lighter or heavier products was observed. Therefore, the probability of a failure occurring during NGL service is taken as the overall POF multiplied by the percentage of NGL transported which is approximately 16%. The overall probability of failure in NGL service overall as well the probability of release of larger volumes (>334 barrels) for each route are summarized in Table 5.

Table 5. Pipeline Route in NGL Service (probability of failure per mile per year)

	Proposed	RA-01	RA-02	RA-03
Overall	$6.34x10^{-7}$	$1.63x10^{-6}$	$1.43x10^{-6}$	$6.16x10^{-7}$
>334 barrels	$1.10x10^{-7}$	$2.78x10^{-7}$	$2.45x10^{-7}$	$1.05x10^{-7}$
>1911 barrels	$4.26x10^{-8}$	$1.09x10^{-7}$	$9.57x10^{-8}$	$4.13x10^{-8}$
Full bore rupture	$1.01x10^{-8}$	$2.61x10^{-8}$	$2.29x10^{-8}$	$9.86x10^{-9}$

4 CONCLUSION

DNV was tasked by Enbridge with examining the POF of the Line 5 Wisconsin Segment Relocation Project. PHMSA data and DNV's proprietary probabilistic risk model were utilized to calculate the POF of the mainline pipe for the proposed route, as well as the alternate RA-01, RA-02, and RA-03 routes. Additionally, the POF for a release of NGLs was calculated. Finally, the POF for the Bad River and White River HDD crossings and open cut crossings were calculated to provide an upper bound POF for all water crossings. The probability of various release volumes from the resultant failures was also calculated.

It is estimated that the POF, considering all commodities transported, for the Line 5 Wisconsin Segment Relocation Project for the proposed route is 3.96x10-6 failures per mile per year for all release sizes and the POF of a full-bore rupture is 6.34x10-8 per mile per year. This is equivalent to the extremely remote chance of a failure occurring somewhere on a given mile of pipe of 1 in 252,000 and a full-bore rupture of 1 in 15,700,000 for any given year.

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