# Risk of Dangerous Goods Spills in Abegweit Passage: Ferry Versus Bridge Crossing

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The relative risks of hazardous material spills in the 13-km-wide Abegweit Passage between Prince Edward Island and mainland Canada are analyzed, and counteractive measures are discussed for an existing ferry crossing and an alternative link by a bridge. The spills can originate from trucks hauling dangerous goods on board ferries or over the bridge, ships involved in collisions with the ferries or in strikings of the bridge piers, and ferry or bridge maintenance operations. A methodology is developed for the analysis of the marine spill risks associated with the vessel traffic stream crossing (a) a ferry route and (b) a bridge line. Because study-specific data are available neither on spill sizes nor on the conditional probability of a release from a vessel or truck damaged in an accident, an upper bound of probabilities and sizes of spills is estimated. The analysis results represent current traffic volumes and makeup of dangerous goods shipments. They do not reflect possible effects of future legislative, technological, and operations management changes that will undoubtedly aim at preventing and countering the effects of spills. Petrochemical products are the most likely spill commodity, and the potential size of a spill is similar for the two transportation alternatives. The return periods are orders of magnitude higher for the ferry than for the bridge. The return periods and sizes of spills can be improved by instituting traffic management systems for vessels and trucks. Bridge and waterborne emergency response, containment of spills in the bridge drainage system, and more stringent operating and maintenance procedures should reduce the volume of hazardous materials spilled into the water.

Prince Edward Island (PEI) has been linked to mainland Canada by a ferry service provided by the federal government since 1876. The service is subject to disruptions due to inclement weather and technical problems, delays during the peak season, and escalating operating costs. Private-sector groups expressed interest in providing a Northumberland Strait crossing that would offer improved transportation. Out of numerous proposals submitted by private consortia to Public Works Canada (PWC), three bridge options remained by September 1988.

The analysis presented addresses spills from dangerous goods transportation over a proposed generic bridge compared with the existing ferry crossing. The study focuses on the transportation risks of spills that might affect the biophysical environment. The actual consequential risks of such events in terms of environmental impact were not analyzed. Risks arising in the construction phase of the bridge were also excluded.

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## MARINE ENVIRONMENT

Environmental acceptability was one of the principal considerations in assessing the viability of the crossing proposals (*1*). The marine ecosystem is susceptible to damage resulting from an accidental spill of dangerous goods. The strait is one of the richest fishing areas in Atlantic Canada, and tourism is PEI's second most important industry.

Spills would have direct, measurable effects on the fisheries and tourism. Long-term effects on the local ecosystem would also be significant. Recognizing these risks, PWC requested that all bridge proposals outline an environmental protection plan that specifies mitigating, monitoring, and contingency-planning activities to deal effectively with possible discharge of hydrocarbons and other hazardous materials into the marine environment.

The marine environment is challenging to both bridge construction and vessel traffic year round. Sea ice conditions in the Northumberland Strait pose the most difficult winter navigation in southern Canada. Sea currents and tides in the strait are strongest in the Abegwait Passage. Adverse marine conditions aggravate the risk of marine accidents in the vicinity of bridges (*2,3*). Winds, fog, snow, and ice affect the safety of vehicular traffic on a bridge. The elements would also hamper any spill containment and cleanup attempts.

## EXISTING FERRY CROSSING

The bridge alignment would be close to the existing ferry route between Port Borden, PEI, and Cape Tormentine, New Brunswick (Figure 1). Four ferries (Table 1), owned and operated by Marine Atlantic, make a total of almost 12,000 trips per year on a continuous schedule year round. Sailing frequency is lower in the winter months (Table 2). The average crossing time is 100 min, which includes waiting and boarding time.

In 1989, the ferries carried 687,000 passenger vehicles and 153,000 commercial vehicles both ways over the strait, yielding an average of 68 vehicles per sailing. Because of the increase in visitors during summer months, about 40 percent of the total annual passenger vehicle traffic is transported across the strait in July and August. Operating expenses amounted to almost $35 million, 60 percent of which were federal subsidies.

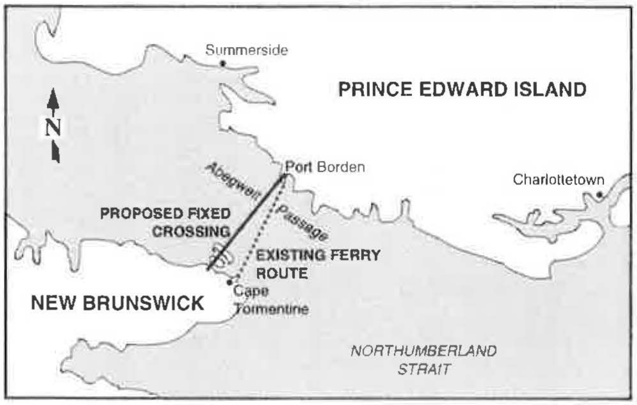


**FIGURE 1 Location map.**

In 1954, one crossing per week was introduced for the segregated transportation of trucks hauling dangerous goods. At present an average of five such sailings are made weekly.

## PROPOSED BRIDGE

The crossing is considered one of Canada's most challenging engineering projects of the century. The structure would be one of the longest highway bridges in a marine environment anywhere in the world. It would span 13 km of the Northumberland Strait at its narrows, called the Abegweit Passage, where the deepest water is 36 m.

Because of the length of the crossing, the bridge design involves a large number of low-level spans supported in concrete piers spaced at 200 m. A vertical clearance of 28 m would allow for safe passage of recreational and fishing craft. One elevated main span with a 200-m-wide by 49-m-high clearance would accommodate oceangoing vessels. Aberrant vessels exceeding 28 m air height would strike the side spans with their masts and other upper parts. Whereas these accidents would not directly damage the hulls, subsequent vessel behavior may lead to striking of the side piers and to spills.

The navigation channel would be located closer to the island than to the mainland, because most of the ports in the strait are on the PEI side. Also, this side of the strait experiences more open water and less severe ice in winter. The piers adjacent to the navigation channel would be protected from vessel impacts by islands.

The bridge deck would be 11 m wide between New Jersey-type barriers. This width would accommodate two lanes satisfying requirements for driver safety and comfort and would allow for shoulders that could be used for emergency access, parking of stalled vehicles, and maintenance operations. A median crash barrier would also be provided to enhance bridge user safety.

TABLE 2 FERRY SAILING FREQUENCY

| Period | No. of Ferries | One-way Trips/Day |
|---|---|---|
| December-April | 2 | 12 |
| May-June | 3 | 16 |
| July-August | 3 | 22 |
| September-mid October | 3 | 16 |
| Mid October-November | 2 | 14 |

The new bridge would divert traffic, particularly trucks, from the nearby Caribou–Woods Islands ferry service. Traffic would also increase by an induced amount. The traffic capacity of the proposed bridge is estimated at 2,000 vehicles per hour. The total crossing time would be 15 min one-way. The trucking industry alone anticipates annual savings of $5 million to $8 million from reduced travel time.

## DANGEROUS GOODS

Spills of the following dangerous goods can occur in the study area:

- Hazardous freight carried by trucks, either on board a ferry or over the bridge;
- Hazardous cargo on board marine traffic through the passage; and
- Propulsion fuel supply contained in fuel tanks of ferries and all vessels passing through.

### Hazardous Freight Carried by Trucks

A total of about 9,200 shipments of dangerous goods were carried by truck on board the special ferry sailings in 1988. The shipments comprised at least 150 different types of substances, of which only nine were selected for analysis on the basis of one or more of three criteria: high hazard to the marine environment, large relative shipment size, and large relative number of shipments.

Typical shipments in 1988 of the selected nine hazardous substances by truck on board the ferries are summarized in

TABLE 1 FERRY VESSEL CHARACTERISTICS

| Characteristics | Abegweit | Holiday Island | John Hamilton Gray | Vacationland |
|---|---|---|---|---|
| Ferry Type [a] | P/V/T | P/V | P/V/T | P/V |
| Delivery Year | 1982 | 1971 | 1968 | 1971 |
| Length Overall, m | 122 | 99.1 | 122 | 99.1 |
| Breadth, m | 21.5 | 20.9 | 20.4 | 20.6 |
| Draft Loaded, m | 6.17 | 5.05 | 6.20 | 5.05 |
| Maximum Speed, m/s | 9.21 | 8.75 | 9.21 | 8.75 |
| Economical Speed, m/s | 5.27 | 6.17 | 6.43 | 6.17 |

[a] P = passenger, V = vehicle, T = train Source: Marine Atlantic

Table 3. Spring and summer sample months have 40 to 50 percent more shipments than fall and winter months, which must be partly due to the reduced frequency of ferry sailings between October and May. Extrapolated over the full year, the total number of truck trips with the selected dangerous goods is 1,500.

Truck shipments of paint, corrosive liquids, and sodium hydroxide were the most frequent, but of small average size with a large variance. Half the shipments were paint, which is most likely to be packaged in small containers. The most probable packing of corrosive liquids and sodium hydroxide is drums.

Automotive and aviation fuels constituted the largest total quantities of dangerous goods and the largest shipment sizes, and they exhibited the smallest variance. This must be due to uniform capacity of tanker trucks used in fuel delivery.

### Hazardous Cargo on Marine Traffic

Table 4 gives total numbers of dangerous goods shipments on nonferry vessels through the crossing area between 1978 and 1986. As in truck transportation, the largest share is taken by petroleum products. No data are available to derive shipment sizes. Instead, vessels indicated in Table 5 were selected to represent shipment size and tank capacity.

### Vessel Propulsion Fuel

Fuel tank sizes of typical vessels in the strait are summarized in Table 6. Potential spills from ruptured fuel tanks of the vessels are small compared with tanker spills but large relative to the size of gasoline and aviation fuel shipments by truck.

## PROBLEM DECOMPOSITION

### Scenarios

Comparison of the risk of dangerous goods spills into the Northumberland Strait can be simplified into the following scenarios. For the ferry alternative, the scenarios are as follows:

TABLE 3 TYPICAL 1988 DANGEROUS GOODS SHIPMENTS BY TRUCK ON FERRY

| | January | May | August | October | Total |
|---|---|---|---|---|---|
| Petrol Gas (Transport Canada Class UN1075) | | | | | |
| n | 1 | 4 | 8 | 2 | 15 |
| sum | 50.0 | 100 | 257 | 75.0 | 482 |
| mean | na | 25.0 | 32.1 | 37.5 | 32.1 |
| cv | na | 100 | 32 | 33 | 52 |
| Gasoline (UN1203) | | | | | |
| n | 1 | 0 | 3 | 0 | 4 |
| sum | 0.06 | na | 49.3 | 90 | 49.4 |
| mean | na | na | 16.4 | na | 12.3 |
| cv | na | na | 90 | na | 118 |
| Paint (UN1263) | | | | | |
| n | 31 | 74 | 92 | 60 | 257 |
| sum | 11.2 | 28.3 | 25.3 | 13.0 | 77.8 |
| mean | 0.36 | 0.38 | 0.28 | 0.22 | 0.69 |
| cv | 222 | 272 | 149 | 126 | 227 |
| Petrol Distillates (UN1268) | | | | | |
| n | 0 | 5 | 4 | 1 | 10 |
| sum | na | 0.60 | 2.26 | 0.43 | 3.29 |
| mean | na | 0.12 | 0.56 | na | 0.33 |
| cv | na | 108 | 129 | na | 156 |
| Corrosive Liquids (UN1760) | | | | | |
| n | 34 | 31 | 23 | 22 | 110 |
| sum | 10.3 | 32.8 | 5.80 | 11.6 | 60.5 |
| mean | 0.30 | 1.06 | 0.25 | 0.53 | 0.55 |
| cv | 114 | 399 | 185 | 158 | 420 |
| Sodium Hydroxide Solution (UN1824) | | | | | |
| n | 28 | 14 | 15 | 11 | 68 |
| sum | 13.7 | 24.0 | 2.56 | 7.06 | 47.4 |
| mean | 0.49 | 1.71 | 0.17 | 0.64 | 0.70 |
| cv | 130 | 238 | 63 | 199 | 293 |
| Aviation Fuel (UN1863) | | | | | |
| n | 4 | 4 | 4 | 3 | 15 |
| sum | 172 | 185 | 180 | 132 | 669 |
| mean | 43.0 | 46.1 | 45.0 | 44.0 | 44.6 |
| cv | 0 | 43 | 7 | 2 | 24 |
| PCB (UN2315) | | | | | |
| n | 0 | 1 | 0 | 0 | 1 |
| sum | na | 0.14 | na | na | 0.14 |
| mean | na | na | na | na | na |
| cv | na | na | na | na | na |
| Pesticides (UN2783) | | | | | |
| n | 4 | 10 | 0 | 1 | 15 |
| sum | 25.2 | 34.0 | na | 0.03 | 59.2 |
| mean | 6.30 | 3.40 | na | na | 3.95 |
| cv | 175 | 173 | na | na | 192 |

n = total number of shipments; sum = total quantity shipped in tonnes; mean = mean shipment size in tonnes; cv = coefficient of variation in percent; na = not applicable
Source: Marine Atlantic records *(4)*

TABLE 4 DANGEROUS GOODS SHIPMENTS ON NONFERRY VESSELS

| Dangerous Goods | Number of Shipments 1978-86 | Number of Shipments Annual Average | Percent Total |
|---|---|---|---|
| Bunker C Oil | 6 | 0.7 | 3 |
| Diesel 32 Oil | 32 | 3.5 | 16 |
| Gasoline | 43 | 4.8 | 21 |
| Petroleum | 114 | 12.7 | 57 |
| Stove Oil | 4 | 0.5 | 2 |
| Unspecified | 2 | 0.3 | 1 |

Source: Vessel Traffic Services, Canadian Coast Guard. Data for vessel traffic through the crossing area *(5)*

TABLE 5 REPRESENTATIVE TANKER CARGO CAPACITIES

| Tanker Name | Size, GRT [a] | Capacity, tonnes | No. of Tanks | Tank Capacity tonnes | Tank Capacity $m^3$ |
|---|---|---|---|---|---|
| Irving Ours Polaire | 4,940 | 7,040 | 12 | 590 | 750 |
| Irving Nordic | 7,750 | 11,500 | 12 | 960 | 1200 |
| Irving Canada | 23,600 | 37,800 | 14 | 2700 | 3400 |

[a] GRT = gross registered tons Source: reference *(5)*

TABLE 6 FUEL TANK CAPACITIES OF REPRESENTATIVE VESSELS

| Vessel Name | Type, GRT[a] | Size, tonnes | Fuel Tank Capacity, tonnes |
|---|---|---|---|
| Point Viking | tug | 200 | 50 |
| Point Halifax | tug | 400 | 200 |
| Leslie Gault | freighter | 1600 | 206 |
| Soodoc | freighter | 4490 | 156 |
| Farnes | freighter | 8100 | 844 |
| Holiday Island | ferry | 3040 | 238 |
| Abegweit | ferry | 13500 | 182 |

[a] GRT = gross registered tons Source: reference *(5)*

1. Collision of through vessels with ferry,
2. Accidents during ferry sailings with hazardous material trucks on board, and
3. Ferry operational pollution.

For the bridge alternative the scenarios are as follows:

1. Striking of through vessels against bridge piers,
2. Hazardous material truck accidents on the bridge, and
3. Bridge operational pollution of the strait.

### Model and Data Compatibility

The preceding structuring of the problem exhausts all relevant spill risks. It permits a comparison of component risks for the alternatives without any loss of realism while using only limited data. Scenarios 1 and 2 involve similar potential consequences for each alternative, but the mechanisms leading to the occurrence of each of these scenarios are distinct for the two alternatives. Consequently, the method presented in this paper aims at developing a compatible measure of the chance of occurrence for each of the scenarios. That measure cannot rely too much on historical data, because such information is scarce and not directly related to the study project, especially for vessel encounters with ferries and bridges. Models fed by study-specific data would be preferable.

The probability of a hazardous cargo spill is the product of the probability of an accident and the conditional probability of a release given that an accident occurs. Data are limited concerning these probabilities for hazardous materials transportation on merchant vessels, ferries, and bridges. An upper bound approach based only on the unconditional probability of an accident was therefore adopted. Actual spill size is subject to similar analytical limitations.

### Counteractive Measures

Legislation, technology, and management of dangerous goods transportation can mitigate accidents and consequences of spills. Traffic management, with special attention to dangerous goods hauled by either land or water, has the largest potential in accident prevention. Remedial technology, such as double hull construction of tankers, is bound to reduce the probability of a release in the future. Contingency response can lessen the size of a spill and its adverse consequences, but the success of marine containment and cleanup operations depends heavily on favorable weather conditions.

These factors are not taken into consideration in the present analysis. Whereas their implementation will reduce the frequency and severity of spills, the relative improvement may be similar for each of the two transportation modes. The relative risk of one alternative compared with another would then not change.

## SCENARIO 1: THROUGH VESSEL COLLISION WITH FERRY OR BRIDGE PIER

### General Model

A general model for frequency of mishaps (*6,7*) serves both transportation alternatives:

$$Nc = k * N * Pa * Pg \quad (1)$$

where

- $Nc$ = number of vessels colliding with ferry or number of vessels striking bridge piers,
- $k$ = 0.5 for ferry and 1.0 for bridge,
- $N$ = annual average traffic volume of through vessels,
- $Pa$ = probability of aberrance of through vessels, and
- $Pg$ = geometric probability of contact of through vessels with ferry or bridge piers

Factor $k$ for collision with ferry reflects the fact that two ships are involved. Otherwise, the collision would be counted twice. $N$ and $Pa$ are identical for the two alternatives.

The model has been applied previously to the assessment of barge impacts on an urban arterial bridge (*2*), vessel impacts on the proposed Northumberland Strait bridge (*3*), and to vessel strikings of bridges in general (*8*). In any analysis using this model, $N$, $Pa$, and $Pg$ are specific to

- Vessel types in the traffic stream;
- Geographical region, as it determines marine environmental conditions and, partly, human behavior;
- Navigational aids systems in the region; and
- Geometry of the obstacle.

### Geometric Probabilities

As seen by through vessels, a ferry is a movable object crossing their path, and a bridge is a stationary object with multiple potential points of contact represented by piers.

#### *Collisions with Ferries*

The ferry traffic is converted into an equivalent solid object (*6*). The solid object becomes a target for the through vessels. The numerical result is the same if the through traffic is assumed to be the target of ferry attacks. From the geometry of a vessel crossing the ferry path,

$$Pg = Q * D/V \quad (2)$$

where

- $Q$ = number of ferry crossings per year,
- $D$ = equivalent width of contact of the two vessels involved in a crossing collision, and
- $V$ = ferry speed over ground.

For a ferry course perpendicular to the through traffic,

$$D = 0.707 * (Li + 2 * Lj) \quad (3)$$

where $Li$ = ferry length overall and $Lj$ through vessel length overall.

#### *Bridge Strikings*

For bridge strikings (*8*), $Pg$ is the sum of the geometric probability of striking main piers, $Pgm$, and the geometric probability of striking side piers, $Pgs$:

$$Pg = Pgm + Pgs \quad (4)$$

These probabilities are

$$Pgm = a * (Bm + w)/Lm \quad (5)$$

and

$$Pgs = b * (Bs + w)/Ls \quad (6)$$

where

- $a$ and $b$ = functions depending on closing distance of the vessel from the bridge
- $Bm$ and $Bs$ = main and side pier diameters,
- $Lm$ and $Ls$ = main and side span lengths, and
- $w$ = effective width of the vessel.

For the closing distance functions, $a$ and $b$ (*8*), the following averages in the interval from zero to one bridge length's distance are used:

| *Closing Distance* | *a* | *b* |
|---|---|---|
| 0.0–0.1 | 1.30 | 0.00 |
| 0.1–0.3 | 0.40 | 0.80 |
| 0.3–1.0 | 0.10 | 0.90 |
| Average | 0.28 | 0.79 |

### Ratio of Mishap Frequencies

One of the most difficult data items to obtain, and one of the most significant variables, is the aberrance probability, $Pa$ (*2,3,8*). In the present analysis, it may be sufficient to produce a ratio, $R$, of $Nc$ values calculated by Equation 1 for the bridge strikings and ferry collisions as follows:

$$R = V * (Pgm + Pgs)/(0.5 * Q * D) \quad (7)$$

Typical geometric data on ferries, tankers, and bridge piers and spans (*5*) were used. $R$ values of 54 and 36 were obtained for present ferry sailing frequency and for a projected 50 percent increase, respectively. These results mean that if similar consequences can be expected from spills associated with the two transportation alternatives, the bridge would be significantly riskier regarding tanker spills than the ferry.

### Return Periods and Consequences

#### *Return Periods*

The reciprocal of Equation 1 yields a return period of the encounters of through vessel traffic with ferries and bridge piers. The return periods for the total traffic and for laden tankers separately are summed up in Table 7.

$Pa$ = 0.00025 is used for both transportation alternatives. $D$ in Equation 3 is not sensitive to vessel type and is assumed to be 0.25 km for all vessel types. It is also assumed that ferries operate 20 hr/day and that all through traffic transits the area during ferry operating hours year round. For 24-hr operation of the through vessels, the return periods should be increased by a factor of 1.2.

#### *Consequences*

Scenario 1 will not involve the entire cargo contents of a vessel. Typical tankers in the area have six to seven cargo holds on each side (Table 5). Not more than two of these tanks can be ruptured in a collision with a ferry or in a bridge pier striking. The pessimistic prediction is then 2,400 to 10,800 tonnes of tanker cargo spilled at 500-year intervals due to bridge strikings. Similar spills would occur as a consequence of tanker collisions with ferries at 36 to 54 times longer intervals, depending on ferry sailing frequency.

Damage to fuel tanks of any vessel, including a ferry, is not likely, unless the penetration reaches into the double bottom, where fuel tanks are usually located. If every mishap resulted in fuel tank rupture, then a spill of 200 to 800 tonnes of diesel or heavy fuel would occur at 38-year intervals for the bridge alternative and at 1,300- to 1,900-year intervals, depending on sailing frequency, for the ferry alternative.

#### *Mitigation Measures*

The return periods could be reduced drastically if an effective vessel traffic management (VTM) system were instituted. The systems have proven effective in preventing potential accidents in waters with high traffic density (*7,9*). A reduction in aberrance resulting from such a system would lengthen the return periods. However, the ratio of mishap frequencies (Equation 7) would not change much if VTM were introduced with both transportation alternatives.

A full-scale VTM system covering Northumberland Strait is not justified for the present vessel traffic volume, but a scaled-down system is in order whether or not a bridge is built. On April 25, 1986, the *Holiday Island* nearly collided with a freighter in restricted visibility due to the ferry master's error. Ferries in the strait occasionally run aground or come close to collision when forced off course by fishing vessels on approaches to docks.

The following recommendations have been made to enhance the safety of vessels navigating under the bridge (*5*):

- Reduce two proposed navigation lanes under the bridge to one and schedule one vessel to pass the bridge at a time,
- Move the location of the navigation channel further offshore to give vessels more room to maneuver,
- Provide visual guidance by means of buoys fitted with radar reflectors to define the navigation channel and to assist vessels in lining up their final approach,
- Provide strobe lights marking the berms on either side of the navigation channel and a sector light on each side of the deck above the center of the channel to illuminate the approaches,
- Place low-intensity navigation lights on each pier or throughout the length of the bridge to assist the passage of small craft outside the main channel, and
- Maintain a traffic control center with radar and radio communication capability and restrict navigation during the ice season (January to April).

Some of these measures are limited by natural constraints. The channel location needs to be balanced against higher construction costs of main piers in deeper water and more difficult winter navigation further offshore. To ensure sufficient clearance for the buoy tenders working in the strong tides of the Abegweit Passage, it may not be possible to lay buoys close to the bridge. The buoys would be lifted for the winter season, and traffic would be rerouted north of the PEI or restricted to ice navigation only in good visibility.

## SCENARIO 2: HAZARDOUS MATERIAL TRUCK ACCIDENTS ON FERRY OR BRIDGE

The spectrum of possible spills from trucks would reflect the relative frequency of shipments by class of material, the size of shipment, and the type of packaging. According to Table 3, the most likely shipment is paint, but the quantity spilled would be small owing to the small average shipment size and the use of small containers for packaging. The largest possible spill would not exceed one truckload of fuel.

TABLE 7 RETURN PERIODS OF SCENARIO 1

| | | | | Return Period, years | | |
|---|---|---|---|---|---|---|
| | | | | Bridge | Ferry Collision | |
| Vessel Type | N | Pgm | Pgs | Striking | Q=12,000 | Q=18,000 |
| All vessels | 260 | 0.16 | 0.24 | 38 | 1,900 | 1,300 |
| Laden tankers | 18 | 0.17 | 0.28 | 500 | 27,000 | 18,000 |

## Ferry

The following events might lead to hazardous cargo release from a truck on board a ferry: rough seas; ferry grounding, sinking or foundering; ferry striking of a fixed object; ferry collision with another vessel; and on-board fire or explosion.

Fires or explosions on ferries are extremely rare events owing to stringent precautions. Dangerous goods ferry sailings could be canceled during inclement weather. Trucks could suffer damage on a grounded ferry. This happened recently in British Columbia when the grounded *Queen of Alberni* listed heavily once the tide ran out.

Vehicle tie-downs to the ferry deck could reduce the risk of truck damage in groundings or strikings of fixed objects. In a collision, however, the bow of the other vessel involved may penetrate the vehicle deck area, causing rupture of the tie-downs and direct damage to the trucks. Positioning of tank trucks on the inside lanes of the ferry deck and trucks with cargo in small containers on the outside lanes would solve the problem. The outside lanes could also be kept entirely clear of dangerous goods vehicles.

According to the records of the ferry operator, the only accidental release from a truck on board took place in 1954, in the first year of exclusive sailings for dangerous goods. The mishap probably occurred because of lack of experience. A tank of a tanker truck carrying gasoline was punctured in rough seas. It is now known whether or how much of the gasoline flowed overboard.

The single event is not a sufficient basis for calculating the frequency of mishaps occurring during hazardous materials sailings. Technology and procedures have improved substantially owing to environmental awareness and regulatory requirements of hazardous materials transportation. Also, because of lack of detailed historical records of the special sailings, it is not possible to relate the data to an objective measure of transportation productivity, such as vehicle-kilometers or tonne-kilometers.

An upper bound estimate of the return period of collision of hazardous material ferry with another vessel can be calculated from Equation 1. For two sailings per day, the return period is 30,000 years. A dangerous goods truck spill from such a collision would be even less likely, because the containers would have to be damaged and the hazardous material would have to find its way overboard.

## Bridge

Truck accident rates on the proposed bridge were estimated from the following rates at other locations (*4*): 0.787 accidents per million vehicle km (mvk) on the Mackinac Strait Bridge in Michigan (1986 to 1988), 0.697 accidents/mvk on the Seven Mile Bridge in the Florida Keys (1986 to 1988), and 0.946 accidents/mvk on two-way, controlled-access freeways in Nova Scotia (1978 to 1983). Data from these locations is not disaggregated as to type of vehicles involved, type of accident, and severity of accident. These figures represent upper bounds of hazardous cargo spill probabilities. Although estimates of 0.36 to 0.62 for the conditional probability of a release from a dangerous goods truck involved in a highway accident are available (*4*), these data have not been considered for analytical consistency with the truck-on-ferry scenario.

If each accident results in a release, and 9,200 shipments of dangerous cargo are made over the length of the bridge per year, the upper bound on the return period of a release is about 10 years. Even with a typical 0.5 rate of release, this return period would be unacceptable. The following mitigative and contingency measures have been requested for bridge design and operation (*1,10*):

- Control and monitor traffic in adverse weather conditions, during maintenance lane closures, and after accidents;
- Inspect vehicles hauling oversize loads and dangerous goods, limit their passage to hours of low traffic and good weather conditions, and dispatch under escort if required;
- Provide median crash barrier on the bridge deck to prevent head-on collisions and guardrails along the shoulders to prevent vehicles from falling into the water;
- Provide emergency telephones and video traffic surveillance to facilitate quick responses to accidents and fires on the bridge;
- Institute procedures and resources for fire fighting, emergency cleanup of roadway, towing of disabled or leaking vehicles, and emergency storage of such vehicles; and
- Provide check valves in bridge downspouts to contain the spilled material on the deck.

## SCENARIO 3: OPERATIONAL SPILLS OF HAZARDOUS MATERIALS

Between 1979 and 1988, five releases of dangerous goods from the Northumberland Strait ferry vessels took place during normal operations (*4*). The releases included leaks and fueling spills of 50 to 2300 L of diesel fuel and lubricating oil, and they occurred every 2 years on the average (Table 8). Most of these accidents were caused by negligence and human error and could be prevented in the future by improved operating procedures, better preventive maintenance, and stricter periodic inspections.

There is a possibility of spill incidents involving vessels and road vehicles engaged in operating and maintaining the bridge, its navigational aids and furniture, and the pavement surface. By judgment, risks of these incidents may be lower than in ferry operations, because no large vessels will be involved. Maintenance activities, such as preservation of the structure from the marine environment or application of antifouling chemicals, must be monitored to ensure that the marine habitat is not contaminated.

## CONCLUSIONS

Spills in the Abegweit Passage can occur from vessels involved in collisions with the existing ferry or with the proposed bridge. They can also originate from trucks transporting dangerous goods on board the ferry or over the bridge. Because site-specific data on accident frequencies and the release rates for dangerous goods from vessels and trucks are lacking, only a comparative risk analysis of the two tranportation alternatives is possible.

Petrochemicals are the most likely spill commodity. The potential maximum size of a spill is similar for the two trans-

TABLE 8 SPILL SUMMARY

| Scenario | Ferry T, year | Ferry Spill | Bridge T, year | Bridge Spill |
|---|---|---|---|---|
| 1a [a] | 18000-27000 | 2400-10800 t | 500 | 2400-10800 t |
| 1b [b] | 1300-1900 | 200-800 t | 38 | 200-800 t |
| 2 | 30000 | 40 t | 10 | 40 t |
| 3 | 2 | 50-2300 L | nd | nd |

[a] tanker spill from two tanks; [b] spill from vessel fuel tank;
T = return period assuming 100% conditional probability of release; nd = no data

portation alternatives, but the return period is several orders of magnitude higher for the ferry than for the bridge (Table 8). The size of the spill decreases by at least one order of magnitude each time the scenario changes from tanker mishap, to vessel fuel tank rupture, to truck spill, to operational spill. A similar pattern can be seen in the return periods, except truck-on-ferry accident is the most unlikely event.

The short return periods and large spill quantities can be improved by instituting traffic management systems for vessels and trucks, by providing on-site emergency response and containment of spills in the bridge drainage system, and by requiring more stringent operating and maintenance procedures.

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