Radioactive Material Transport Probabilistic Risk Assessment – Large Truck Accidents on Canadian Roadways

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SIGNATURE PAGE

RADIOACTIVE MATERIAL TRANSPORT PROBABILISTIC RISK ASSESSMENT – LARGE TRUCK ACCIDENTS ON CANADIAN ROADWAYS

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EXECUTIVE SUMMARY

In this study, the feasibility of using probabilistic methods to assess the safety risks associated with radioactive material transport is explored. Specifically, the objective is to gather and analyze available accident data and develop an event tree that is specific to accidents involving large trucks on Canadian roadways. Since radioactive material transport accidents are extremely rare, the associated statistics are insufficient as the basis for the accident event tree. Therefore, the event tree in this study is based on general transport accident data.

Comprehensive and relevant accident data for 2011-2015 has been obtained from Transport Canada's National Collision Database and is used as the basis for the accident event tree. After assessment, screening and consolidation of this data, the branches of the tree are outlined and associated probabilities calculated.

The study also encompasses a literature review, which confirms the assumption that overall, limited experience exists, to date, with regards to probabilistic methods for assessing safety risks during radioactive material transport. But as concluded in this study, when reliable, recent and comprehensive accident data is available, event trees have the potential to serve as a valuable complement to the existing safety assessment regime.

Due to its graphical form and relative simplicity, the event tree can also serve as a useful tool for communicating the relative safety risks associated with road transport in Canada.

Further studies will be needed, in order to confirm if and how probabilistic transport risk assessments can be used. Recommendations for such future studies include addressing: 1) how vehicle damage severity translates into consequences for Type B packages (and which sequences that potentially could affect the Type B packages); 2) how the generic accident event tree best can be tailored for assessment of transport along specific routes; 3) whether a framework can be created with guidance on how to reduce probability of accidents that are more likely to lead to vehicle damage that is severe or demolished; and 4) if reliable accident event trees can be developed for other modes of transport.

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1.0 INTRODUCTION

Transportation of radioactive material in Canada is subject to Canadian regulations and is regulated by the Canadian Nuclear Safety Commission (CNSC).

The basic philosophy behind CNSC's transport regulations is that safety relies heavily on robust transport packages; that is, in the event of a traffic accident, a transport package would not be breached and, hence, its contents not released – even if the accident is severe.

The type of package used depends on the nature, form and quantity or activity of the substance that is being transported; the greater the quantity or activity – the greater the robustness of the transport package. The package type that is used for transport of material with higher activity levels, such as large quantities of cobalt-60 or used nuclear fuel, is referred to as Type B. Type B packages are, among other things, designed and tested to withstand the cumulative effect of being dropped from a height of 9 metres onto an unyielding surface; exposed to a temperature of 800°C for 30 minutes (to simulate a fire); and immersed in water at a depth of 15 metres for 8 hours – without a breach of containment.

While Canadian regulations for the transportation of radioactive material ensure protection of the environment and the health and safety of people, the CNSC have initiated a project to quantitatively assess the safety risks associated with this activity using probabilistic methods. This study is the first phase of this project, which is intended to complement current practices, as well as facilitate communication of safety risks associated with radioactive material transport.

1.1 OBJECTIVES OF THE STUDY

The overall purpose of this study is to explore the feasibility of using probabilistic methods to assess the safety risks associated with radioactive material transport by road in Canada. Specifically, the objective is to gather and analyze relevant road accident data and develop an accident event tree that is specific to Canadian conditions.

1.2 SCOPE OF THE STUDY

The scope of this study is to create a generic accident event tree that is based on Canadian road traffic accident data. In order for the event tree to be reliable, the accident input data needs to be comprehensive, relevant and as recent as possible.

The scope is limited to large trucks that could transport Type B packages with high activity content (such as cobalt-60 sources or used nuclear fuel), as these would pose the highest risk in the event of a traffic accident, compared to transport of material with lower activity content (such as medical isotopes and industrial equipment).

The study covers accident data on public roadways only and excludes accidents during intermodal transfer. While accidents during transport by rail are excluded, the potential for collision with a train during transport by road is included. Human factors and human risk assessment are assumed to be implicitly included in the accident data. Aspects of security, safeguards or the possibility of malevolent acts are out of scope.

To estimate the probability of a specific type of postulated accident along a given route, detailed information about that route is required. Analysis of specific routes is outside the scope of this study, but the generic event tree generated can be used as the basis for specific route risk assessments in the future.

The focus of the event tree is to outline a range of different traffic accident scenarios and their respective probability of occurrence, while the consequences if they were to occur is outside the scope. As such, the output of this study is a depiction of the conditional failure probabilities[1] of accidents involving large trucks on Canadian roadways.

[1] A conditional failure probability is the probability of a certain event – given that another event has occurred. In this study, the conditional failure probabilities refer to probabilities of specific accident scenarios – under the assumption that an accident has occurred in the first place. The output of this study, therefore, indicates the relative distribution of different accident scenarios – not the actual probabilities that these will occur.

2.0 METHODOLOGY

An event tree is a graphical representation of probabilities that certain series of events will occur. The probability of individual events within a series is shown on the respective branch in the event tree (as a fraction of all the possible events at the associated branch point). The probability that two or more consecutive events will occur is calculated by multiplying the fractions of the individual events on the associated path. A key feature of an event tree is that the sum of all fractions at a given branch point equals 1 (i.e., the tree is designed so that one of the branches at a branch point will always occur – with the conditional failure probability for each of them indicated on the respective branch). To illustrate the structure and main components of an accident event tree, a fictitious example is provided in Figure 2-1. Note that the number of columns, number of branches and selection of categories can vary greatly, and that the event tree in Figure 2-1 serves as a simple example only (including, not having any basis for neither branch structure nor fractions and scenario probabilities).

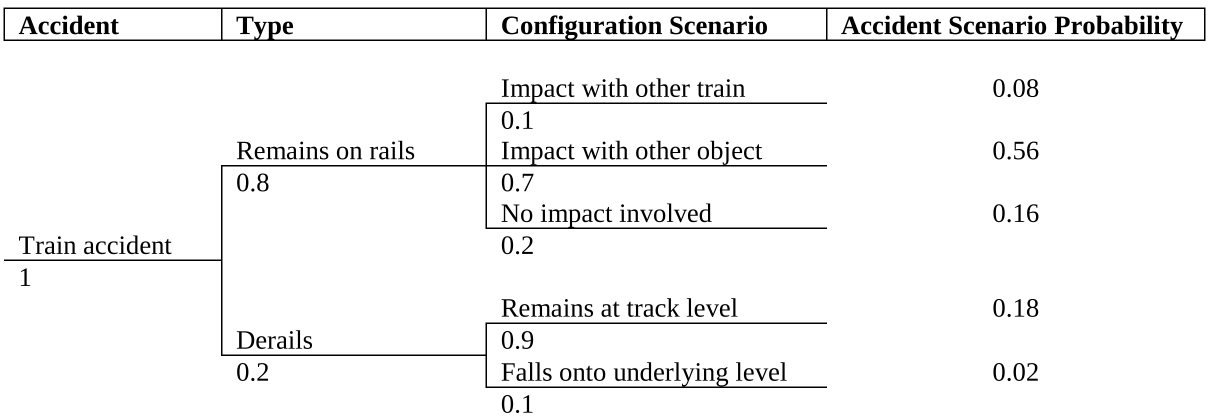

Figure 2-1: Fictitious example to illustrate structure and components of an event tree.

The probabilities in the event tree are calculated using statistical data, which means that the reliability and usefulness of the event tree is dependent on the quality of the input data. Since accidents during radioactive material transport are very rare worldwide, it is not meaningful to create the event tree in this study based on statistical data on accidents involving radioactive material alone. Instead, general traffic accident data is used, as it is assumed that the distribution of accident probabilities involving all truck types in Canada is of relevance also for the type of vehicles that is the subject of this report.

The overall methodology and assumptions in this study are similar to those applied by Sandia National Laboratories in the development of an accident event tree for transport of used fuel casks on U.S. roadways [1]. The methodology in this report also takes into account the generic guidance provided by the International Atomic Energy Agency (IAEA) in its report on *Input Data for Quantifying Risks Associated with the Transport of Radioactive Material* [2]. The data used in this study has been received, managed and calculated using Microsoft Excel.

The main steps that have been used to develop the event tree for a large truck accident in this study are as follows and are described in the respective section of the report:

- Literature Review – Section 3.0
- Data Sources – Section 4.0
- Bounding Assumptions of the Data and Analysis – Section 5.0
- Quantification of the Accident Event Tree – Section 6.0
- Assessment and Discussion of the Accident Probabilities – Section 7.0
- Conclusions and Recommendations – Section 8.0

References are provided in Section 9.0, and a list of acronyms and abbreviations that are used in this report is provided in Section 10.0.

3.0 LITERATURE REVIEW

Prior to creating the accident event tree, a literature review has been carried out – for context and to identify any input that may be of value (i.e., beyond data sources, which are described in Section 4.0). The review encompassed the regulatory landscape, as well as technical and scientific literature related to radioactive material transport risks. Highlights of the results of this review are provided in the following subsections.

3.1 CANADIAN AND INTERNATIONAL REGULATIONS

The transport of radioactive material is controlled by a stringent regulatory regime that includes standards, codes and regulations to protect members of the public, transport workers, emergency responders, property and the environment. The IAEA, under the auspices of the United Nations (UN), publishes Safety Standard No. SSR-6, *Regulations for the Safe Transport of Radioactive Material* [3] [4], which applies to radioactive material transport by road, rail, sea and air. These regulations are reviewed and updated regularly, and are incorporated into the UN Recommendations on the Transport of Dangerous Goods, also known as the UN Orange Book.

The IAEA regulations are also adopted into modal requirements established by other UN bodies, such as the International Civil Aviation Organization and International Maritime Organization, and by a majority of countries into national regulations, thereby creating a strong global regulatory framework. In Canada, the CNSC *Packaging and Transport of Nuclear Substances Regulations, 2015* and Transport Canada's *Transport of Dangerous Goods Regulations* for radioactive materials, are based on the 2012 edition of SSR-6 [4]. A new edition of SSR-6 was published in 2018 [3], which will come into force in Canada in 2020.

The basic philosophy of the IAEA regulations is that safety relies heavily on the design of the transport package. A graded approach is applied to limiting the radioactive contents of the packages and to performance standards applied to the design, depending on the hazard of the radioactive contents. Package designs are combined with additional regulatory controls, including labelling, placarding, quality assurance, maintenance records, external radiation limits, operational controls, and notification and approval of certain shipments and package types – which allow for radioactive material to be carried safely in all modes of transport.

The IAEA regulations are supplemented by a hierarchy of safety guides, including: Advisory Material [5]; Planning and Preparing for Emergency Response [6]; Compliance Assurance [7]; Management System [8]; Radiation Protection Programmes [9]; and Schedules of Provisions [10] for the safe transport of radioactive material.

3.2 TECHNICAL AND SCIENTIFIC LITERATURE

A scan of publically available technical reports from key organizations in the nuclear industry reveals that the use of probabilistic methods in assessing safety risks associated with radioactive material transport is uncommon (unlike, e.g., probabilistic risk assessment of power reactors). It is recognized, however, that additional reports may exist but are not accessible for security or proprietary reasons.

Most of the reports that address radioactive material transport safety are focused on the potential consequences in the event that an accident occurs. In some cases, the reports address general accident probabilities, in accordance with the objective of this study. In particular:

- The IAEA has produced a report on *Input Data for Quantifying Risks Associated with the Transport of Radioactive Material* [2]. A wide range of aspects are addressed, all with the aim of assisting risk analysts by providing support on assessment techniques and information resources. The use of accident event trees is among the techniques addressed. A general overview of event trees for transport accidents can be found in the report's Annex I, and two specific examples are detailed in Annex II. Both examples relate to freight train accidents – one in Germany and one in the U.K.

- As mentioned in Section 2.0, Sandia National Laboratories has created an accident event tree for transport of used fuel casks on U.S. roadways in its report on *Tractor/Trailer Accident Statistics* [1]. The report builds on and includes an updated version of an event tree presented in *Shipping Container Response to Severe Highway and Railway Accident Conditions* [11] (often referred to as the Modal Study). The new version of the event tree is, among other things, based on detailed analyses to derive fractional occurrences of route wayside surfaces (categorized as "Hard Rock," "Soft Rock, Rocky Soil," etc.). The report also encompasses new truck accident speed distributions and new estimates of truck accident fire probabilities.

- The U.S. Nuclear Regulatory Commission has published a report on *Spent Fuel Transportation Risk Assessment*, NUREG-2125 [12]. The report includes detailed assessments of risk associated with both routine transportation and accident conditions, much of which it dedicated to analysis of how transport casks respond during different accident scenarios. The probability that accidents occur is also addressed, including the application of event trees.

As part of the review, reports from international organizations that may have published literature relevant to transport accident event trees were also scanned. As well, the scan encompassed conference proceedings that include scientific papers of relevance for transport risk assessment – in particular, the proceedings from the International Symposium on the Packaging and Transportation of Radioactive Materials (PATRAM)[2].

[2] PATRAM proceedings are publically available and can be searched at: https://www.inmm.org/INMM-Resources/Proceedings-Presentations/PATRAM-Proceedings

While none other than the reports listed above were found to contain information that would be of any direct use in this study, the literature review helped in providing a general picture of the field of transport risk assessment.

A selection of the technical and scientific literature scanned in this study (beyond those already listed above) is included in Table 3-1. The purpose of Table 3-1 being two-fold: to serve as an illustrative sample of the types of publications that were scanned, as well, in the event that they may be of use as input to subsequent studies.

Table 3-1: Sample of technical and scientific publications scanned.

Author, Title and Publisher	Year
Gothié, M. *Heavy Vehicle Accident Factors.* Proceedings of the 9th International Symposium on Heavy Vehicle Weights and Dimensions.	2006
Ammerman, D. *Recent Assessments in the U.S. of Type B Packages to Impacts Beyond the Regulatory Package Test Standards.* PATRAM Proceedings.	2007
Greenberg, A., et al. *Analysis of Serious Truck Crashes in the United States.* PATRAM Proceedings.	2007
Schwarz, G., and F.-N. Sentuc. *A Review of 10 Years Radioactive Material Transport Incidents and Accidents Experience in Germany.* PATRAM Proceedings.	2007
Sert, G., O. Doaré, and M.T. Lizot. *Evaluation of Safety of French Type B Package Designs in Severe Accident Environments Other Than Regulatory.* PATRAM Proceedings.	2007
den Boer, E., et al. *Are Trucks Taking Their Toll? The Environmental, Safety and Congestion Impacts of Lorries in the EU.* CE Delft.	2009
Carenini, L., et al. *Lessons from Transport Events Involving Radioactive Materials Occurred in France Between 1999 and 2009.* PATRAM Proceedings.	2010
Road Safety in France, 2012 Annual Report. French Road Safety Observatory.	2013
Connolly, K.J., and R.B. Pope. *A Historical Review of the Safe Transport of Spent Nuclear Fuel.* US Department of Energy Nuclear Fuels Storage and Transportation Planning Project.	2016
Evgenikos, P., et al. *Characteristics and Causes of Heavy Goods Vehicles and Buses Accidents in Europe.* Transportation Research Procedia, ELSEVIER.	2016
Transport Statistics Great Britain 2016. Department for Transport.	2016
Freight Facts and Figures 2017. Bureau of Transportation Statistics, U.S. Department of Transportation.	2017
Kockum, S., et al. *Volvo Trucks Safety Report 2017.* Volvo Trucks Accident Research Team, VOLVO.	2017
Road Safety Annual Report 2018. International Transport Forum, OECD.	2018
Speed and Crash Risk. International Transport Forum, OECD.	2018

4.0 DATA SOURCES

To ensure that the event tree in this study is based on reliable and comprehensive data, a review of potential sources of Canadian transport accident statistics was performed. Highlights of the most relevant organizations and databases that were identified are provided in the following subsections. In addition to those mentioned below, data sources from the Transportation Association of Canada were reviewed, but these were found not to contain any information of relevance for this study.

4.1 CANADIAN NUCLEAR SAFETY COMMISSION

The CNSC maintains an Event Information and Tracking System (EITS), in which motor vehicle accidents are logged (starting in 2002). The majority of these are minor accidents involving pick-up trucks carrying mostly portable gauges with lower activity sources, less than Type B quantities. Very few incidents are associated with larger trucks.

In 2001 (i.e., prior to the EITS database commenced), a serious head-on collision occurred between two transport trucks – one of which was carrying two Type B source changers that were loaded with Ir-192 radiography sources. Both trucks burst into flames and were reduced to rubble, but the Type B source changers remained leak tight (although charred and slightly dented). This accident – which occurred in Dryden, Ontario – is the only major accident in Canada involving Type B transports. As such, it confirms the assumption that the event tree in this study needs to be based on general transport accident data, since radioactive transport accidents are so rare and the associated statistics insufficient to be the basis of an accident event tree.

4.2 TRANSPORT CANADA

Transport Canada is a federal-level institution that is responsible for transportation policies and programs throughout Canada. As part of its portfolio, Transport Canada maintains a set of databases that have been reviewed in detail, as potential data sources for this study.

4.2.1 National Collision Database

The National Collision Database (NCDB) contains all police-reported motor vehicle collisions on public roads in Canada. In this database, the most severe consequence is reported, along with other information related to the accident (such as vehicle type, speed, road surface and contributing factors). A subset of this data is publically available via NCDB Online[3].

To ensure that input data is as comprehensive and recent as possible, an export of the NCDB was obtained directly from Transport Canada for use in this study. The NCDB data provided

[3] For access to NCDB Online, see: http://wwwapps2.tc.gc.ca/saf-sec-sur/7/ncdb-bndc/p.aspx?c=100-0-0&l=en

by Transport Canada was for the years 2011-2015 and, as such, this is the time span of the accident data upon which the event tree in this study has been based.

It needs to be emphasized that transport of radioactive material is subject to more stringent requirements than general transports. This includes factors such as vehicle performance and maintenance, driver training and emergency preparedness. The data in the NCDB is, therefore, viewed as a worst case; in practice, the probability of a truck accident involving radioactive material is expected to be lower – and the consequences if one does occur, less severe.

As noted in Section 2.0, it is, however, assumed that the relative distribution of different accident types involving all large trucks in Canada is of relevance for this study. Consequently – and since the NCDB includes the type of information required for the creation of an event tree – the data export from the NCDB for the years 2011-2015 is deemed to be applicable and is used as the main data source in this study. The number of road accidents included in the NCDB data that was provided by Transport Canada is summarized in Table 4-1.

Table 4-1: Road accidents in the National Collision Database.

Year	Total Number of Accidents
2011	45,364
2012	41,486
2013	43,408
2014	43,681
2015	41,516

4.2.2 Dangerous Goods Accident Information System

In accordance with the *Transportation of Dangerous Goods Act, 1992*, the term dangerous goods means "a product, substance or organism included by its nature or by the regulations in any of the classes listed in the schedule." The classes referred to include one class (Class 7) for "Nuclear substances, within the meaning of the *Nuclear Safety and Control Act*, that are radioactive". The remaining eight classes are used for non-radioactive dangerous goods.

To enable tracking of accidents associated with dangerous goods, Transport Canada uses a Dangerous Goods Accident Information System (DGAIS). At the time of writing this report, the DGAIS includes data up to and including 2016, but to align with the time period of the NCDB data received from Transport Canada, data from 2011-2015[4] was selected and assessed. Worth noting is that none of the accidents in the DGAIS during this time period related to Class 7 substances. This confirms, further, that the frequency of accidents associated with radioactive material transport on Canadian roadways is very low and insufficient to be used as input statistics in this study.

[4] DGAIS is available online at: https://www150.statcan.gc.ca/t1/tbl1/en/tv.action?pid=3810025201. The data for this study was obtained by selecting 2011-2015 as the reference period and 'Road' as the type of accidents.

The DGAIS contains reports provided at the time of an accident, in the event that a release (or anticipated release) of the dangerous goods endangers (or could endanger) public safety. The accidents are divided into reportable and non-reportable events – with the former being the more significant accidents in terms of consequences or risk of a subsequent release.

The focus of this database is the transported substances and their containment and, as such, the DGAIS does not encompass information on vehicle type, accident type, etc., which is required to create the accident probabilities that are the subject of this study. The DGAIS, therefore, does not contain data that would be of use for the accident event tree, but for information purposes, the number of road accidents that the DGAIS contains is summarized in Table 4-2.

Table 4-2: Road accidents in the Dangerous Goods Accident Information System.

Year	Reportable	Non-Reportable	Total
2011	91	207	298
2012	85	217	302
2013	105	113	218
2014	111	244	355
2015	88	367	455

4.2.3 Statistics Canada

To enable comparison of traffic accident data with the total number of relevant vehicles on the road, data was also gathered from Statistics Canada's *Table 23-10-0067-01, Road motor vehicle registrations, by type of vehicle*[5]. Given the scope of this study, only two types of vehicles were deemed applicable: "Vehicles weighing 4,500 kilograms to 14,999 kilograms" and "Vehicles weighing 15,000 kilograms or more." To align with the time period of the NCDB data used in this study, data from 2011-2015 was captured, see Table 4-3.

Table 4-3: Road motor vehicle registrations for heavy vehicles.

Year	Vehicles Weighing 4,500 kg to 14,999 kg	Vehicles Weighing 15,000 kg or More	Total – Vehicles Weighing 4,500 kg or More
2011	505,702	415,422	921,124
2012	533,824	431,614	965,438
2013	550,572	432,684	983,256
2014	575,363	455,004	1,030,367
2015	591,897	464,322	1,056,219

[5] Available online at: https://www150.statcan.gc.ca/t1/tbl1/en/tv.action?pid=2310006701

5.0 BOUNDING ASSUMPTIONS OF THE DATA AND ANALYSIS

The statistical data obtained from the NCDB was first assessed in terms of relevance and usability for an accident event tree for large trucks. The data was then screened, consolidated and used as the basis for derivation of the event tree branches. These steps are described in the following subsections, whereas the quantification of the event tree – i.e., the calculation of branch point fractions and accident scenario probabilities – is described in Section 6.0.

5.1 SCREENING OF THE ACCIDENT EVENTS

As part of reviewing the NCDB data, the applicability of the various data categories was assessed. In two of the categories, some of the data referred to accidents that are not relevant to the scope of this study, as follows:

- Vehicle type – the classification in this category ranges from heavy transport vehicles and fire engines to bicycles and snowmobiles. Of a total of 20 classification options, only two were deemed applicable to this study (i.e., the remaining were screened out to limit the study to two vehicle types, and as such, the input data provided by Transport Canada had already been screened to cover only the following):
    - Unit truck >4536 kg (which is a heavy unit truck, with or without a trailer)
    - Truck tractor (which is a tractor-trailer, with or without a semi-trailer)
- Contributing factor – this category outlines a wide range of factors, such as weather, other driver action and animal on road. While it is recognized that human factors can cause accidents during radioactive material transport, some of the contributing factors are deemed not applicable to drivers of trucks that carry Type B containers, namely:
    - Alcohol
    - Drugs
    - Disobey traffic control

  The reason for this is that drivers of the type of transports referred to in this study can be assumed to be specially trained and subject to much more rigorous requirements regarding being fit for duty. An awareness of the type of material transported is also assumed to ensure that alcohol or drugs will not be a factor and that traffic controls are always obeyed. The accidents associated with the three contributing factors above are, therefore, screened out for any further analysis. The fraction of these is approximately 68% of all accidents over the time period 2011-2015 (147,558 of 215,455 in all). Consequently, the remaining 32% (67,897 of 215,455 in all) of the accidents in the NCDB data file received are considered for further analysis.

5.2 SELECTION OF THE ACCIDENT TYPES

For the first set of branches following the initiating event – a large truck accident – it was deemed appropriate to differentiate in accordance with the event tree developed by Sandia National Laboratories [1]. Consequently, the first branch point in the accident event tree in this study is set to lead to the following three types of accidents:

- Collision with non-fixed object
- Collision with fixed object
- Non-collision

5.3 CONSOLIDATION OF THE ACCIDENT EVENTS

Of the data categories in the NCDB, the following contain information that is useful for creation of the accident event tree:

- Vehicle type
- Vehicle event category
- Roadway configuration
- Collision configuration
- Vehicle damage severity

To align with the first set of branches (which relate to collision, as outlined in Section 5.2), information in the vehicle event category was used to create a second set of branches referring to object struck. To ensure a manageable number of branches, some of the categories were consolidated, see Table 5-1.

For collisions that occur on bridges, it is of particular interest to enable assessment of whether the vehicle is likely to remain on the bridge (not run-off) or not (run-off) – this due to the potential of an extreme scenario of a truck falling a significant distance (if it occurs on a tall bridge and results in run-off). As such, the branch associated with a bridge structure being struck was subdivided into the collision configurations run-off vs not run-off.

Guidance during this consolidation of events was taken from the corresponding branches for object struck in Sandia's event tree [1].

Table 5-1: Consolidation of vehicle event categories into objects struck.

Type	Vehicle Event Category	Consolidated Vehicle Event Category – Object Struck
Collision with non-fixed object	Hit train	Train
	Hit another moving vehicle	Other moving vehicle
	Hit streetcar	
	Hit other moving object	Other non-fixed/ moving object
	Hit pedestrian	
	Hit cyclist	
	Hit animal	
	Hit non-fixed object	
Collision with fixed object	Hit fixed object part of road structure (bridge)	Bridge
	Hit other fixed object (bridge)	
	Hit building	Other fixed road structure
	Hit fixed object part of road structure not mentioned above (e.g., gore, railing)	
	Hit parked vehicle (including trailers, farm or construction equipment, etc.)	Other fixed object
	Hit end of culvert, drainage structure	
	Hit tree, large bush/hedge	
	Hit utility pole, lamp pole	
	Hit curb	
	Hit sign post	
	Hit traffic barrier (e.g., median barrier, impact attenuator, moveable barrier, fence)	
	Hit fixed object that is NOT part of the road structure and not mentioned above (e.g., utility box, parking meter, hydrant)	
	Hit other fixed objects	
	Hit ditch	Ditch
	Hit embankment, dirt pile, rock	Embankment, dirt pile, rock
Non-collision	Fire or explosion	Fire/explosion
	Other non-collision event	Other non-collision
	Skid/spun	
	Ran off road	
	Overturned, roll-over	
	Jack-knife or trailer swing	

As the NCDB categorizes the accidents in terms of vehicle damage severity, this was deemed valuable and appropriate to assign as the last set of branches in the event tree for all preceding columns. The reason for this is that it indicates the degree of impact that the vehicle is subject to, as a result of the initiating event. It is worth noting that this differs from Sandia's accident event tree [1], in which the last two columns relate to speed distribution and surface struck – both of which are indirect indicators of the degree of impact. As such, the vehicle damage severity in the NCDB is a more direct measure of the impact and is deemed to correspond to the intent of the speed distribution and surface struck columns in the Sandia event tree [1].

Four main classifications are available for vehicle damage severity and defined[6] as follows:

- Light – Superficial, driven away from the scene
- Moderate – Still drivable but does not meet requirements of the law (exclude windshields and lights) for further use without repairs, driven away from the scene
- Severe – Not drivable, but worth repairing, towed from the scene
- Demolished – Totally destroyed, not worth repairing

For purposes of the event tree, accidents leading to light or moderate vehicle damage severity were consolidated, as it is the accidents that lead to higher impacts that are of main interest in this study (considered a necessity for a potential impact on the transport package). However, even if the truck is heavily affected it cannot directly be concluded that the transport package is damaged.

After derivation of the branches as per above, the resulting event tree – with its branches associated with type, object struck, collision configuration and vehicle damage severity – is illustrated in Figure 5-1.

[6] Vehicle damage severity definitions obtained through correspondence with Transport Canada.

Accident	Type	Object struck	Collision configuration	Vehicle damage severity
Large truck accident	Collision with non-fixed object	Train		Demolished
				Severe
				Light/moderate
		Other moving vehicle		Demolished
				Severe
				Light/moderate
		Other non-fixed/moving object		Demolished
				Severe
				Light/moderate
	Collision with fixed object	Bridge	Run-off	Demolished
				Severe
				Light/moderate
			Not run-off	Demolished
				Severe
				Light/moderate
		Other fixed road structure		Demolished
				Severe
				Light/moderate
		Other fixed object		Demolished
				Severe
				Light/moderate
		Ditch		Demolished
				Severe
				Light/moderate
		Embankment, dirt pile, rock		Demolished
				Severe
				Light/moderate
	Non-collision	Fire/explosion		Demolished
				Severe
				Light/moderate
		Other non-collision		Demolished
				Severe
				Light/moderate

Figure 5-1: Branches of the accident event tree derived in this study.

6.0 QUANTIFICATION OF THE ACCIDENT EVENT TREE

This section describes the steps involved in populating the branches in Figure 5-1 with probabilities – first the branch point fractions and then the probabilities that the accident scenarios will occur in the event of a large truck accident. The result – the completed event tree, including quantification – is shown in Figure 6-1.

6.1 CALCULATION OF THE BRANCH POINT FRACTIONS

Using the screened data from the NCDB (as described in Section 5.1) and the consolidated structure in Table 5-1, the fractions of the respective branches for object struck were calculated, see Table 6-1. Subsequently, the fractions of the resulting vehicle damage severity (demolished, severe and light/moderate) were calculated for each of the objects struck. The totals for the main accident types (collision with non-fixed object, collision with fixed object and non-collision) are also included in Table 6-1. The fractions were calculated for each of the years (2011-2015), followed by the average ± standard deviation over the five-year period.

To calculate the fractions of collision with a train and the configuration for collision with a bridge (run-off and not run-off), additional steps were required, as described in Section 6.1.1 and 6.1.2, respectively.

Table 6-1: Calculated fractions of the large truck accident event tree branches.

Type and Object Struck	Collision Configu-ration	Vehicle Damage Severity	2011	2012	2013	2014	2015	Average	± Std. Dev.
Collision with non-fixed object			0.756	0.723	0.769	0.778	0.786	0.762	0.025
Train		Total	0.001	0.001	0.001	0.001	0.001	0.001	0.0003
		Demolished	0.286	0.400	0.375	0.467	0.333	0.372	0.068
		Severe	0.571	0.200	0.375	0.333	0.500	0.396	0.145
		Light/moderate	0.143	0.400	0.250	0.200	0.167	0.232	0.102
Other moving vehicle		Total	0.921	0.909	0.861	0.854	0.861	0.881	0.031
		Demolished	0.027	0.026	0.025	0.027	0.023	0.026	0.001
		Severe	0.072	0.073	0.081	0.087	0.070	0.076	0.007
		Light/moderate	0.902	0.901	0.894	0.886	0.907	0.898	0.008
Other non-fixed/ moving object		Total	0.079	0.090	0.138	0.144	0.138	0.118	0.031
		Demolished	0.021	0.021	0.223	0.237	0.198	0.140	0.109
		Severe	0.169	0.169	0.105	0.094	0.088	0.125	0.041
		Light/moderate	0.810	0.810	0.672	0.669	0.715	0.735	0.071

Type and Object Struck	Collision Configu-ration	Vehicle Damage Severity	2011	2012	2013	2014	2015	Average	± Std. Dev.
Collision with fixed object			0.125	0.150	0.102	0.094	0.106	0.115	0.022
Bridge		Total	0.024	0.023	0.031	0.026	0.022	0.025	0.003
	Run-off	Total	0.182	0.071	0.286	0.200	0.219	0.192	0.078
		Demolished	0.750	0.000	0.417	0.429	0.429	0.405	0.267
		Severe	0.125	0.333	0.417	0.286	0.286	0.289	0.106
		Light/moderate	0.125	0.667	0.167	0.286	0.286	0.306	0.214
	Not run-off	Total	0.818	0.929	0.714	0.800	0.781	0.808	0.078
		Demolished	0.111	0.103	0.133	0.143	0.160	0.130	0.023
		Severe	0.194	0.128	0.200	0.143	0.160	0.165	0.031
		Light/moderate	0.694	0.769	0.667	0.714	0.680	0.705	0.040
Other fixed road structure		Total	0.033	0.033	0.047	0.047	0.048	0.042	0.008
		Demolished	0.085	0.016	0.031	0.016	0.029	0.035	0.028
		Severe	0.153	0.210	0.156	0.175	0.250	0.189	0.041
		Light/moderate	0.763	0.774	0.813	0.810	0.721	0.776	0.038
Other fixed object		Total	0.761	0.807	0.687	0.680	0.667	0.720	0.061
		Demolished	0.234	0.238	0.071	0.083	0.084	0.142	0.086
		Severe	0.112	0.111	0.134	0.168	0.157	0.136	0.026
		Light/moderate	0.655	0.651	0.794	0.749	0.759	0.722	0.065
Ditch		Total	0.175	0.132	0.227	0.233	0.248	0.203	0.048
		Demolished	0.246	0.220	0.210	0.216	0.203	0.219	0.016
		Severe	0.300	0.346	0.297	0.384	0.316	0.328	0.037
		Light/moderate	0.454	0.435	0.494	0.400	0.480	0.453	0.037
Embankment, dirt pile, rock		Total	0.008	0.005	0.009	0.014	0.014	0.010	0.004
		Demolished	0.286	0.300	0.167	0.389	0.500	0.328	0.124
		Severe	0.286	0.200	0.250	0.222	0.300	0.252	0.042
		Light/moderate	0.429	0.500	0.583	0.389	0.200	0.420	0.144
Non-collision			0.119	0.127	0.130	0.128	0.107	0.122	0.009
Fire/explosion		Total	0.032	0.030	0.030	0.024	0.012	0.026	0.008
		Demolished	0.636	0.667	0.558	0.558	0.647	0.613	0.052
		Severe	0.145	0.104	0.231	0.140	0.176	0.159	0.047
		Light/moderate	0.218	0.229	0.212	0.302	0.176	0.228	0.046
Other non-collision		Total	0.968	0.970	0.970	0.976	0.988	0.974	0.008
		Demolished	0.228	0.250	0.198	0.175	0.243	0.219	0.032
		Severe	0.253	0.240	0.269	0.279	0.246	0.257	0.016
		Light/moderate	0.519	0.510	0.533	0.546	0.511	0.524	0.015

As noted in Section 2.0, a key feature of an event tree is that the sum of all fractions at a given branch point equals 1; however, due to rounding of the calculated results to three decimal points, some exceptions to this may occur. For example, the fractions for the type of accident in Table 6-1 are:

- Collision with non-fixed object = 0.762
- Collision with fixed object = 0.115
- Non-collision = 0.122

Consequently, the equation to verify that the total probability at this branch point equals 1 is:

$$P_{\text{total, branch point 1}} = 0.762 + 0.115 + 0.122 = 0.999$$ [7]

For purposes of this study, this is considered acceptable, as the objective is limited to assessing feasibility of applying probabilistic methods – not become the basis of actual risk assessments associated with radioactive material transport.

6.1.1 Accidents with Trains

While the NCDB indicates that collisions between trucks and trains do occur, these are very rare. As shown in Table 6-2, the annual number of large trucks (truck tractor and unit truck >4536 kg, of the NCDB vehicle types and after screening) range between 6 and 15 for the years 2011-2015. Since the fractions in Table 6-1 are calculated to three decimals, this translates to a fraction of 0.001 for collision with a train. This value is consistent with the corresponding fraction assigned in Sandia's event tree [1], and as such, is deemed appropriate as the branch point fraction for collision with a train in this study. While the fraction of accidents with trains is the smallest of all objects struck in the event tree, it is recognized that when this type of accident does occur, the probability of it leading to demolished or severe vehicle damage will be higher.

Table 6-2: Summary of truck accidents involving collision with a train.

Object Struck	Vehicle Damage Severity	2011	2012	2013	2014	2015
Train	Total	7	10	8	15	6
	Demolished	2	4	3	7	2
	Severe	4	2	3	5	3
	Light/moderate	1	4	2	3	1

[7] Without the initial rounding, the actual equation is: $P_{\text{total, branch point 1}} = 0.7623 + 0.1155 + 0.1223 = 1.0001$ (which when rounded equals 1.000).

6.1.2 Accidents on Bridges

As mentioned in Section 5.3, it is of particular interest to enable assessment of the probabilities associated with accidents on bridges – i.e., in regards to probability that the collision leads to run-off from the bridge or not.

In the NCDB, these scenarios are not explicitly noted, but by combining information in two of the data categories, the fractions associated with run-off and not run-off from a bridge were calculated as follows:

- Roadway configuration – When classified "Bridge," the collision was assumed to be with a bridge structure
- Collision configuration – When classified "Run-off – Left" or "Run-off – Right," the accident was included in the run-off fraction of the event tree (whereas all the other classifications in this data category were assumed to lead to not run-off)

In Table 6-3, the annual number of large trucks (truck tractor and unit truck >4536 kg, of the NCDB vehicle types and after screening) that were involved in a bridge accident 2011-2015 is shown, including the associated collision configuration and vehicle damage severity. For the resulting branch point fractions by year, as well as average ± standard deviation, see Table 6-1.

Table 6-3: Summary of truck accidents involving collision with a bridge structure.

Object Struck	Collision Configuration	Vehicle Damage Severity	2011	2012	2013	2014	2015
Bridge	Total		44	42	42	35	32
	Run-off	Total	8	3	12	7	7
		Demolished	6	0	5	3	3
		Severe	1	1	5	2	2
		Light/moderate	1	2	2	2	2
	Not run-off	Total	36	39	30	28	25
		Demolished	4	4	4	4	4
		Severe	7	5	6	4	4
		Light/moderate	25	30	20	20	17

6.2 Calculation of the Accident Scenario Probabilities

To calculate the probabilities of each of the accident scenarios, the branch point fractions for the respective path in the event tree were multiplied. To exemplify, the probability of the first scenario in the event tree – that a truck is demolished as a result of a collision with a train – was calculated by multiplying the following branch point fractions:

- Type – Collision with non-fixed object = 0.762
- Object struck – Train = 0.001
- Vehicle damage severity – Demolished = 0.372

As such, the equation for calculating the probability of the first accident scenario is:

$$P_{\text{accident scenario 1}} = 0.762 \text{ x } 0.001 \text{ x } 0.372 = 0.000283$$

The resulting accident scenario probability – 0.000283 – has, consequently, been entered as the probability of the associated scenario (Index 1) in Figure 6-1.

Similarly, the probabilities of all other accident scenarios in the transport accident event tree have been calculated and included in Figure 6-1.

6.3 Completion of the Large Truck Accident Event Tree

After calculation of the branch point fractions and accident scenario probabilities for all the branches outlined in Figure 5-1, the event tree for a large truck accident could be completed. The branch point fractions have been taken from the average values in Table 6-1, whereas the accident scenario probabilities are the products of the calculations described in Section 6.2. The resulting event tree for a large truck accident on Canadian roadways is illustrated in Figure 6-1. For convenience, an index number has also been added for each of the, in all 33, accident scenarios.

It is important to emphasize that the accident scenario probabilities in Figure 6-1 all assume that an accident involving a large truck has occurred. In other words, the probability that a given scenario will actually occur is significantly smaller than the values listed in the probability column in Figure 6-1 (since most transports do not result in an accident). This is discussed further in Section 7.3.

Accident	Type	Object struck	Collision configuration	Vehicle damage severity		Probability	Index
				Demolished	0.372	2.83E-04	1
		Train		Severe	0.396	3.02E-04	2
		0.001		Light/moderate	0.232	1.77E-04	3
				Demolished	0.026	1.75E-02	4
	Collision with non-fixed object	Other moving vehicle		Severe	0.076	5.10E-02	5
	0.762	0.881		Light/moderate	0.898	6.03E-01	6
				Demolished	0.140	1.26E-02	7
		Other non-fixed/moving object		Severe	0.125	1.12E-02	8
		0.118		Light/moderate	0.735	6.61E-02	9
				Demolished	0.405	2.24E-04	10
		Bridge	Run-off	Severe	0.289	1.60E-04	11
		0.025	0.192	Light/moderate	0.306	1.69E-04	12
				Demolished	0.130	3.02E-04	13
			Not run-off	Severe	0.165	3.83E-04	14
			0.808	Light/moderate	0.705	1.64E-03	15
				Demolished	0.035	1.69E-04	16
		Other fixed road structure		Severe	0.189	9.13E-04	17
Large truck accident	Collision with fixed object	0.042		Light/moderate	0.776	3.75E-03	18
1	0.115			Demolished	0.142	1.18E-02	19
		Other fixed object		Severe	0.136	1.13E-02	20
		0.720		Light/moderate	0.722	5.98E-02	21
				Demolished	0.219	5.11E-03	22
		Ditch		Severe	0.328	7.66E-03	23
		0.203		Light/moderate	0.453	1.06E-02	24
				Demolished	0.328	3.77E-04	25
		Embankment, dirt pile, rock		Severe	0.252	2.90E-04	26
		0.010		Light/moderate	0.420	4.83E-04	27
				Demolished	0.613	1.94E-03	28
		Fire/explosion		Severe	0.159	5.04E-04	29
		0.026		Light/moderate	0.228	7.23E-04	30
	Non-collision			Demolished	0.219	2.60E-02	31
	0.122	Other non-collision		Severe	0.257	3.05E-02	32
		0.974		Light/moderate	0.524	6.23E-02	33

Figure 6-1: Event tree for accidents involving large trucks on Canadian roadways.

7.0 ASSESSMENT AND DISCUSSION OF THE ACCIDENT PROBABILITIES

7.1 SENSITIVITY ANALYSIS

Based on the average branch fractions + standard deviations in Table 6-1, a sensitivity analysis was performed for a selection of scenarios. For this analysis, the event sequences that were deemed to have potential to lead to the worst consequences were chosen, namely:

- Collision with a train – resulting in demolished or severe vehicle damage
- Collision with a bridge that leads to run-off – resulting in demolished or severe vehicle damage
- Collision with a bridge that does not lead to run-off – but resulting in demolished or severe vehicle damage
- Collision with other fixed road structure – resulting in demolished or severe vehicle damage
- Collision with embankment, dirt pile, rock – resulting in demolished or severe vehicle damage
- Fire/explosion – resulting in demolished or severe vehicle damage

The associated averages for the branch point probabilities + the standard deviations (taken from Table 6-1) are used as an estimate of an upper bound (i.e., the worst case accident scenario probability). The results are shown in Table 7-2, along with the previously calculated estimate of the accident scenario probability. Bridge run-off shows the largest relative increase (indicating largest uncertainty). It is worth noting that 'demolished' vehicle damage severity means fractional conditional failure probability that the truck is heavily affected and has potential to impact the transport package; however, it is not guaranteed.

7.2 COMPARISON WITH SANDIA NATIONAL LABORATORIES' ACCIDENT EVENT TREE

The structure of the event tree in Figure 6-1 and the Sandia tree [1] align to a large degree for the first few sets of branches. But subsequently, they differ substantially (due to the selection of vehicle damage severity, instead of speed distribution and surface struck in Sandia's study [1]). For this reason, a comparison of accident scenario probabilities in the two studies is not applicable. As some form of comparison, nevertheless, is of interest to make, the ratio between the fractions in the first few, comparable sets of branches has been compiled, see Table 7-3.

As shown in Table 7-3, the ratio between the fractions in the two event trees generally ranges between 0.5 and 2. Generally, the branch point fraction numbers are reasonably very close, with a difference of 0.05 to 0.2. It is noteworthy that they are this closely aligned, since some branches are defined differently and the event trees rely on different data sources. The one exception is a ratio of nearly 10 for bridge accidents leading to run-off. Further study would be needed to explain this, but a plausible reason is differences in interpretation and application of the data.

7.3 TAKING INTO ACCOUNT THE NUMBER OF REGISTERED VEHICLES

While the focus of this study is conditional failure probabilities, it was assessed whether an indication could be obtained of the frequency that a large truck accident occurs in the first place. This was done by comparing the NCDB data with the number of vehicle registrations for a given year, as shown in Table 7-1. It is important to note that the weight limits of the vehicle types differ between the NCDB and vehicle registrations (>4536 kg and >4500 kg, respectively). As well, it is unclear to which degree the vehicle registrations captured in Table 4-3 also includes vehicle types other than trucks for heavy transport. Nevertheless, for an order of magnitude of the frequency that an accident involving a large truck occurs, this is deemed acceptable for purposes of this study.

Table 7-1: Overall accident frequency (comparison with vehicle registrations).

Year	Total Number of Accidents in NCDB	Accidents in NCDB After Screening	Total Number of Vehicles Weighing 4,500 kg or More	Frequency – Total Number of Accidents/ Total Number of Vehicles	Frequency – Accidents After Screening/ Total Number of Vehicles
2011	45,364	14,523	921,124	0.049	0.016
2012	41,486	12,435	965,438	0.043	0.013
2013	43,408	13,397	983,256	0.044	0.014
2014	43,681	14,141	1,030,367	0.042	0.014
2015	41,516	13,401	1,056,219	0.039	0.013
			Average	**0.044**	**0.014**

The average of the resulting annual frequencies – that an accident involving a large truck occurs– is, as shown in Table 7-1:

- 0.044 per year and truck, for all trucks weighing more than approximately 4,500 kg
- 0.014 per year and truck, after removal of screened accident events (those associated with alcohol, drugs or disobeying traffic control, as described in Section 5.1)

The frequency of a specific type of accident is the product of the initiating event frequency of an accident involving a heavy truck carrying a Type B package per year and the conditional failure probability of the given accident scenario. The estimate 1.4E-2 per year and truck should hence be combined with conditional probability for the specific sequence in the event tree developed in this study.

To exemplify: The conditional failure probability of collision with a train leading to demolished vehicle damage severity is 2.8E-04 (Index 1 in Figure 6-1). The frequency of a heavy truck accident involving a Type B package transport per year is 1.4E-02. Thus, the frequency for this accident scenario is 4.0E-6 (1.4E-02 x 2.8E-04) per year and truck.

It shall be observed that the above frequencies are very rough as they do not include any estimate of the exposure of the vehicle (that is, how many miles is the truck in use on an annual basis). It would be expected that a truck used for transportation of Type B packages would have a less exposure than an average truck, and hence the frequency for an accident would be expected to be lower.

Table 7-2: Select accident events with vehicle damage severity demolished or severe.

Object Struck	Collision Configuration	Vehicle Damage Severity	Average	+ Std. Dev.	Upper Bound	Accident Scenario (Upper Bound) Probability	Original Estimate
Collision with non-fixed object			**0.762**	**0.025**	**0.787**		
Train		Total	0.001	0.0003	0.001		
		Demolished	0.372	0.068	0.441	**4.26E-04**	**2.83E-04**
		Severe	0.396	0.145	0.541	**5.23E-04**	**3.02E-04**
Collision with fixed object			**0.115**	**0.022**	**0.138**		
Bridge		Total	0.025	0.003	0.029		
	Run-off	Total	0.192	0.078	0.269		
		Demolished	0.405	0.267	0.671	**7.15E-04**	**2.24E-04**
		Severe	0.289	0.106	0.396	**4.21E-04**	**1.60E-04**
	Not run-off	Total	0.808	0.078	0.886		
		Demolished	0.130	0.023	0.153	**5.37E-04**	**3.02E-04**
		Severe	0.165	0.031	0.197	**6.89E-04**	**3.83E-04**
Other fixed road structure		Total	0.042	0.008	0.049		
		Demolished	0.035	0.028	0.064	**4.35E-04**	**1.69E-04**
		Severe	0.189	0.041	0.230	**1.56E-03**	**9.13E-04**
Embankment, dirt pile, rock		Total	0.010	0.004	0.014		
		Demolished	0.328	0.124	0.453	**8.51E-04**	**3.77E-04**
		Severe	0.252	0.042	0.294	**5.52E-04**	**2.90E-04**
Non-collision			**0.122**	**0.009**	**0.132**		
Fire/explosion		Total	0.026	0.008	0.034		
		Demolished	0.613	0.052	0.665	**2.95E-03**	**1.94E-03**
		Severe	0.159	0.047	0.207	**9.19E-04**	**5.04E-04**

Table 7-3: Comparison of initial branch point fractions with the Sandia study.

Type and Object Struck	Collision Configuration	Sandia Study [1]	This Study	Ratio This Study/Sandia Study
Collision with non-fixed object		0.820	0.762	0.9
Train		0.001	0.001	1[3]
Other moving vehicle		0.942[1]	0.881	0.9
Other non-fixed/moving object		0.058	0.118	2.0
Collision with fixed object		0.054	0.115	2.1
Bridge		0.064	0.025	0.4
	Run-off	0.02	0.192	9.6
	Not run-off	0.98	0.808	0.8
Other fixed road structure + Other fixed object		0.010 + 0.697[2]	0.042 + 0.720	1.1
Ditch		0.183	0.203	1.1
Embankment, dirt pile, rock		0.046	0.010	0.2
Non-collision		0.126	0.122	1.0
Fire/explosion		0.050	0.026	0.5
Other non-collision		0.950	0.974	1.0

1 Combines “Gasoline Tanker Truck” and “Other Vehicles.”
2 Combines “Building, Wall” and “Other fixed objects.”
3 Both studies assumed the same branch point fraction for accidents with trains, so by definition, the ratio is 1.

7.4 TRANSPORT ACCIDENTS ON ICY AND PACKED SNOW ROAD SURFACES

The data in the NCDB includes information on the condition of the road surface at the time of the accident. This information has not been used in the event tree, but given the cold winter climate throughout Canada, mention of such statistics in this report is deemed appropriate.

As indicated in Table 7-4, of all accidents involving large trucks 2011-2015, close to 11% occurred on a road surface with ice or packed snow[8]. Of these, 25% resulted in a vehicle damage severity that was demolished or severe (approximately 7% and 18%, respectively).

Based on these statistics it can be observed that the likelihood of demolished or severely damaged vehicles is roughly a factor of 10 higher on icy/packed snow roads.

Table 7-4: Summary of transport accidents on road surface ice/packed snow.

Year	Ice/ Packed Snow Accidents (% of All Accidents)	Vehicle Damage Severity for Ice/Packed Snow Accidents			
		Fraction of All Accidents		Fraction of Ice/Packed Snow Accidents	
		Demolished (% of All Accidents)	Severe (% of All Accidents)	Demolished (% of Ice/Packed Snow Accidents)	Severe (% of Ice/Packed Snow Accidents)
2011	11.08	0.89	1.90	8.02	17.15
2012	9.05	0.76	1.73	8.36	19.11
2013	12.20	0.66	2.21	5.39	18.12
2014	13.46	0.81	2.48	6.04	18.39
2015	8.80	0.56	1.61	6.36	18.32
Average	10.92	0.73	1.99	6.83	18.22

[8] The NCDB road surface classification also includes ”Fresh Snow” and ”Slush,” but for purposes of this study, it is assumed that “Ice/Packed Snow” represents the worst-case conditions and, furthermore, the main purpose of inclusion of these statistics is to investigate the fraction of accidents that lead to demolished or severe vehicle damage severity when road conditions are poor.

7.5 TRANSPORT ACCIDENTS ON URBAN VS RURAL ROADWAYS

In the NCDB, the accident data includes classification of the road as urban or rural. Similar to the statistics on icy and snowy roads above, this information has not been used in the accident event tree; however, highlights are included in this report for information.

Urban and rural areas are defined by Statistics Canada based on population size and density. Rural area is defined[9] as persons living in sparsely populated lands lying outside urban areas (i.e., persons living outside places of 1,000 people or more, or outside places with population densities of 400 or more people per square kilometre).

As shown in Table 7-5 and Table 7-6, more accidents occur on rural than urban roadways – around 55% vs 36%[10]. This can generally be attributed to the higher vehicle speeds in rural areas and is consistent with trends noted in the literature review.

Table 7-5: Summary of transport accidents with urban road classification.

Year	Urban Accidents (% of All Accidents)	Vehicle Damage Severity for Urban Accidents			
		Fraction of All Accidents		Fraction of Urban Accidents	
		Demolished (% of All Accidents)	Severe (% of All Accidents)	Demolished (% of Urban Accidents)	Severe (% of Urban Accidents)
2011	41.36	1.63	2.99	3.95	7.22
2012	37.72	1.67	2.48	4.43	6.59
2013	35.90	1.52	2.81	4.24	7.84
2014	32.26	1.56	2.52	4.82	7.80
2015	34.19	1.83	2.44	5.35	7.14
Average	36.29	1.64	2.65	4.56	7.32

[9] From: https://www150.statcan.gc.ca/n1/en/pub/21-601-m/2002061/4193597-eng.pdf?st=POl4zQQK
[10] In the NCDB, roads may also be classified as "Other" or "Unknown", which is the reason that the sum of rural and urban accidents is not 100%.

Table 7-6: Summary of transport accidents with rural road classification.

Year	Rural Accidents (% of All Accidents)	Vehicle Damage Severity for Rural Accidents			
		Fraction of All Accidents		Fraction of Rural Accidents	
		Demolished (% of All Accidents)	Severe (% of All Accidents)	Demolished (% of Rural Accidents)	Severe (% of Rural Accidents)
2011	50.20	6.08	7.76	12.11	15.46
2012	53.75	6.86	8.44	12.76	15.71
2013	56.01	6.28	8.82	11.21	15.74
2014	58.73	6.36	9.77	10.82	16.64
2015	55.67	5.81	7.81	10.44	14.03
Average	54.87	6.28	8.52	11.47	15.52

8.0 CONCLUSIONS AND RECOMMENDATIONS

By analyzing and applying statistics provided by Transport Canada, this study has shown that sufficiently comprehensive and detailed data exists for the creation and use of event trees that are specific to accident probabilities on Canadian roadways. The output of this study – a generic accident event tree involving large trucks on Canadian roadways – can, e.g., be adapted and used to probabilistically assess safety along specific transport routes in the future.

The generic accident event tree can also be used to inform the CNSC, waste owners and other stakeholders of the relative transport accident risks, as a basis for future studies, plans and priorities. This includes route option assessments, vehicle and transport package design, driver training and other risk-reducing initiatives. Given its graphical form and relative simplicity, the event tree can also serve as a tool for communicating general transport accident risks more broadly.

Overall, limited experience exists, to date, with regards to probabilistic methods for assessing safety risks during radioactive material transport. But based on the results of this study, it is concluded that, when reliable, recent and comprehensive accident data is available, event trees have the potential to also serve as a valuable complement to the existing deterministic safety assessment regime.

However, as limited experience exists worldwide, further work is needed to confirm if and how probabilistic transport risk assessments can be used. In particular, future studies that include addressing the following questions are recommended:

- How does vehicle damage severity translate into consequences for Type B packages (and which sequences could potentially affect the Type B packages)?
- How can the generic accident event tree best be tailored for assessment of transport along specific routes?
- Can a framework be created with guidance on how to reduce probability of accidents that are more likely to lead to vehicle damage that is severe or demolished?
- Can reliable accident event trees be developed for other modes of transport?

9.0 REFERENCES

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10.0 ACRONYMS AND ABBREVIATIONS

CNSC Canadian Nuclear Safety Commission

DGAIS Dangerous Goods Accident Information System

EITS Event Information and Tracking System

IAEA International Atomic Energy Agency

NCDB National Collision Database

PATRAM International Symposium on the Packaging and Transportation of Radioactive Materials

UN United Nations