

Assessing Radiological Dose to Members of the Public and Workers during UFTP Transportation

NWMO-TR-2015-17

September 2015

U. Stahmer

Nuclear Waste Management Organization

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EXECUTIVE SUMMARY

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Report No.: NWMO-TR-2015-17

Author(s): U. Stahmer

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Abstract

In 2012, the NWMO prepared an assessment that estimated radiological dose to members of the public resulting from the transport of used nuclear fuel in the Used Fuel Transportation Package (UFTP) (Batters et al., 2012). The dose estimates were built around generic, internationally available exposure time, distance and frequency assumptions.

In 2014, work was initiated to refine these assumptions and to frame them in a Canadian context. Carleton University was contracted by the NWMO to assess exposure times, distances and frequencies between the members of the public and a passing UFTP along a hypothetical transport route. The data collected by Carleton reflects a realistic, current Canadian perspective on the time, distance and frequency relationships between members of the public and a UFTP shipment.

This assessment uses the data collected by Carleton to re-examine and update the generic public dose estimates prepared in 2012 and provides an estimate of public dose within a Canadian context. Furthermore, this report summarises radiological doses to workers involved in the transport of used nuclear fuel in Canada, assessed in Stahmer (2014).

Public Dose Assessment

Using dose rates established in Batters et al. (2012) and the time, distance and frequency data collected by Carleton, the public dose assessment was updated. Activities placing members of the public in the proximity of a UFTP shipment were identified and grouped into the following eight categories:

1. Resident – a member of the public living along a UFTP transport route;
2. Pedestrian – a member of the public present at the roadside of a passing UFTP shipment;
3. Hitchhiker – a member of the public on the roadside soliciting a ride from passing vehicles as a UFTP shipment passes by;
4. Roadside Worker – a member of the public working along the roadside as a UFTP shipment passes by;
5. Cyclist – a member of the public cycling along the roadside as a UFTP shipment passes by;
6. Vehicle Occupant – a member of the public in a vehicle sharing the road with a UFTP shipment;

7. Traveler at a Stop – a member of the public present near a UFTP shipment during an en-route stop; and
8. Commercial Driver at a Refuelling Stop – a member of the public refuelling their vehicle in the proximity of a UFTP shipment also being refueled.

Exposure time is determined as a factor of transport speed of the UFTP shipment. Exposure distance is determined by the relative position between a member of the public and a UFTP shipment. As both exposure time and distance are related to the road type the shipment is travelling along, transport along three road types (urban, highway, and controlled access highway) were also considered.

Radiological doses to members of the public were estimated to range between approximately 0.0000013 to 0.00054 mSv per year with certain roadway workers potentially receiving the highest dose. Findings for the eight categories of members of the public are tabulated in Figure S-1 below. All doses were calculated to be orders of magnitude below the regulatory dose limit of 1 mSv per year for a member of the public. The member of the public receiving the highest annual dose was determined to be a traffic control person (roadside worker), who may receive an annual dose 1900 times less than the public dose limit or a dose equivalent to that received during 8 minutes of flight in a jet airplane.

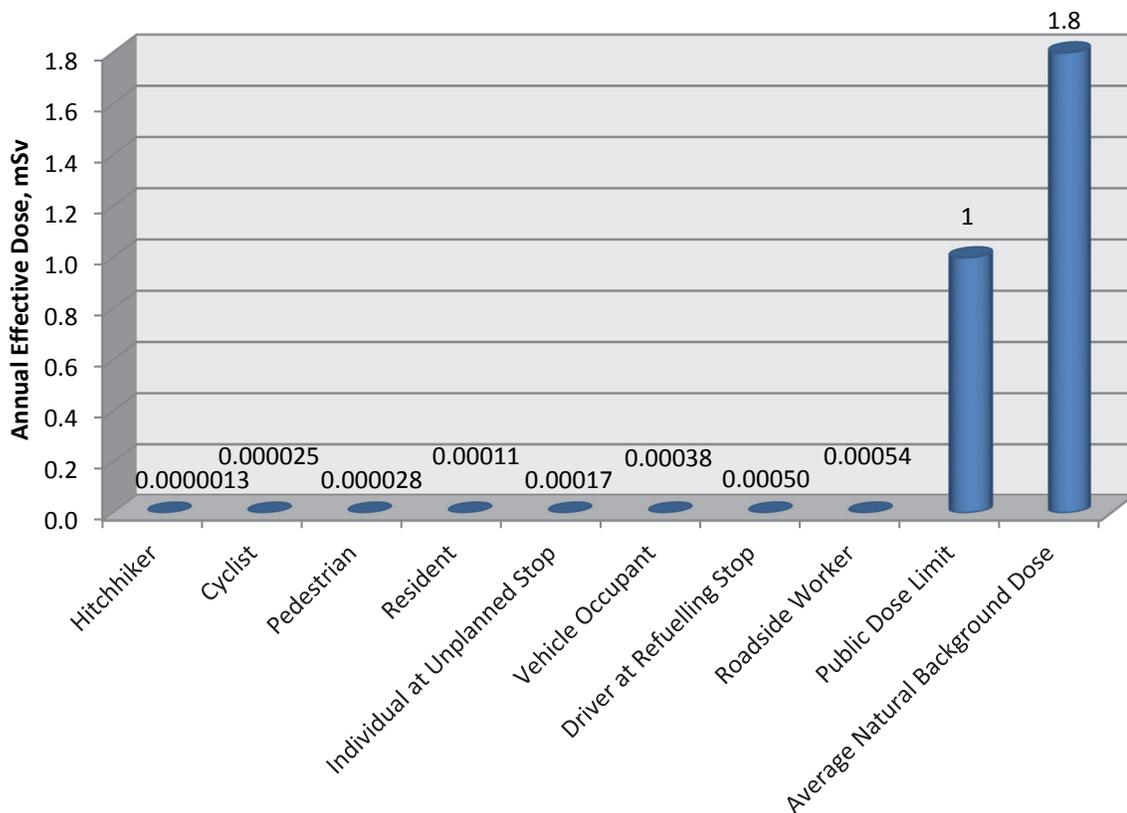


Figure S-1: Comparison of Public Doses

Worker Dose Assessment

In 2014, the NWMO prepared a companion report to the 2012 Generic Public Dose Assessment which assessed the radiological dose to workers associated with the transportation of used nuclear fuel (Stahmer, 2014). The results from the worker dose assessment are included in this report for completeness.

The report (Stahmer, 2014) focuses on activities performed by workers from the time a used nuclear fuel shipment departs from the reactor site where the fuel is currently stored until its arrival at the repository site. Occupational doses were assessed to be within a range of approximately 0.012 to 0.35 mSv per year with members of the transport crew receiving the highest dose; approximately 1/3rd of the public dose limit or equivalent to the dose received during 88½ hours of flight in a jet airplane. The transport crew would receive only about 15% of the dose a typical flight crew receives annually (Shea and Smart, 2001).

Since calculated doses remained below the regulatory dose limit of 1 mSv per year for a member of the public, the assessment concludes that transportation workers would not need to be designated as Nuclear Energy Workers (NEWs)¹ (Stahmer, 2014). However, dose monitoring of occupational activities for the transport crew should be evaluated as the radiation protection program is developed, prior to the operational start-up of the used fuel transportation program. Findings for different transportation worker categories are tabulated in Figure S-2.

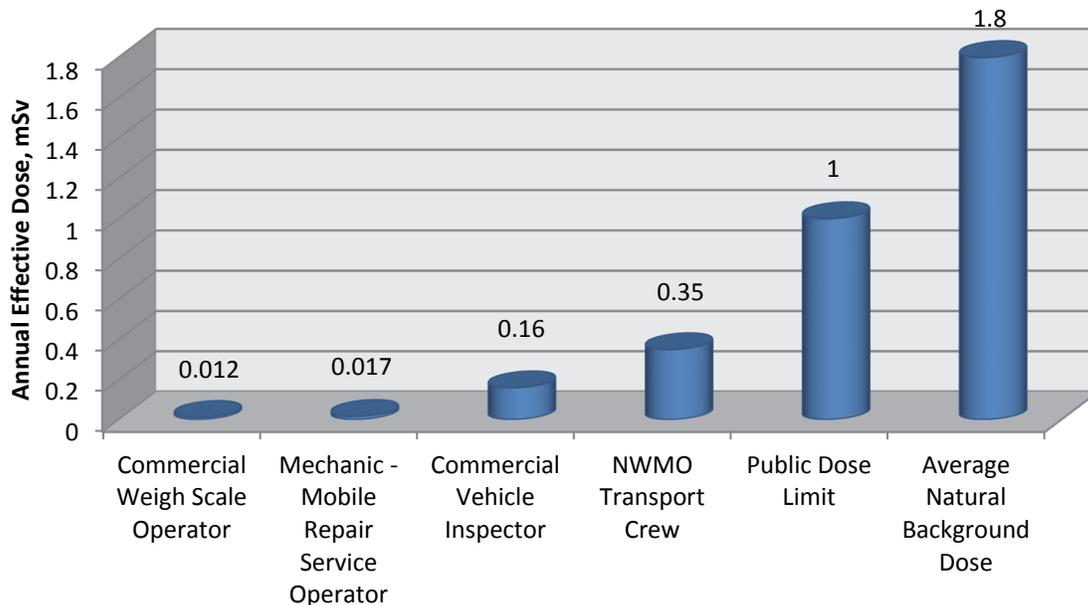


Figure S-2: Comparison of Worker Doses

As the location of the Adaptive Phased Management (APM) repository site is currently unknown, program specific calculations and risk assessments are still premature. The intent of this assessment is to provide a starting point to address concerns about the safety of the transportation system in a transparent manner.

¹ A Nuclear Energy Worker (NEW) is a worker who is required to perform duties that may result in a dose of radiation that is greater than the prescribed limit for the general public (GoC, 1997). See the Acronyms and Definitions section.

ACRONYMS AND DEFINITIONS

ALARA	As Low As Reasonably Achievable. An optimization tool in radiation protection used to keep individual, workplace, and public dose exposure as low as reasonably achievable, social and economic factors being taken into account. ALARA is not a dose limit; it is a practice that aims to keep dose levels as far as possible below regulatory limits.
APM	Adaptive Phased Management. Canada's plan for long-term management of used nuclear fuel.
Burnup	A measure of how much energy has been extracted from a fuel bundle. The unit used for presenting burnup is megawatt hours per kilogram of initial uranium (MWh/kgU).
CANDU	CANada Deuterium Uranium. Canadian-invented, pressurized heavy water reactor. The acronym refers to its deuterium-oxide (heavy water) moderator and its use of natural uranium fuel.
CNSC	Canadian Nuclear Safety Commission. Canada's nuclear regulatory agency.
CVSA	Commercial Vehicle Safety Alliance. An international not-for-profit organization comprised of local, state, provincial, territorial, and federal motor carrier safety officials and industry representatives from the United States, Canada, and Mexico.
Conveyance	Any vehicle such as a truck, train, or ship used to transport radioactive material.
DGR	Deep Geological Repository as it applies to used nuclear fuel.
Effective Dose	The sum of the products, in sieverts, obtained by multiplying the equivalent dose of radiation received by and committed to each organ or tissue, as set out in CNSC's Radiation Protection Regulations.
Equivalent Dose	The product, in sieverts, obtained by multiplying the absorbed dose of radiation type by the radiation weighting factor, as set out in CNSC's Radiation Protection Regulations.
Factor to Dose Limit	The factor by which a radiological dose is <u>below</u> the regulatory dose limit of 1 mSv per year for members of the public.
Flight-Time Equivalent Dose (FED)	The length of time spent travelling in a jet airplane at an altitude of 10 000 m that will result in a radiological dose approximately equal to the effective dose received during an activity in the proximity of a radiological source.
IAEA	International Atomic Energy Agency. An international organization that seeks to promote the peaceful use of nuclear energy. The IAEA reports to both the United Nations and Security Council.
ICRP	International Commission on Radiological Protection. An advisory body providing recommendations and guidance on radiation protection.
MCNP	Monte Carlo N-Particle Transport Code. The software code used to calculate dose rates emitted by the UFTP. See Section 3.2.
MTO	The Ontario Ministry of Transportation.

NEW	Nuclear Energy Worker. A person who is required, in the course of the person's business or occupation in connection with a nuclear substance or nuclear facility, to perform duties in such circumstances that there is a reasonable probability that the person may receive a dose of radiation that is greater than the prescribed limit for the general public.
Normal Conditions of Transport	'Normal conditions of transport (minor mishaps)' are intended to cover situations in which the package is subjected to mishaps or incidents that range in severity and would continue its journey safely after having been subjected to these minor mishaps.
Sv	Sievert. A sievert is the International System of Units (SI) used to measure radiation dose. The unit as used in this assessment is the millisievert (mSv), or one thousandth ($1/1000$) of a sievert (Sv).
Tractor	The heavy-duty towing engine that provides motive power for hauling a load on a trailer. In this case, the tractor provides the motive power for the UFTP on the trailer.
Type B(U)	The type of package required for the transport of highly radioactive material including used nuclear fuel. The concept of a Type B(U) package is that it is capable of withstanding severe accident conditions in transport without loss of containment or increase in external radiation level to an extent which would endanger the general public or those involved in rescue or cleanup operations.
UFTP	Used Fuel Transportation Package. The transportation package used to assess the radiation dose reported in this study. The UFTP is certified by the CNSC as a Type B(U) package.
Used Nuclear Fuel	The term given to nuclear fuel after being irradiated in and removed from a CANDU style nuclear reactor. In some cases, the shortened term 'used fuel' also used in this report.

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1. INTRODUCTION

In 2012, the Nuclear Waste Management Organization (NWMO) prepared an assessment (Batters et al., 2012) which estimated radiological dose to members of the public due to the transport of used nuclear fuel in the Used Fuel Transportation Package (UFTP). The dose estimates were built around generic, internationally available exposure time, distance and frequency assumptions.

In 2014, work was initiated to refine these assumptions and to frame them in a Canadian context. Carleton University was contracted by the NWMO to explore the exposure time, distance and frequency relationships between a member of the public and a passing UFTP.

Data on activities members of the public are engaged in and their proximity to the transport route were collected along a hypothetical transport route. This included data on building setback distances, vehicle speeds and separation distances, population densities, etc. The data collected and assessed by Carleton (Khan, et al., 2015) reflects a current, realistic Canadian perspective on the time, distance and frequency relationships between members of the public and a UFTP shipment.

This assessment uses the data collected by Carleton to re-examine the generic public dose estimates prepared in 2012 within a Canadian context and, for completeness, also incorporates the worker dose assessment completed in 2014. This report summarises radiological doses to workers involved in the transport of used nuclear fuel in Canada, assessed in Stahmer (2014).

Public Dose Assessment

Using dose rates established in Batters et al. (2012) and the time, distance and frequency data collected by Carleton, the public dose assessment was updated. Activities placing members of the public in the proximity of a UFTP shipment were identified and grouped into the following eight categories:

1. Resident – a member of the public living or working along a UFTP transport route;
2. Pedestrian – a member of the public present along the roadside of a passing UFTP shipment;
3. Hitchhiker – a member of the public on the roadside soliciting a ride from passing vehicles as a UFTP shipment passes by;
4. Roadside Worker – a member of the public working along the roadside as a UFTP shipment passes by;
5. Cyclist – a member of the public cycling along the roadside as a UFTP shipment passes by;
6. Vehicle Occupant – a member of the public in a vehicle sharing the road with a UFTP shipment;
7. Traveler at a Stop – a member of the public present near a UFTP shipment during an en-route stop; and
8. Commercial Driver at a Refuelling Stop – a member of the public refuelling a vehicle in the proximity of a refuelling UFTP shipment.

Exposure time is determined as a factor of transport speed. Exposure distance is determined by the relative position between a member of the public and a UFTP shipment. As both

exposure time and distance are related to the road type the shipment is travelling along, transport on three road types (urban, highway and controlled access highway) was also considered.

Worker Dose Assessment

The NWMO conducted a detailed assessment of radiological dose to transportation workers engaged in the transport of the UFTP from the interim storage facilities to an eventual deep geological repository site (Stahmer, 2014).

The worker dose assessment looked at individuals that would come into contact with a UFTP shipment as a result of their occupation. The following workers were identified:

1. Transport Crew – the driver and security escort for the UFTP shipment;
2. Commercial Vehicle Inspector – an inspector (typically working for the ministry of transportation) conducting a detailed safety inspection of the UFTP shipment;
3. Mechanic – a mobile repair service operator who may make a minor roadside repair to a UFTP shipment; and
4. Commercial Weigh Scale Operator – an operator at a commercial vehicle weigh scale. As the vehicle weight will be very consistent from one shipment to the next, vehicle weights will likely only be made at ministry scales.

1.1 ASSESSMENT PURPOSE

This report provides an assessment of the potential dose to members of the public present along or sharing the transport route and to transportation workers engaged in used fuel transport using the UFTP. Because the location of the Adaptive Phased Management (APM) repository site is still undetermined, this information will provide a basis for decision making, program planning and provide input for design optimization of the components of the transportation system.

1.2 ASSESSMENT SCOPE

This assessment estimates potential individual effective dose, hereafter referred to as 'dose' received by members of the public and summarises transportation workers dose presented in Stahmer (2014) resulting from the transportation of used nuclear fuel by road.

Road transportation was determined to be the bounding transport mode for calculating dose to members of the public and transportation workers (see Appendix E). This is due to the fact that members of the public and transportation workers in the road transport realm are, on average, in closer proximity to the UFTP for longer periods of time than during rail transport.

Each transportation shipment is considered to start with the loaded package on the trailer ready to be picked up for transport. The shipment is considered to end when the trailer arrives at the APM repository site receiving bay and is disconnected from the tractor.

Dose estimates to members of the public and transportation workers are limited to those received during normal conditions of transport. Activities including package loading, preparation for shipment, and securing onto the transport trailer which are conducted by workers at a licensed facility are outside of the scope of this assessment.

Doses are calculated for members of the public and transportation workers in variety of transportation scenarios. The calculated doses are compared to the regulatory dose limits defined in the Canadian Nuclear Safety Commission's (CNSC) Radiation Protection Regulations

(CNSC, 2000). As described in Stahmer (2014), calculated doses to transportation workers remain below the regulatory dose limit of 1 mSv per year for a member of the public, therefore transportation workers would not need to be designated as Nuclear Energy Workers (NEWs).

1.3 ASSESSMENT BASIS

This analysis is based upon the following assumptions:

- a) Use of the reference transportation package, the UFTP. The UFTP was first certified in the 1980's. In 2013, the UFTP was recertified to demonstrate compliance with current regulatory requirements.
- b) The UFTP is loaded with 192 CANDU style 37 element used fuel bundles aged 30 years out-of-reactor. Fuel burnup is discussed under h) below.

Note: Although the UFTP is certified to transport 10 year old used fuel (Stahmer, 2013), the bases of this work assume the fuel to be on average 30 years old to align with the reference repository design (Garisto et. al., 2009).

- c) Only doses associated with road transport are assessed. Dose received by members of the public and workers during road transport is shown to be higher than dose received during rail transport. See assessment in Appendix E. The transport crew accompanying a road shipment and members of the public are in closer proximity to the package during transport than for similar transport by rail.
- d) The road conveyance consists of a tractor and trailer loaded with a single UFTP. An annual total of 620 shipments is assumed. The Deep Geological Repository (DGR) is designed to process and emplace approximately 120,000 used fuel bundles per year. Approximately 620 UFTP shipments per year are required to meet this processing and storage target.
- e) Each used fuel shipment cycle consists of two transport segments: the outbound segment where the UFTP loaded with used fuel is transported from the reactor sites where it is currently stored to the repository site; and the inbound segment where the empty package is returned to the point of origin. Only outbound (loaded) segments are assumed to contribute to occupational dose. Once unloaded, the empty UFTP will be decontaminated as necessary at the repository site prior to the return shipment.
- f) Only normal conditions of transport, as defined by the transportation regulations (CNSC, 2015) and (IAEA, 2012), are considered. Normal conditions of transport are intended to cover situations in which the package is subjected to minor mishaps or incidents ranging in severity, but would continue its journey after having been subjected to these minor mishaps.
- g) Only individuals within a 30 m radius of the package are considered. See Appendix A.
- h) The dose rates at various distances from the UFTP are calculated in the generic transportation dose assessment (Batters et al., 2012). Reference fuel with two burnup rates are considered: an average burnup of 220 MWh/kgU and a peak burnup of 280 MWh/kgU. All used fuel bundles within the UFTP are assumed to have the identical burnup. Used fuel with an average burnup of 220 MWh/kgU is used in annualized dose calculations (assuming peak burnup fuel in annualized calculations would result in higher than realistic calculated dose). Used fuel with a peak burnup of 280 MWh/kgU is used in dose calculations for single occurrence activities to ensure conservative dose estimates. Burnup is described in greater detail in Section 3.1.1 (b).

2. RADIATION AND RADIOLOGICAL REGULATORY CONTEXT

2.1 RADIATION

Radiation emitted by used fuel is primarily in the form of alpha particles, beta particles, neutrons and photons (gamma rays). Alpha and beta particles are shielded by the thick steel walls of the transportation package. Hence, only gamma and neutron radiation levels at various distances from a loaded used fuel transportation package are considered since they are not fully shielded by the thick steel walls.

Radiation dose, measured in sieverts (Sv), is an indicator of the potential radiation effect on the human body. Dose rate is the measurement of radiation exposure over a period of time. The dose rate (dose received during a given amount of time) decreases as the distance from the source increases or as protective shielding is added.

2.2 REGULATORY CONTEXT

In Canada, the CNSC sets radiological dose limits to protect the health and safety of persons. This is done by following the recommendations of the International Commission on Radiological Protection (ICRP), which comprises some of the world's leading scientists and other professionals in the field of radiation protection, and by using many of the standards and guides of the International Atomic Energy Agency (IAEA).

Dose limits are established for:

1. a member of the general public; and
2. a Nuclear Energy Worker (NEW), defined as a person who is required, in the course of the person's business or occupation in connection with a nuclear substance or nuclear facility, to perform duties in such circumstances that there is a reasonable probability that the person may receive a dose of radiation that is greater than the prescribed limit for the general public (Nuclear Safety and Control Act, S.C. 1997, c.9).

2.2.1 Regulatory Dose Limits

Effective dose limits for the public and nuclear energy workers have been set by the Radiation Protection Regulations (CNSC, 2000) and are shown in Table 1, below. As described in Stahmer (2014), for transportation workers, calculated doses remain below the regulatory dose limit of 1 mSv per year for a member of the public, therefore the assessment concludes that transport workers would not need to be designated as a NEW.

Table 1: Regulatory Effective Dose Limits

Person	Period	Effective Dose
Nuclear energy worker, including a pregnant nuclear energy worker	(a) One-year dosimetry period	50 mSv
	(b) Five-year dosimetry period	100 mSv
Pregnant nuclear energy worker	Balance of the pregnancy	4 mSv
A person who is not a nuclear energy worker	One calendar year	1 mSv

Source: CNSC, 2000

2.2.2 Maximum Radiation Levels

To protect workers and the public, the transportation regulations set maximum radiation levels for transportation packages and the conveyances in which the packages are transported. Additionally, a distinction for shipments requiring *exclusive use* is made. Exclusive use (IAEA, 2012) is the term used to define shipments by a sole consignor with control over the shipment and all initial, intermediate and final loading and unloading operations. According to regulatory requirements, the UFTP is required to be shipped under exclusive use.

Maximum radiation levels for transportation packages and conveyances under exclusive use are defined as follows:

a) Maximum Radiation Levels for Transportation Packages

The radiation level at any point on the external surface of the transportation package shall not exceed 10 mSv/h (CNSC, 2015).

b) Maximum Radiation Levels for Conveyances

The radiation level at any point on the external surface of a conveyance shall not exceed 2 mSv/h, and shall not exceed 0.1 mSv/h at a distance of 2 m from the surface of the conveyance (CNSC, 2015).

Maximum radiation levels for the UFTP in its road configuration are illustrated in Figure 1, below.

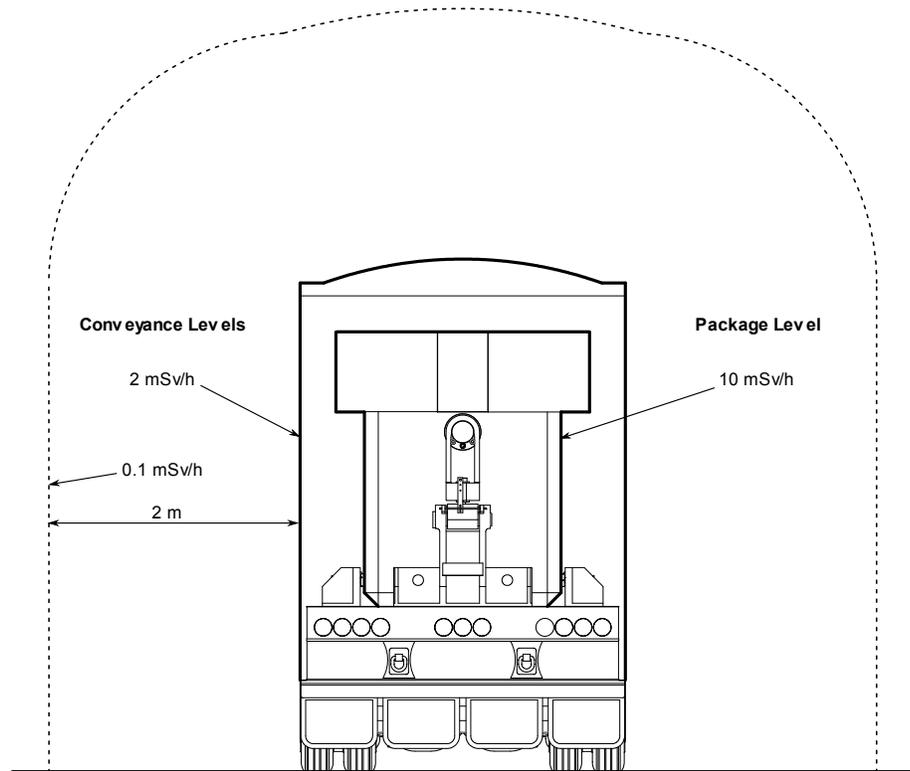


Figure 1: Maximum Radiation Levels for Packages and Conveyances Transported under Exclusive Use

3. ASSUMPTIONS AND ANALYSIS METHODOLOGY

3.1 USED FUEL TRANSPORTATION PACKAGE

The cube shaped UFTP is designed to contain a total of 192 used fuel bundles in two stacked modules. The body and lid of the package are manufactured from Type 304L stainless steel. Both are constructed from single piece forgings. The lid is bolted to the body using 32 bolts. An impact limiter made from redwood encased in a stainless steel shell is bolted to the UFTP lid to protect containment by reducing impact forces in the event of an accident. The impact limiter also serves as a thermal shield to protect the package seals during a fire. An illustration of the UFTP is provided in Figure 2.

The overall package dimensions are 2335 x 2020 x 2194 mm (body, lid and impact limiter). The empty package weighs approximately 30 tonnes and weighs approximately 35 tonnes when fully loaded with used fuel. The two long walls of the body are 272 mm thick and the base, lid, and short walls are 267 mm thick. The package can be lifted using trunnions on either side of the body and the lid is lifted via a central flange. The package design incorporates a vent port in the lid and a drain port in the body. Both ports are sealed with a plug and a cover during transport.

Used fuel bundles are held inside the UFTP within fuel modules. The fuel module is a rack system used by OPG for holding used fuel bundles in interim storage. Each stainless steel fuel module contains 96 fuel bundles stored in linear pairs within 48 horizontal module tubes. These tubes are held together in a rectangular framework. A typical module filled with used fuel bundles as illustrated in Figure 2 weighs approximately 2,500 kg.

The UFTP was designed, tested, manufactured by Ontario Hydro (now Ontario Power Generation) in the mid 1980's. The package design was first certified in the 1980's by the Atomic Energy Control Board (the predecessor of the CNSC). In July 2013, the package design was re-certified to meet current Canadian regulations (CNSC, 2013) and international regulations (IAEA, 2012).

3.1.1 Used Fuel Properties

All used fuel bundles are assumed to have uniform decay and discharge burnup:

a) Used Fuel Decay Time

All fuel bundles inside the UFTP are assumed to be 30 years out-of-reactor.

b) Fuel Discharge Burnup

The radiation emitted by each fuel bundle after discharge from the reactor is dependent on the length of time spent in the reactor and the power level. It is characterized by the fuel burnup rating. Burnup is a measure of how much fission energy has been produced per unit mass of fuel. Irradiated fuel bundles with higher discharge burnup emit more radiation.

Bundle-discharge burnups for Pickering A, Pickering B, Bruce A, Bruce B, and Darlington stations have been examined. A burnup of 220 MWh/kgU represents the highest of the average burnups at these plants (Wilk, 2013). A burnup of 280 MWh/kgU represents the 95th percentile of all discharged fuel bundles from the Pickering A, Pickering B, and Bruce A stations; and the 99th percentile of all discharged bundles from the Darlington and Bruce B stations.

The burnup for used fuel from Gentilly 2 and Point Lepreau stations is generally below 190 MWh/kgU (Wilk, 2013), and hence is bounded by the OPG/Bruce Power values.

For the purposes of this assessment, the average burnup of 220 MWh/kgU is assumed for dose calculations involving multiple annual occurrences (e.g. transport crew dose, resident along roadway). For single occurrences (i.e., a mechanic changing a tire en-route, vehicle occupant in congested traffic, individual at unplanned stop), the more conservative peak burnup of 280 MWh/kgU is used in the dose calculations.

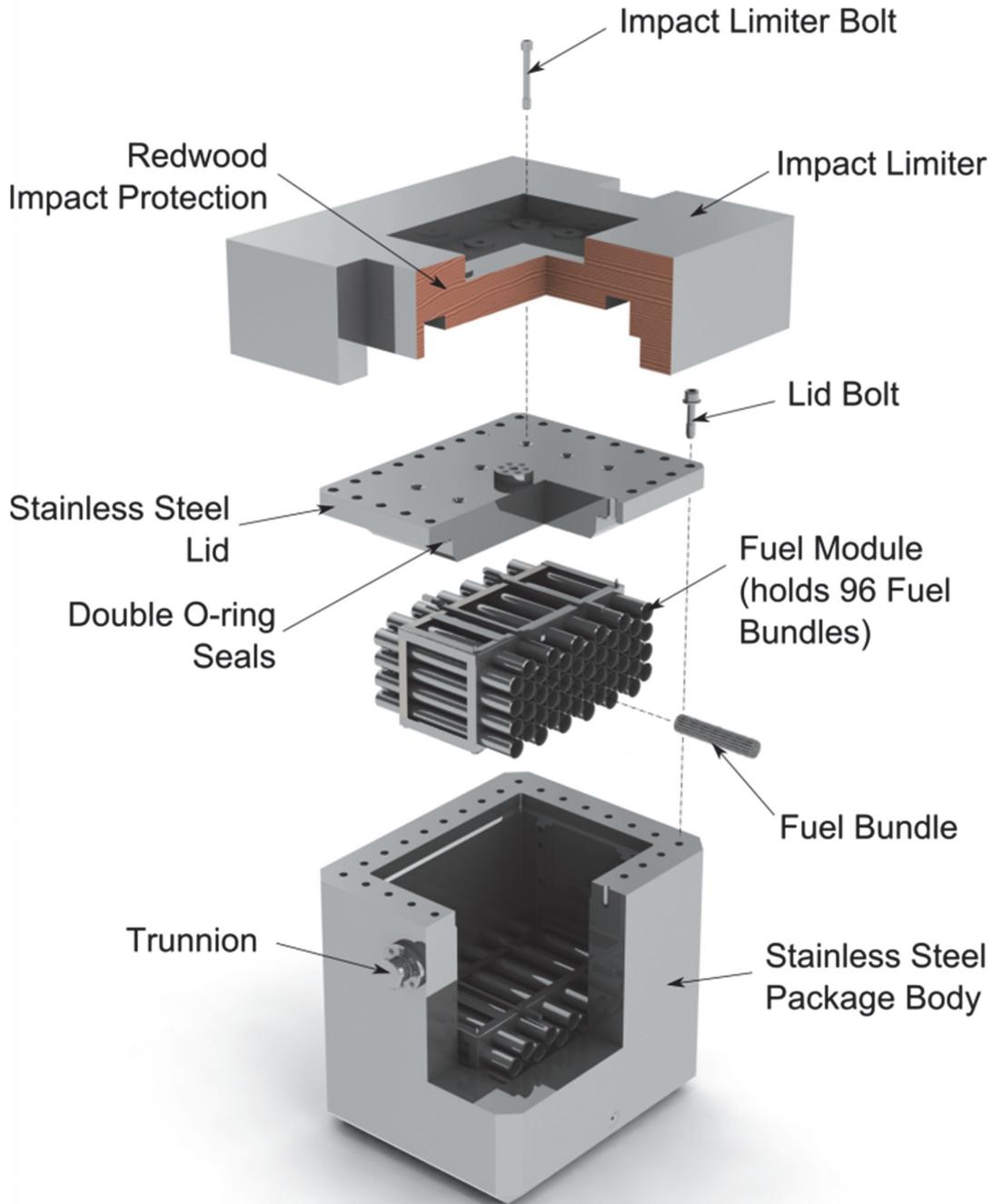


Figure 2: UFTP Assembly

3.1.2 Weather Cover (Neutron Shield)

The stainless steel construction of the UFTP provides a very effective shield for gamma radiation; however, it is less effective for shielding neutrons. Although the radiation levels for the UFTP design are below the maximum radiation levels for transportation packages, a neutron shield (doubling as a weather cover and subsequently referred to as such) could be added over top of the package to reduce radiological exposure to the public and workers thereby implementing the As Low As Reasonably Achievable (ALARA) concept (note: ALARA is defined in the Acronyms and Definitions section). The weather cover is assumed to be a 10 cm thick high-density polyethylene cover placed over top of the UFTP during transport operations. All radiological doses to the public and workers presented in this assessment are calculated with the weather cover in place.

3.1.3 Road Transport Configuration

The assumed road transport configuration consists of a single UFTP on a tractor-trailer unit. The long walls of the UFTP are parallel to the direction of travel and the short walls are in line with the ends of the truck.

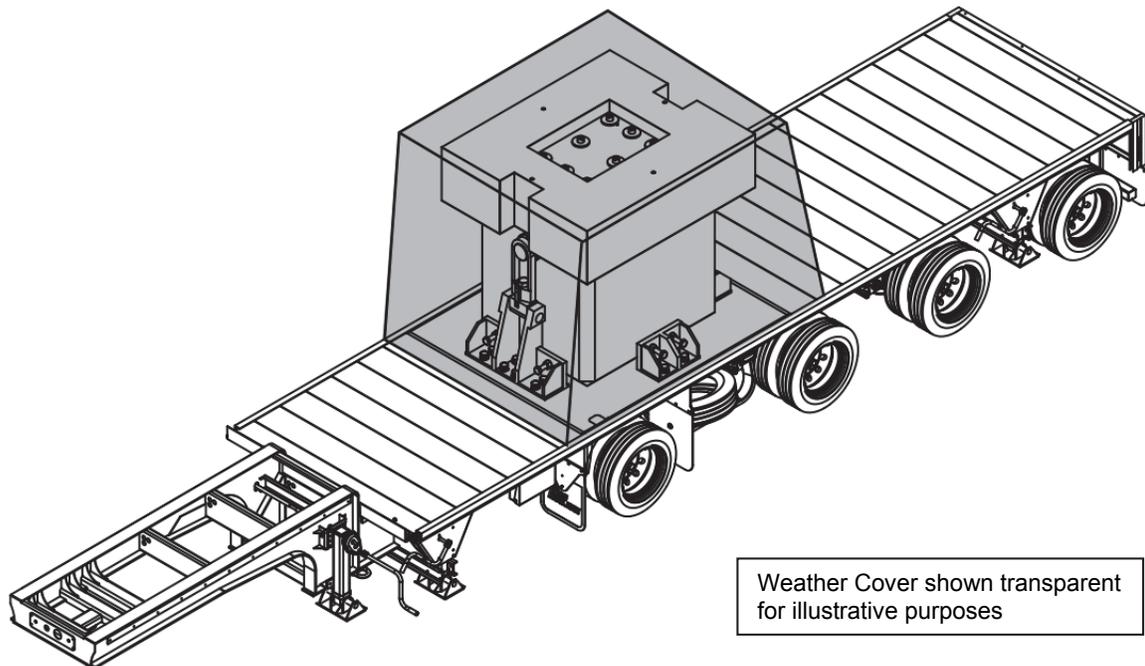


Figure 3: Typical Road Transport Configuration

The weight of the fully loaded UFTP is such that only one package can be transported on a tractor-trailer unit at a time and still comply with provincial transportation regulations in Ontario. The semi-trailer configuration consisting of a single UFTP underneath a weather cover (shown transparent for illustrative purposes) is illustrated in Figure 3. The used fuel processing facility at the repository site is designed to handle approximately 120,000 used fuel bundles per year requiring approximately 620 road shipments per year.

3.2 DESCRIPTION OF THE MONTE CARLO N-PARTICLE MODEL

A computer model of the UFTP (Batters et al., 2012) was generated using the Monte Carlo N-Particle (MCNP) transport code 5 (LANL, 2008). This code was used to calculate dose rates emitted by the UFTP at various distances from the side of the package. The model considered the four major UFTP components:

1. the used fuel (in bundles);
2. the fuel module (the frame in which the used fuel bundles are held);
3. the UFTP itself; and
4. the weather cover (which provides neutron shielding in addition to weather protection).

Each of these components was previously described in Section 3.1. The Monte Carlo model itself is described in detail in Appendix A of Batters et al. (2012).

Using the Monte Carlo model, dose rates external to the UFTP were calculated at discrete distances along lines radiating from 8 receptor locations on two planes from the package. The planes were located at package mid-height (shown in red in Figure 4), and at the mid-height of the lower fuel module (shown in blue in Figure 4). Receptor lines were located at mid-face and at the edge of both the side on (short) and end-on (long) sides of the package. Dose rates were calculated at contact with the package surface and at distances of 0.3 m, 1 m, 2 m, 3 m, 10 m, and 30 m from the surface along each receptor line. Dose rates were calculated for the package with and without the weather cover in place. This provided a dose rate profile of the package with respect to the used fuel inside.

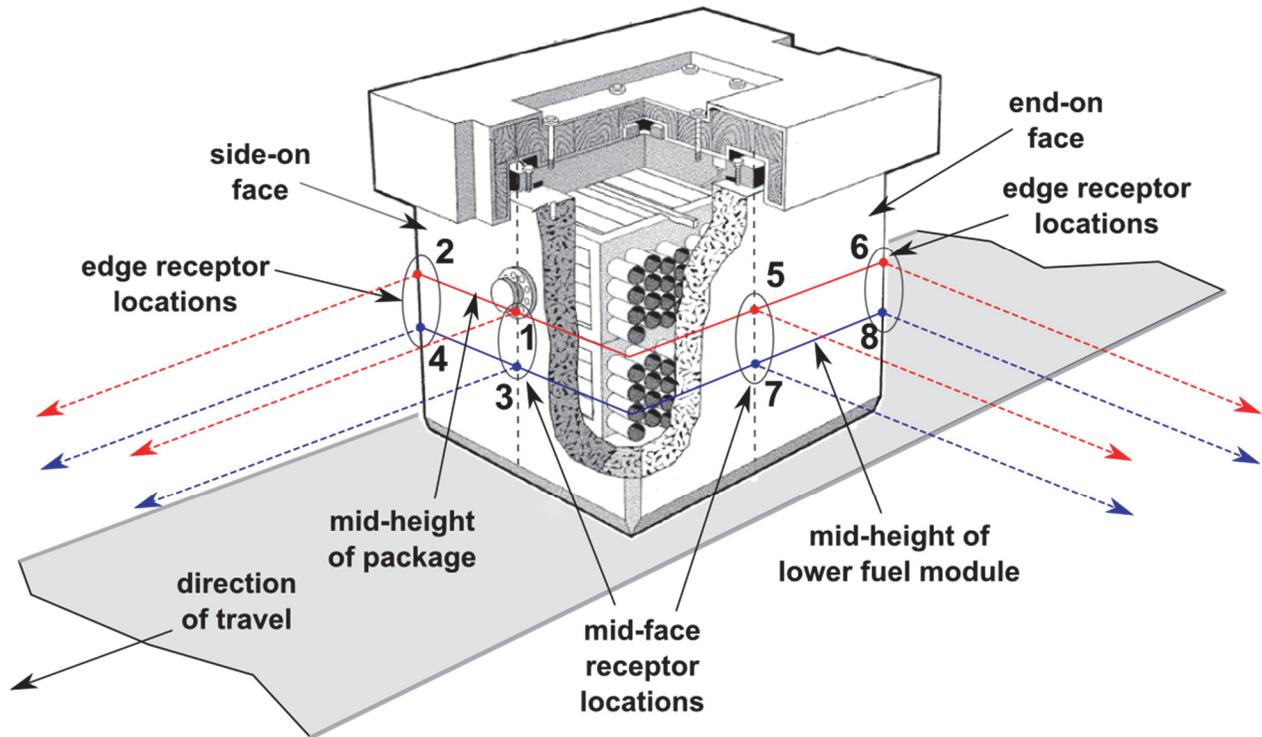


Figure 4: Dose Receptor Locations

Note that the fuel bundles are situated parallel to the short wall of the UFTP and the ends of the fuel bundles face the long wall. Doses from the short wall are termed “side-on” and the long wall, “end-on” reflecting the relative location to the used fuel bundle orientation. In the road configuration, the UFTP was assumed to be situated with the side-on face in the direction of travel. Thus, individuals travelling in front or behind the UFTP shipment would be exposed to the side-on face of the UFTP, whereas individuals along the transport route and individuals in passing vehicles would be exposed to the end-on face of the UFTP.

3.3 UFTP DOSE RATES

Dose rates emitted by a UFTP containing 192 bundles of used fuel were calculated for two fuel discharge burnups: an average burnup of 220 MWh/kgU and peak burnup of 280 MWh/kgU.

Dose rates calculated at the mid-height of the package (shown in red in Figure 4) exceeded the dose rates at mid-height of the lower fuel module (shown in blue in Figure 4). However, the difference in dose rates from the end-on and side-on faces was minimal. Dose rates along the edge receptor lines were found to be lower than their counterparts along the mid-face receptor lines. This was expected as the effective shielding thickness increases in the package corners due to package geometry (see Figure 5).

Overall, the maximum dose rates were calculated to occur along receptor line 1 (package mid-height and mid-face on the side-on face). For conservatism and simplification of dose calculations in this assessment, only the dose rates calculated along receptor line 1 are considered.

The dose rates along receptor line 1 for both average and peak discharge burnups are tabulated in Table 2 below and graphed in Figures 6 and 7.

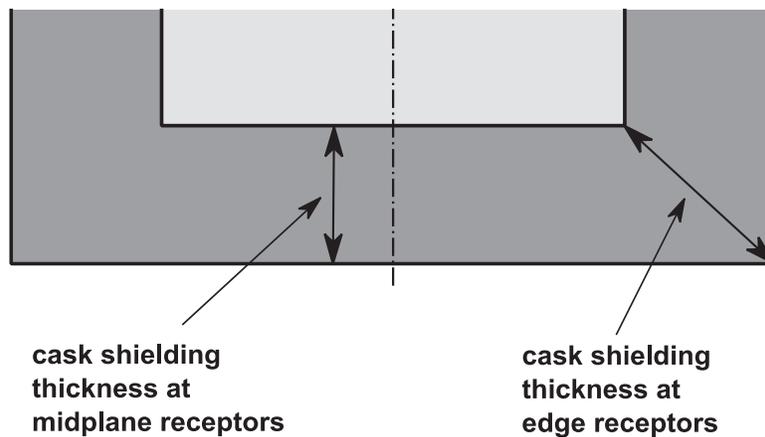


Figure 5: Shielding Thicknesses at Mid-plane and Edge Receptor Locations

Table 2: Dose Rates from UFTP

Distance from Package	220 MWh/kgU burnup			280 MWh/kgU burnup		
	Neutron	Gamma	Total	Neutron	Gamma	Total
Contact	0.0404	0.0208	0.061	0.0852	0.0168	0.10
0.3 m	0.0245	0.0125	0.037	0.0510	0.0153	0.067
1 m	0.00799 0.000445	0.00547	0.014 0.0060	0.0166 0.000445	0.00763	0.024 0.0082
2 m	0.00275 0.00017	0.00224	0.0050 0.0024	0.00575 0.000169	0.00310	0.0089 0.0033
3 m	0.00136 0.000094	0.00114	0.0025 0.0012	0.00283 0.000091	0.00150	0.0043 0.0016
10 m	0.00015 0.000018	0.000116	0.00027 0.00013	0.000314 0.000018	0.000142	0.00046 0.00016
30 m	0.000018 0.000003	0.000012	0.000029 0.000015	0.000037 0.000003	0.000014	0.000051 0.000018

Notes: - all dose rates are in mSv/h
 - dose rates for the package only are shown in plain text.
 - dose rates for the package and the weather cover are shown in **bold**.
 - gamma dose rates include secondary gamma radiation from neutron interaction with the weather cover.
 - The external surface of the weather cover is assumed to be approximately 0.4 m from the external surface of the UFTP.

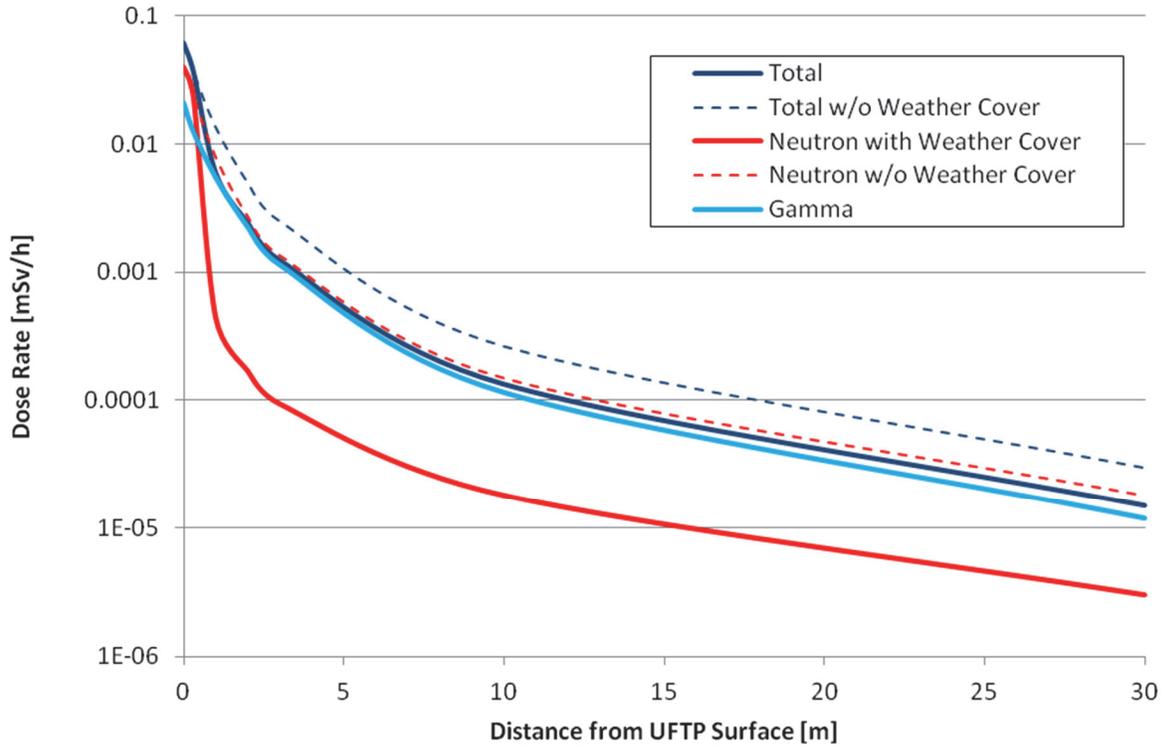


Figure 6: Maximum Dose Rates from UFTP (Average Burnup – 220 MWh/kgU)

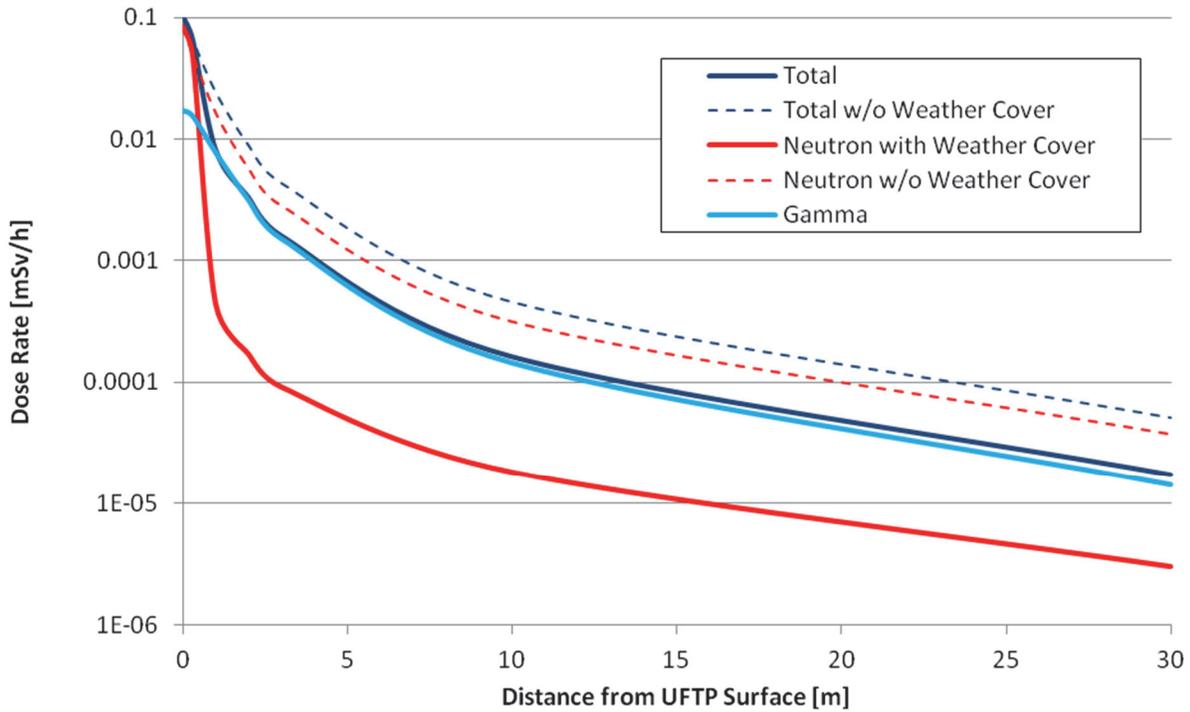


Figure 7: Maximum Dose Rates from UFTP (Peak Burnup – 280 MWh/kgU)

3.3.1 Comparison with Regulatory Limits

The dose rates calculated along receptor line 1 were compared to the maximum allowable radiation levels described in Section 2.2.2. This comparison is presented in Table 3, below. In all cases, the dose rates calculated by the MCNP model were shown to be significantly less than the acceptance criterion.

Note: The weather cover is a tool used to implement the ALARA principle to minimize operational dose exposure. It is not a regulatory requirement. Hence, dose rates from the package without the weather cover in place are used for comparison with regulatory limits.

Table 3: Maximum Dose Rates from UFTP (without Weather Cover)

Distance from Package	Maximum Radiation Level (mSv/h)	UFTP (Calculated Dose Rates)	
		220 MWh/kgU	280 MWh/kgU
Contact	2 (conveyance)	0.061 mSv/h	0.10 mSv/h
	10 (exclusive use package)		
1 m	-	0.014 mSv/h	0.024 mSv/h
2 m	0.1 (conveyance)	0.0050 mSv/h	0.0089 mSv/h

3.4 CALCULATION OF DOSE – AN ILLUSTRATIVE EXAMPLE

Calculation of dose to an individual in a given scenario is the product of the dose rate at the distance defined in the scenario, the exposure time and the exposure frequency. The relative distance between the individual and UFTP is assumed to be fixed during this time.

For example, from Table 3, the dose rate at 10 m from the package and weather cover is 0.00013 mSv/h. This means an individual standing 10 m away from the long side of the package for one hour would receive a dose of 0.00013 mSv. An individual present at that location for 15 minutes would receive one quarter of the hourly dose, or 0.000033 mSv. Likewise, an individual present at that location for 3 hours would receive three times the hourly dose, or a dose of 0.00039 mSv.

Exposure frequency must also be considered to calculate annual dose. From the example in the paragraph above, an individual located 10 m away from the long side of the package for 15 minutes receives a dose of 0.000033 mSv. Assuming the individual experiences this scenario 5 times during the span of a year, the individual then receives 5 times the dose received in the 15 minute exposure, or 0.00016 mSv per year.

As mentioned in Section 3.1.2, the weather cover provides additional shielding of neutron radiation. The weather cover is an integral part of the transportation system and the UFTP will be covered during all shipments.

There are instances where the relative distance between the individual and the UFTP are not fixed, such as a UFTP shipment passing a weigh scale operator. In cases such as this, calculation of dose to the individual differs somewhat from the calculations described above. Here the individual is assumed to be stationary at a given distance perpendicular to the passing UFTP shipment. As the vehicle approaches, the dose rate the individual is exposed to will increase until it reaches a maximum when the transportation package is closest to the individual. The dose rate then decreases as the vehicle continues on its route. The total dose received is dependent on vehicle speed; the faster the vehicle speed, the lower the dose because of the reduced exposure time. This methodology is discussed in more detail in Appendix D.

3.5 FLIGHT-TIME EQUIVALENT DOSE

People are exposed to low levels of radiation every day from many sources including cosmic rays and natural radioactivity in soil, rocks, and food. Medical procedures, flying in an airplane, and even some objects around the house may additionally expose people to small amounts of radiation.

As noted in Section 2.2.1, the CNSC sets the dose limits for nuclear related activities for NEWs and persons who are not NEWs (e.g., members of the public). The dose limit for members of the public is one milliSievert per year (1 mSv per year). A person would be designated as a NEW if there is a reasonable probability through their occupation that they may receive a dose greater than 1 mSv/year.

The total population-weighted average annual effective dose from natural sources of radiation in Canada is approximately 1.8 mSv per year (Grasty and LeMarre, 2004). This is lower than the worldwide average of approximately 2.4 mSv per year. In Canada, at ground elevation, approximately 0.32 mSv or 18% (Grasty and LeMarre, 2004) of the natural dose is due to cosmic radiation arising from radiation entering the earth's atmosphere from space. From the earth's surface, cosmic radiation typically doubles with every increase of 1800 m in altitude.

Thus, a person living on a mountain top will typically receive more cosmic dose than a person living at sea level.

The radiological dose received by an individual from a passing UFTP shipment can be put into context by relating it to the dose received during time spent travelling in an airplane. An individual travelling in an airplane flying at 10 000 m will receive an average radiological dose of approximately 0.004 mSv per hour of travel (Shea and Smart, 2001), (Reitz, 1993), (Bennett et al., 2013). This means that during a 2½ hour airplane flight from Toronto to Winnipeg, an individual would receive a dose of approximately 0.01 mSv, or a dose approximately equivalent to a full-mouth or panoramic dental x-ray (NCRP, 2009). In other words, the dose received from a dental x-ray is approximately equal to the flight-time equivalent dose (FED) received during a 2½ hour flight. The FED for the average natural background radiation per year in Canada is approximately 450 hours.

This concept provides a good comparison benchmark for the radiological doses calculated in this report. All doses calculated in this report are presented in both milliSieverts (mSv) and in the FED in units of time (hours, minutes, or seconds).

4. PUBLIC ACTIVITIES ALONG THE TRANSPORT ROUTE

Roads and highways serve as the primary transport infrastructure for Canadians. Transport routes are typically in the public domain as they are comprised of the public roads and highways linking the shipment origin to its destination. Members of the public will share the transport route with the UFTP shipments and will be present alongside the transport route as UFTP shipments pass by. Over the course of the UFTP transportation program, members of the public will be exposed to radiation fields emanating from the UFTP shipments.

The proximity of members of the public to a UFTP shipment is generally dependent on the type of roadway the shipment is travelling along. For the purposes of this study, public roadways have been grouped into three categories: urban roads, highways (typically single lane) and controlled access highways. Recognising the differences in physical features of the roads and the surrounding land use (dwellings, buildings, activity areas, etc.) within each group is important as this affects the radiological dose received by individuals on or along the route. For example, urban roads are typically narrower than highways, have narrow or no shoulders, but often have sidewalks, have closer dwelling encroachment and have lower speed limits. Due to the closer proximity to the route and the slower shipment speed, a person in an urban setting may receive more dose from a passing shipment than a person along a highway.

To examine the relationships between UFTP shipments and members of the public, transportation experts from Carleton University in Ottawa were contracted to use the Darlington to Ignace road corridor to:

1. identify bounding conditions under which a member of the public could receive a radiological dose from the transportation of used nuclear fuel;
2. define a comprehensive set of scenarios within the bounding conditions that required analysis in terms of distance, time, and frequency over one year that can provide a basis for estimating the expected level of radiological dose; and
3. develop and apply methods for obtaining data on transportation, land use, and human activities that enable the analysis of scenarios for the purpose of quantifying the exposure distance, time and frequency factors that are potentially applicable to a variety of routes that the NWMO may use for transporting the UFTP.

For a moving shipment, activities engaged in by members of the public placing them in the proximity of a UFTP shipment were grouped into six categories along each of the road types identified earlier. These groupings and applicable sections of this report in which they are discussed are identified in Table 4, below. For periods during which the shipment is stationary (i.e.: a UFTP shipment stopped for refuelling, at a rest stop or during an unplanned stop), three additional activities were identified:

1. a member of the public near the UFTP at a rest stop (see Section 5.1);
2. a member of the public near the UFTP during refuelling (see Section 5.2); and
3. a member of the public near the UFTP during an unplanned stop (see Section 5.3).

Exposure frequencies for each activity have been established based on available data. Determination of exposure frequencies along a given route is dependent on shipping schedules. For example, the maximum annual shipment rate from the Bruce site is 295 shipments (Stahmer, 2009). Thus, an individual along a shipping route near the Bruce site would only be exposed to these shipments, whereas an individual living on a shipping route near the repository site may be exposed to a higher shipment frequency.

Additionally, the CNSC provides guidance on security measures for the transport of nuclear material (CNSC, 2003) that may influence the exposure frequency to individuals. These measures may include the following:

1. routes should be chosen that bypass urban areas wherever practical;
2. if the proposed route is to pass through an urban area, the shipment is to be scheduled to avoid times of peak traffic;
3. the total time that the nuclear material is in transport should be minimized;
4. fixed transport schedules for the movement of nuclear material should be avoided; and
5. the routes used to transport the nuclear material should be varied.

As neither the location of the repository site nor the transport routes have yet been determined, the exposure frequencies assumed in this work will need to be reassessed as repository location and shipping routes become known.

Table 4: Identification of Members of the Public in Proximity to a Moving UFTP Shipment

Member of the Public	Present along Urban Road	Present along Highway	Present along Controlled Access Highway
Resident	Section 4.1.1 (typical) Section 4.1.2 (Sensitivity Case A) Section 4.1.3 (Sensitivity Case B)	Section 4.1.4	Section 4.1.5
Pedestrian	Section 4.2	Captured by Pedestrian along Urban Road. See Section 4.2	n/a
Hitchhiker	Captured by Pedestrian along Urban Road. See Section 4.2	Section 4.3	n/a
Roadside Worker	Captured by Highway Construction Worker and Traffic Control Person. See Sections 4.4.1 and 4.4.2	Sections 4.4.1 and 4.4.2	Captured by Highway Construction Worker. See Section 4.4.1
Cyclist	Section 4.5.1	Section 4.5.2	n/a
Vehicle Occupant (normal traffic)	Section 4.6.1 (beside UFTP) Section 4.6.2 (behind UFTP)	Section 4.6.3 (passing UFTP)	Captured by Vehicle Occupant passing UFTP. See Section 4.6.3
Vehicle Occupant (congested traffic)	Captured by Vehicle Occupant in congested traffic. See Section 4.6.4	Section 4.6.4 (behind UFTP)	Section 4.6.5 (beside UFTP) Section 4.6.6 (behind UFTP)

The estimated annual dose to members of the public for each of the scenarios discussed in Sections 4 and 5 are summarized in Table 17 in Section 7.

4.1 RESIDENT

Members of the public are present as residents, occupants, or individuals in or around buildings along roadways and highways. Minimal radiological exposure may occur to these individuals if they are present along transport routes used to transport used fuel. This section examines the potential doses received by these members of the public, termed residents in this assessment, present along the three different categories of roads identified previously. Examining residents along each road category is important as the typical building set-back distance and transport speed will vary thereby affecting the dose received by the resident.

Urban areas are considered to be areas along sections of the transport route where the traffic speed is limited to 50 km/h or less. Data on building set-back distances (Khan, et al., 2015) along the study route (Darlington to Ignace) indicates that the typical building set-back is in the range of 26 to 30 m. However, considering routes from the Pickering and Bruce stations, building set-back distances could be as little 5 m.

Variations in the urban landscape along the transport route suggest that several different scenarios are possible for an urban resident. Using typical set-back distances in dose calculations yields a dose representative for a typical resident along a route. However, it does not capture a more limiting dose scenario such as a resident in a small south-western Ontario town where the building may be much closer to the route. (In the scenarios examined, the resident is assumed to be in or near a building, thus building set-back distances are used in to calculate dose to the resident.) Likewise, only calculating the limiting dose would not be representative for the typical resident.

For residents in urban areas, three scenarios are examined: a typical scenario and two sensitivity case scenarios. The typical scenario explores the circumstances that are expected to relate to a typical resident along a transport route in an urban area. The sensitivity case scenarios explore the circumstances that might be anticipated for a specific individual given a very specific set of circumstances. The two sensitivity cases are included to demonstrate how low the dose to a resident is, even in the sensitivity cases.

4.1.1 Resident along Urban Road – Typical

4.1.1.1 Scenario Description

The typical minimum set-back distance for buildings along the representative route was determined to be 25 m. Buildings frequently have areas such as parking lots located in front of them placing individuals, at times, closer to passing UFTP shipments. In this scenario the resident is assumed to be located in or around the building at a distance of 25 m from the passing UFTP shipment for 50% of the shipments and is assumed to be located in the parking lot in front of the building at a distance of 20 m from the shipment for an additional 10% of the shipments. The posted speed limit on municipal streets in Ontario is typically 40 km/h or 50 km/h. For calculations, an average speed of 24 km/h is assumed for the passing UFTP shipments. This speed accounts for variations in shipment speed due to traffic signs and signals. The scenario is illustrated in Figure 8, below. Additional details are provided in Appendix B.1 under the activity “Resident along Urban Road - Typical”.

4.1.1.2 Dose to Resident along Urban Road – Typical

The annual dose received by the resident is the sum of the doses received from the passing shipments when the resident is located at 20 m and at 25 m. In the described scenario, a resident at 20 m from a single UFTP shipment passing at 24 km/h is calculated to receive a dose of 0.000000105 mSv. At an exposure distance of 25 m and the same shipment speed, the dose to the resident would be 0.0000000818 mSv. For 62 shipments at 20 m (10% of the shipments), the dose received by the resident would be 0.00000649 mSv and for 310 shipments at 25 m (50% of the shipments), the dose received by the resident would be 0.0000254 mSv. Thus, the total annual dose received by the resident is calculated to be 0.000032 mSv (see Appendix B.1).

4.1.1.3 Discussion – Resident along Urban Road – Typical

The annual dose received by a resident along a highway is very low; approximately 31 000 times below the regulatory limit or equal to an annual FED of 29 seconds. In fact, the received dose may be lower. Shielding provided by buildings or other sources is not credited, but will reduce dose exposure to the resident.

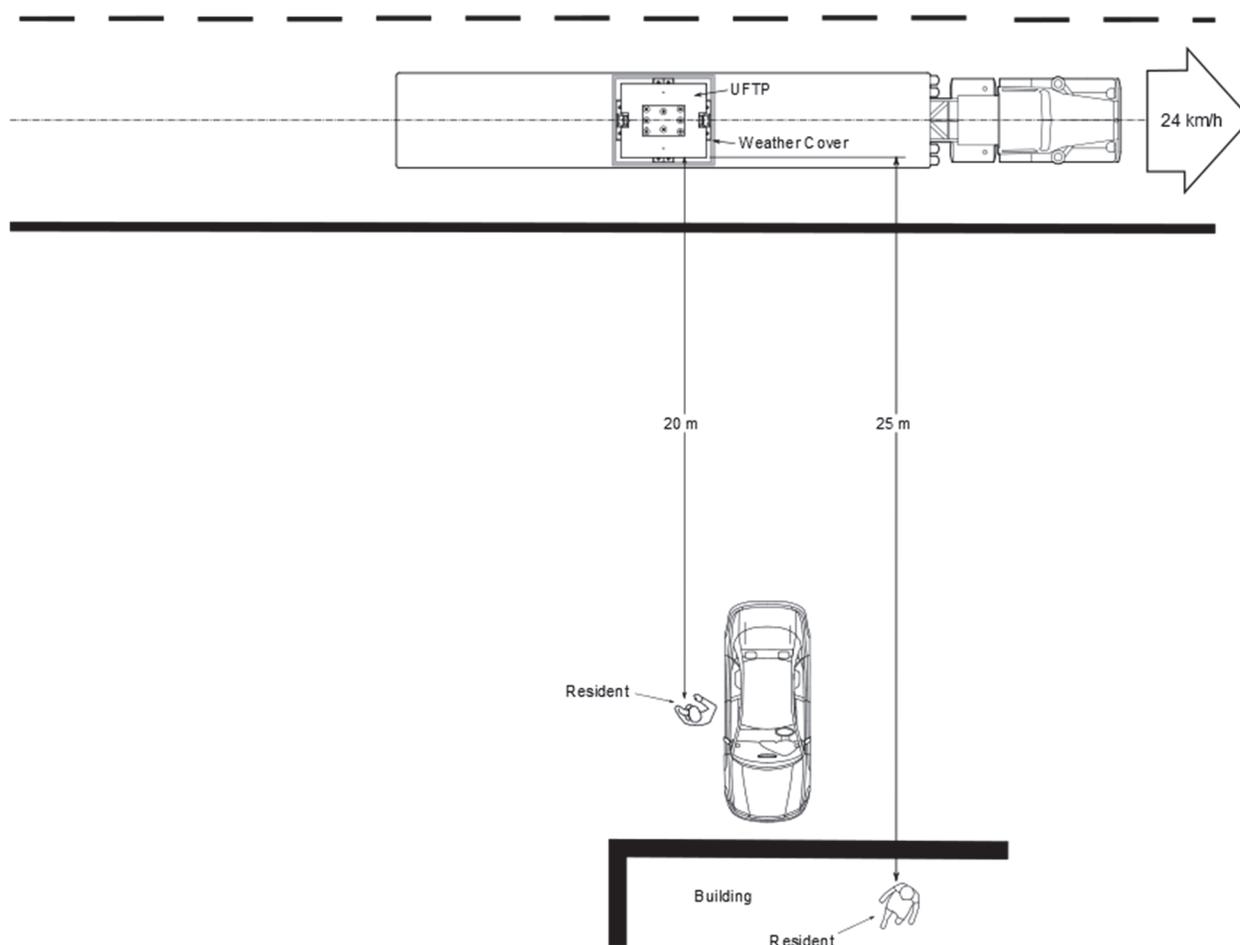


Figure 8: Resident along Urban Road – Typical

4.1.2 Resident along Urban Road – Sensitivity Case A

4.1.2.1 Scenario Description

The minimum set-back distance for buildings along the representative route for both urban areas can be as low as 8 m. In this scenario, a resident is assumed to be located in or around a building in an urban area at a distance 8 m from the transport route. The UFTP shipment is assumed to be travelling at an average speed of 24 km/h to account for normal traffic stops at signs or signals. The resident is assumed to be exposed to 50% of all 620 annual shipments. The scenario is illustrated in Figure 9, below. Additional details are provided in Appendix B.2 under the activity “Resident along Urban Road – Sensitivity Case A”.

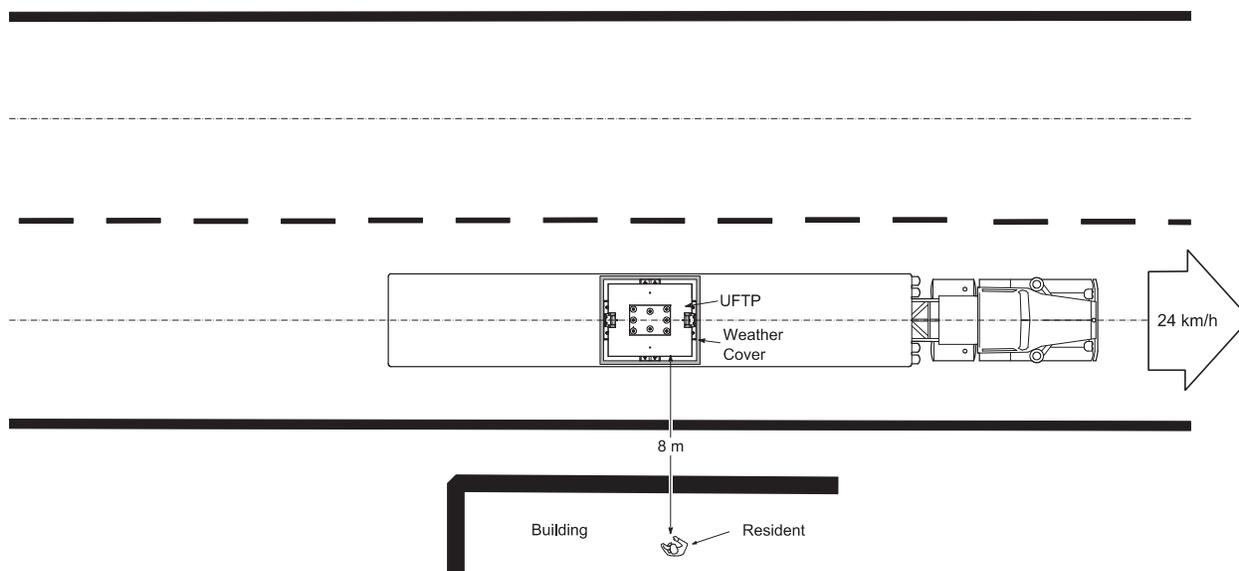


Figure 9: Resident along Urban Road – Sensitivity Case A

4.1.2.2 Dose to Resident along Urban Road – Sensitivity Case A

The dose received by the resident per occurrence is simply the dose received from the passing shipment. In the described scenario, the dose to the resident at 8 m from a single UFTP shipment travelling at 24 km/h is calculated to be 0.00000209 mSv. The annual dose received by the resident exposed to 310 shipments is calculated to be 0.000065 mSv per year (see Appendix B.2).

4.1.2.3 Discussion along Urban Road – Sensitivity Case A

The annual dose received by a resident in an urban area is low; approximately 15 000 times below the regulatory limit or equal to an annual FED of 58 seconds. In fact, the received dose may be lower. Shielding provided by buildings or other structures is not credited, but will reduce dose exposure to the resident. Additionally, minimal building setback distances are more common to urban planning in southern Ontario but are uncommon as one travels north. It is highly unlikely that a given resident will be present at a distance of 8 m for 50% of all passing UFTP shipments.

4.1.3 Resident along Urban Road – Sensitivity Case B

4.1.3.1 Scenario Description

This section describes a specific scenario developed to estimate the maximum potential dose or limiting dose to a resident along a transportation route. Here the resident such as a shop owner sitting in front of a shop in a rural town in southern Ontario is assumed to be positioned at a minimum distance of 5 m from the passing UFTP shipment. As the close proximity of a resident to a UFTP shipment is unique to southern Ontario, the number of annual shipments is assumed to be 295, the maximum number of shipments originating from the Bruce site per year.

The resident is assumed to be exposed to 40% or 118 of the 295 annual UFTP shipments along the route. 40% was chosen as it is unlikely that the shop owner will be sitting in front of the shop all day long, during all weather conditions over the course of the year.

Of these 118 shipments, 75% are assumed to pass by the resident at a speed of 30 km/h and the remainder are assumed to be stopped by a traffic signal with a 1.5 minute cycle time. The approach and departure speed of the shipments stopped by the traffic signal is assumed to be 5 km/h. Additionally, 10% of the shipments stopped by the traffic signal are assumed to stop such that the UFTP is positioned directly in front of the resident located 5 m away. The scenario is illustrated in Figure 10, below. Additional details are provided in Appendix B.3 under the activity “Resident along Urban Road – Sensitivity Case B”.

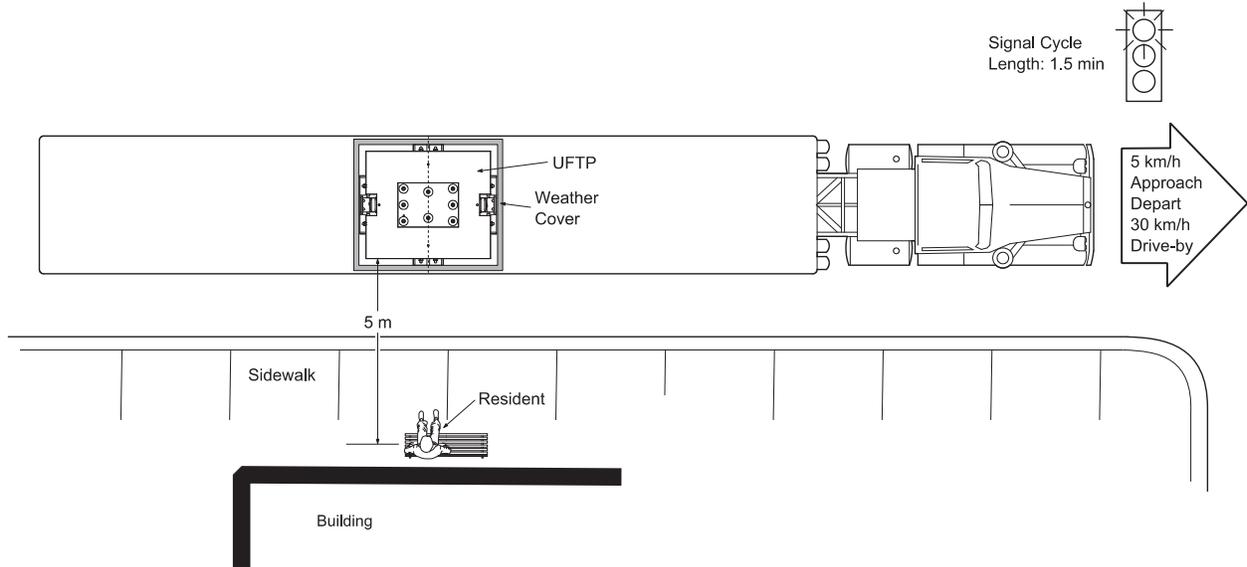


Figure 10: Resident in Urban Area – Sensitivity Case B

4.1.3.2 Dose to Resident in Urban Area – Sensitivity Case B

The dose received by the resident per occurrence is the sum of the dose received from the passing shipment at speeds of 5 and 30 km/h and the dose received during the time the UFTP shipment is stopped at the traffic signal with the UFTP positioned directly in front of the resident. In the described scenario, the annual dose to the resident is calculated to be 0.00011 mSv per year (see Appendix B.3).

4.1.3.3 Discussion – Resident in Urban Area – Sensitivity Case B

Even in this limiting case, the annual dose received by this resident is low; approximately 8900 times below the regulatory limit or equal to an annual FED of $1\frac{3}{4}$ minutes. In fact, the received dose may be lower.

4.1.4 Resident along Highway

4.1.4.1 Scenario Description

This scenario is identical to the one described in Section 4.1.1 except for the speed of the passing UFTP shipment. The typical minimum set-back distance for buildings along the representative route for both highways and controlled access highways was determined to be 25 m. Buildings along highways, however, frequently have areas such as parking areas located in front of them, at times placing individuals closer to passing UFTP shipments. In this scenario the resident is assumed to be located in or around the building at a distance of 25 m from the

passing UFTP shipment for 50% of the shipments and is assumed to be located in the parking area in front of the building at a distance of 20 m from the shipment for an additional 10% of the shipments. The posted speed limit of Ontario highways is typically 80 km/h or 90 km/h. For calculations, an average speed of 80 km/h is assumed for the passing UFTP shipments. The scenario is illustrated in Figure 11, below. Additional details are provided in Appendix B.4 under the activity "Resident along Highway".

4.1.4.2 Dose to Resident along Highway

The dose received by the resident per occurrence is the sum of the doses received from the passing shipments when the resident is located at 20 m and at 25 m. In the described scenario, the dose to the resident at 20 m from a UFTP shipment passing at 80 km/h is calculated to be 0.0000000314 mSv. At the same shipment speed and an exposure distance of 25 m, the dose would be 0.0000000245 mSv. For 62 shipments at 20 m (10% of the shipments), the received dose would be 0.00000195 mSv and for 310 shipments at 25 m (50% of the shipments), the received dose would be 0.00000761 mSv. The total annual dose received by the resident is calculated to be 0.0000096 mSv (see Appendix B.4).

4.1.4.3 Discussion – Resident along Highway

The annual dose received by a resident along a highway is very low; approximately 100 000 times below the regulatory limit or equal to an annual FED of 9 seconds. Shielding provided by buildings or other sources is not credited, but will reduce dose exposure to the resident.

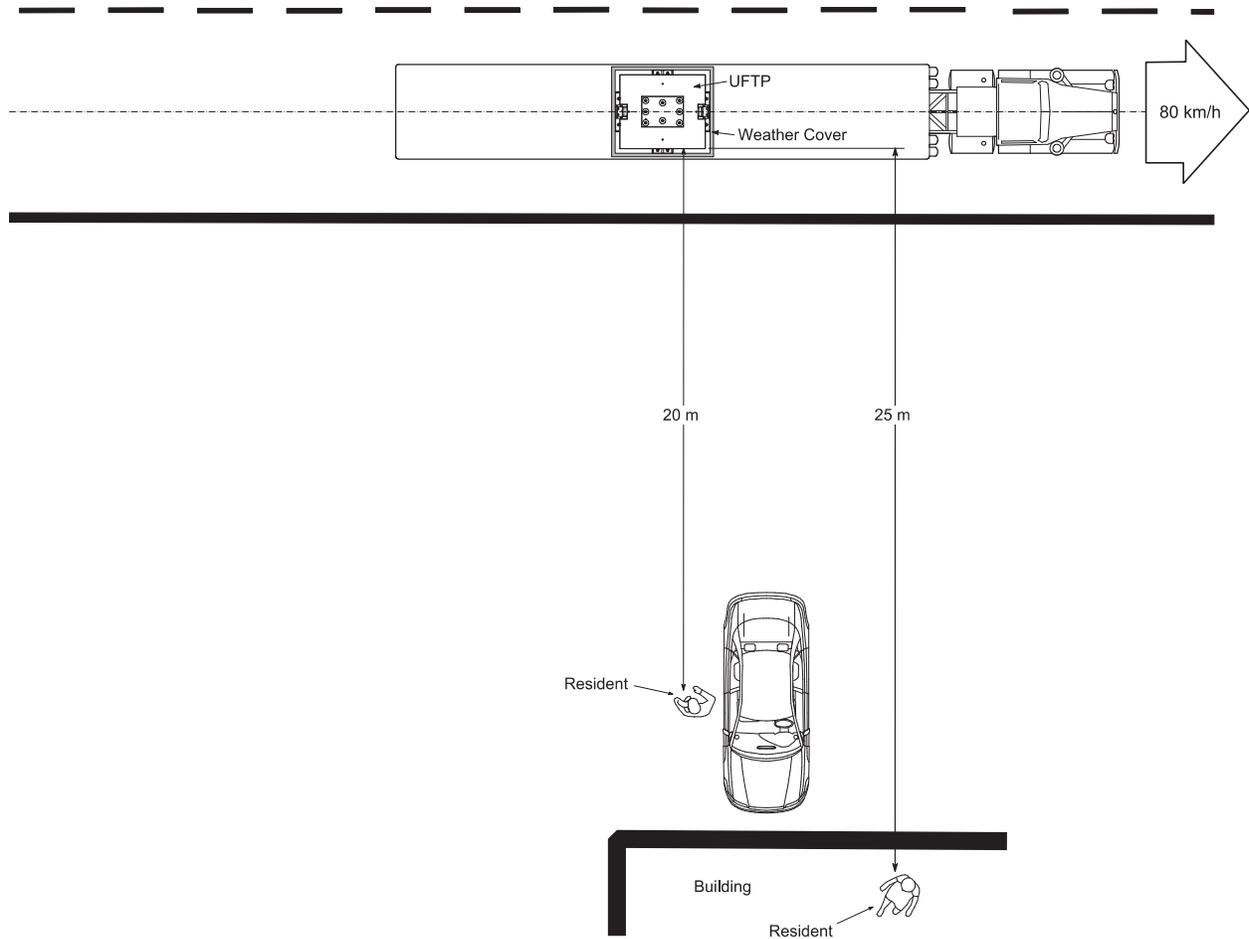


Figure 11: Resident along Highway

4.1.5 Resident along Controlled Access Highway

4.1.5.1 Scenario Description

As stated in Section 4.1.1.1, the typical minimum set-back distance for buildings along the representative route for both highways and controlled access highways was determined to be 25 m. The posted speed limit on the 400 series highways in Ontario highways is typically 100 km/h. However, traffic congestion on controlled access highways is a frequent reality. In this scenario a resident along a controlled access highway is assumed to be present at 25 m from the passing UFTP shipment for 50% of all 620 annual shipments. Of these 310 shipments, 90% are assumed to pass at 100 km/h and the remaining 10% of shipments are assumed to pass at 24 km/h due to traffic congestion. The scenario is illustrated in Figure 12, below. Additional details are provided in Appendix B.5 under the activity “Resident along Controlled Access Highway”.

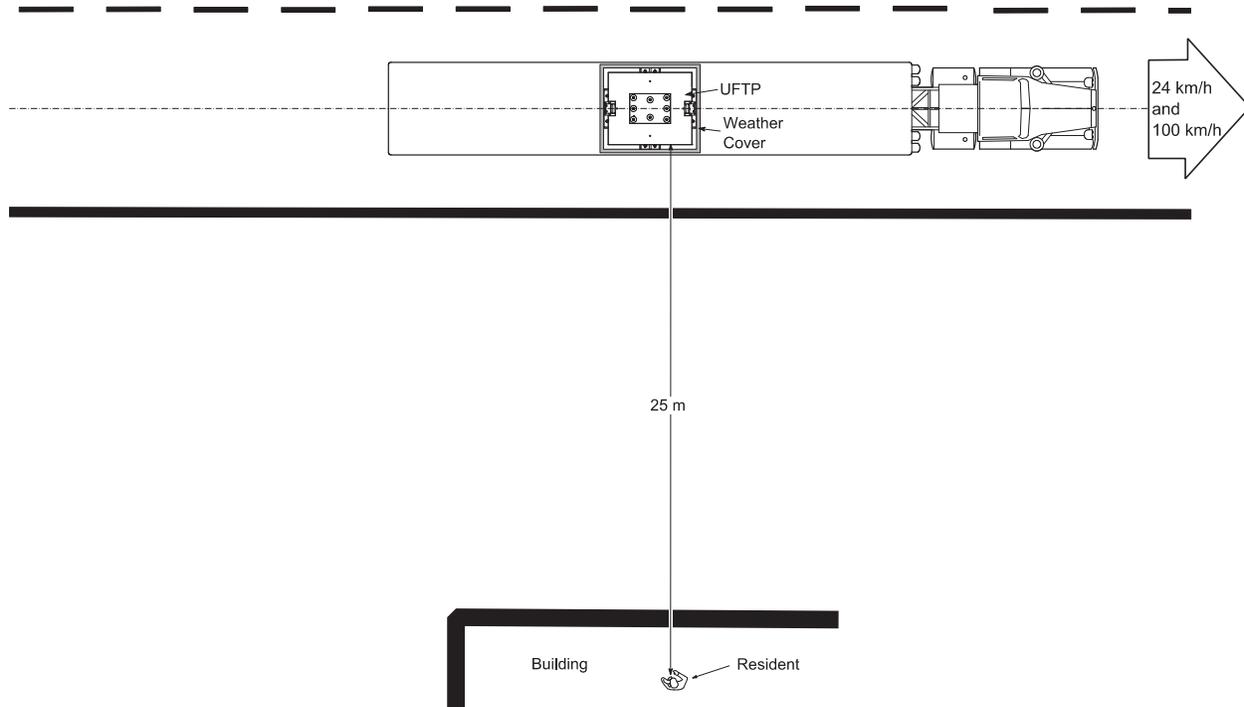


Figure 12: Resident along Controlled Access Highway

4.1.5.2 Dose to Resident along Controlled Access Highway

The dose received by the resident per occurrence is simply the dose received from the passing shipment. In the described scenario, the dose to the resident exposed to a single UFTP shipment travelling at 100 km/h is calculated to be 0.000000196 mSv. At 24 km/h, the dose would be 0.000000818 mSv. For 310 occurrences annually, the total dose received by the resident is calculated to be 0.000080 mSv (see Appendix B.5).

4.1.5.3 Discussion – Resident along Controlled Access Highway

The annual dose received by a resident along a controlled access highway is very low; approximately 130 000 times below the regulatory limit or equal to an annual FED of 7 seconds. The received dose will likely be significantly lower. The described scenario assumes that the resident will be exposed to 50% of the shipments or 310 shipments per year. However, considering the location of the used fuel, it is unlikely that all 620 annual UFTP shipments will use the same stretch of controlled access highway (approximately 45% of all used fuel is located at the Bruce site and another 45% split between the Pickering and Darlington sites). This it is very unlikely that a resident would experience 310 shipments per year. Additionally, shielding provided by buildings or other sources is not credited, but will reduce dose exposure to the resident.

4.1.6 Summary of Estimated Annual Dose to Residents along Transport Route

Table 5 summarizes the estimated annual dose received by residents along the various road types discussed in Sections 4.1.1 to 4.1.5, above. In all cases, the dose estimated to be

received by a resident is many orders of magnitude below the regulatory dose limit of 1 mSv per year for members of the public.

Table 5: Summary of Estimated Annual Dose to Residents along Transport Route

Resident	Estimated Annual Dose	Factor to Dose Limit (1 mSv/year)	FED (rounded)
Resident in Urban Area – Sensitivity Case B	0.00011 mSv	8900	1¼ minutes
Resident in Urban Area – Sensitivity Case A	0.000065 mSv	15 000	1 minute
Resident in Urban Area – Typical	0.000032 mSv	31 000	29 seconds
Resident along Highway	0.0000096 mSv	100 000	9 seconds
Resident along Controlled Access Highway	0.0000080 mSv	130 000	7 seconds

Residents are assumed to be present for 40% to 60% of the passing UFTP shipments in the scenarios analyzed. The annual dose to the residents in each of the each of the scenarios is such that in the unlikely event that a resident would be exposed to 100% of the passing UFTP shipments, the dose estimated to be received by the resident would still be many orders of magnitude below the regulatory dose limit.

4.2 PEDESTRIAN

Members of the public are routinely engaged in activities alongside roadways. People walk to schools, stores, neighbours homes, sit in sidewalk cafes, walk our dogs, exercise, etc. If these activities occur along a UFTP shipment route, there is a possibility of receiving dose from the passing shipment. Pedestrians may be present alongside urban roads as well as highways, but they are prohibited on controlled access highways. Due to the slower traffic speed on urban roadways (slower transport speed relates to an increased exposure time and an increased potential dose), the dose to a pedestrian along an urban road will be higher than for a pedestrian along a highway. Thus, the dose to a pedestrian along a highway is captured by the dose to a pedestrian along an urban road.

4.2.1 Scenario Description

In this scenario, a pedestrian is assumed to be present on a sidewalk, 3.5 m from the side of a passing UFTP shipment as it passes by. For conservatism in calculations, the speed of the UFTP shipment is assumed to be 24 km/h. The pedestrian is assumed to be exposed to 62 shipments per year (10% of all annual shipments). The scenario is illustrated in Figure 13, below. Additional details are provided in Appendix B.6 under the activity “Pedestrian”.

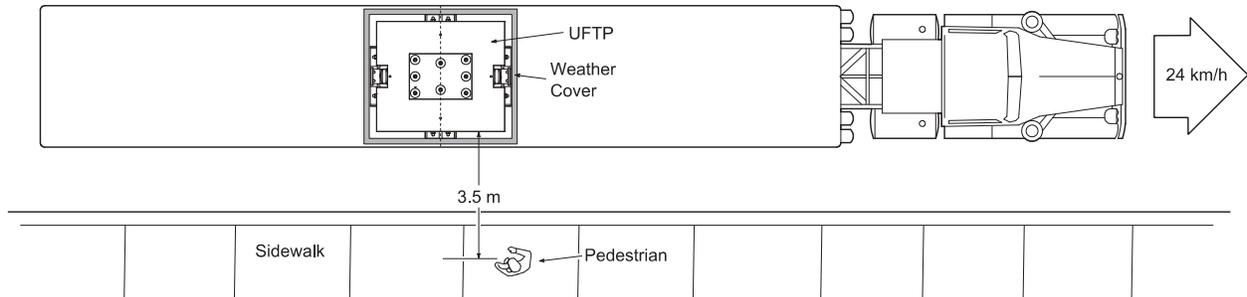


Figure 13: Pedestrian

4.2.2 Dose to Pedestrian

The dose received by the pedestrian per occurrence of UFTP is simply the dose received as the shipment passes by. This is calculated to be 0.000000485 mSv. For 62 occurrences annually, the total dose received by the pedestrian is 0.000028 mSv.

4.2.3 Discussion – Pedestrian

The annual dose received by a pedestrian is very low; approximately 35 000 times below the regulatory limit or equal to an annual FED of 26 seconds.

4.3 HITCHHIKER

Although hitchhiking in Ontario is not legal (the Ontario Highway Traffic Act (GoO, 1990) does not permit a person on any public roadway to solicit a ride from the driver of a motor vehicle, apart from a taxi or transit bus), it does occur. Hitchhiking is not as common as it once was and it is rare to see a hitchhiker in an urban setting. When present, hitchhikers are most often found on the outskirts of urban areas. Within an urban area, there is little to distinguish a hitchhiker from a pedestrian, thus dose to a hitchhiker in an urban area is captured by the dose to a pedestrian presented in Section 4.2. Dose to a hitchhiker along a highway is examined in this section.

4.3.1 Scenario Description

Hitchhikers may be present along highways and in urban areas along roadways, but pedestrians of any kind are prohibited on controlled access highways such as the 400 series highways in Ontario. In this scenario, a hitchhiker is assumed to be standing along the roadside as traffic passes by. The hitchhiker is assumed to be located approximately 3.1 m from the side of the UFTP as it passes by.

The posted speed limits on Ontario highways are typically 80 km/h or 90 km/h, however hitchhikers are typically located on the outskirts of towns where the posted speed is lower. In this scenario, the UFTP shipment is assumed to be passing the hitchhiker at 50 km/h. The hitchhiker is assumed to be exposed to 1% or 6 of the 620 annual shipments. The scenario is illustrated in Figure 14, below. Additional details are provided in Appendix B.7 under the activity “Hitchhiker along Highway”.

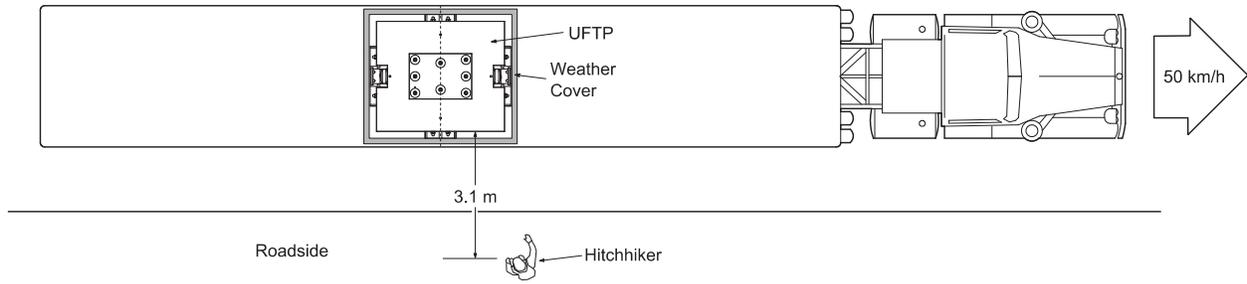


Figure 14: Hitchhiker

4.3.2 Dose to Hitchhiker

The dose received by the hitchhiker per occurrence is simply the dose received from the passing shipment. In the described scenario, the dose to the hitchhiker exposed to a single UFTP shipment is calculated to be 0.000000214 mSv. For 6 occurrences annually, the total dose received by the hitchhiker is 0.0000013 mSv (see Appendix B.7).

4.3.3 Discussion – Hitchhiker

The annual dose received by a hitchhiker is very low, approximately 780 000 times below the regulatory limit or equal to an annual FED of 1 second.

4.4 ROADSIDE WORKER

Workers may be present along roads and highways. These workers are not associated with the transport of used fuel, but are typically involved in work maintaining or upgrading transport infrastructure. In the context of this assessment, these workers are not considered transportation workers, but members of the public. Their duties typically include installing or repairing roadside signs, mowing or clearing vegetation on roadside shoulders, etc. or construction workers involved in the repair or upgrade of roads and associated transport infrastructure such as bridges and culverts. Due to their proximity to the road and project-based work, this assessment examines the radiological dose to these roadside construction workers.

Although road construction occurs on all road types, urban road construction projects tend to be shorter in duration than highway construction projects. In this assessment, the UFTP shipment drive-by speed in work zones is assumed to be 24 km/h, hence radiological dose to workers in urban road work zones is bounded by the analysis of dose to workers along a highway.

Work zones along controlled access highways are generally demarked with construction pylons or concrete barriers. Typically, the speed limit in these zones is reduced to 80 km/h. As the drive-by speed in the scenarios discussed in this section is assumed to be 24 km/h, the dose to workers along controlled access highways is bounded by the analysis of dose to workers along a highway.

Two types of workers are considered: the construction worker along the highway and the traffic control person.

4.4.1 Highway Construction Worker

4.4.1.1 Scenario Description

Roadside construction workers will be present along roads and highways as UFTP shipments pass by. In this scenario, a construction worker is assumed to be working along the side of the road as the UFTP shipment passes by.

Speed limits in construction areas along roads are typically reduced from the posted speeds, however in this scenario, the speed of the UFTP shipment is assumed to be 24 km/h. This conservative assumption takes into account that the construction could be along an urban road or a highway. Since the activities engaged in by the construction worker will vary over the course of the construction project, the construction worker is assumed to be located at 3.1 m from the side of the passing shipment for 25% of the shipments he or she is exposed to and is assumed to be located at 5 m from the shipment for the remaining 75% of the shipments.

The construction worker is assumed to be present for two shipments per day, five days per week for a period of 26 weeks, or a total of 260 UFTP shipments per year. The scenario is illustrated in Figure 15, below. Additional details are provided in Appendix B.8 under the activity “Construction Worker along Highway”.

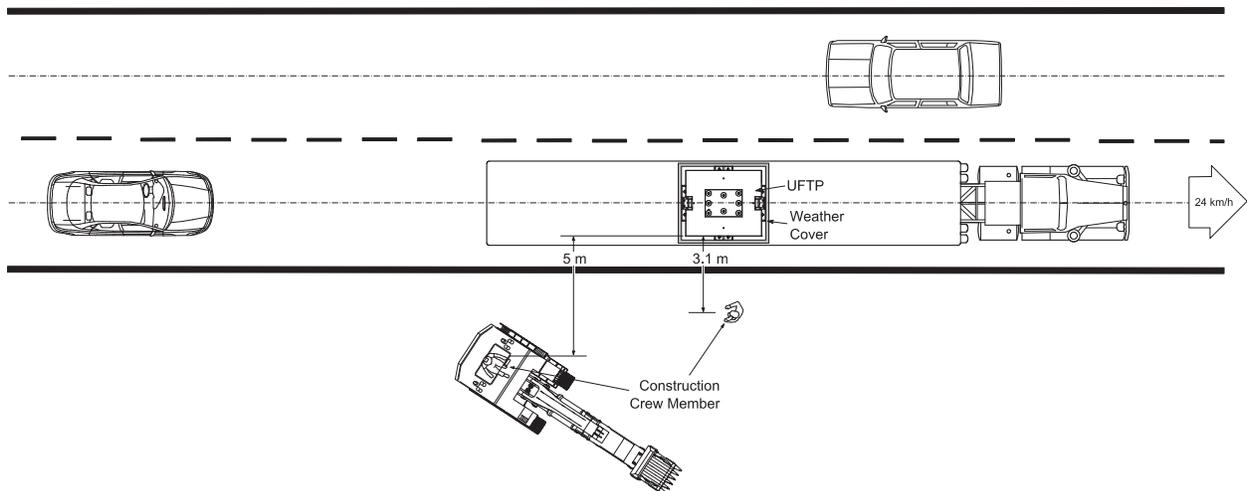


Figure 15: Construction Worker along Highway

4.4.1.2 Dose to Highway Construction Worker

The dose received by the construction worker per occurrence is simply the dose received from the passing shipment. For the shipments passing the construction worker at 3.1 m from the shipment, the dose is calculated to be 0.000000446 mSv per occurrence. When the worker is at 5 m from the UFTP shipment, the dose received by the worker drops to 0.000000340 mSv per occurrence. The annual dose received by the construction worker over the 260 occurrences is calculated to be 0.000095 mSv per year (see Appendix B.8).

4.4.1.3 Discussion – Highway Construction Worker

The annual dose received by a construction worker is low: approximately 10 000 times below the regulatory limit or equal to an annual FED of 1½ minutes. The dose to the construction worker may be lower. This scenario assumes that all shipments will travel through the construction zone during working hours. No credit is given for additional shielding (provided by construction equipment, portable construction offices, etc.) between the worker and the shipment.

It is possible that congested (stopped) traffic in a construction zone could place a construction worker in close proximity to a UFTP shipment for a lengthy period. The dose to the construction worker during this event can be approximated to be equivalent to the dose received by a vehicle occupant in congested traffic as described in Section 4.6.6. The resulting annual dose to the construction worker in this scenario can be estimated to be the sum of the doses calculated in this section (0.000097 mSv) and that from Section 4.6.6 (0.00038 mSv). In this unlikely situation, the construction worker may receive an annual dose of 0.00048 mSv. This dose is still more than 2000 times below the regulatory limit and less than the estimate for a Traffic Control Person discussed in the next section.

4.4.2 Traffic Control Person

4.4.2.1 Scenario Description

Road construction projects may require controls to guide traffic through construction zones. These controls may include temporary automated signal lights or, at times, traffic control persons. This scenario examines how a traffic control person may be exposed to passing UFTP shipments.

The traffic control person is assumed to be stopping traffic along a highway. The traffic control person is assumed to be exposed to two shipments per day, five days per week for a period of 26 weeks, or a total of 260 UFTP shipments per year. 15% of these shipments are assumed to pass the traffic control person at a reduced speed of 24 km/h. It is assumed that the traffic control person will be within 5 m of the passing UFTP shipment. The remaining 50% of the shipments will be stopped by the traffic control person for a period of 5 minutes. 10% of the stopped shipments are assumed to be first in the traffic queue, thereby placing the traffic control person approximately 14 m from the stopped UFTP. As traffic resumes, the UFTP shipment is assumed to pass the traffic control person at a speed of 5 km/h and at a minimum distance of 2 m. The scenario is illustrated in Figure 16, below. Additional details are provided in Appendix B.9 under the activity “Traffic Control Person along Highway”.

4.5.1 Cyclist along Urban Road

4.5.1.1 Scenario Description

Cyclists may be present along urban roads as a UFTP shipment passes by. In this scenario, a cyclist is assumed to be riding along the side of the road as the UFTP shipment approaches the cyclist from behind and passes the cyclist. The cyclist is then assumed to travel behind the shipment at the same speed as the shipment for a period of two and a half minutes (covering a total a distance of 1 km).

Speed limits in urban areas are typically 40 km/h or 50 km/h, however in this scenario, the speed of the UFTP shipment is assumed to be 24 km/h. The cyclist is initially assumed to be travelling at a speed of 20 km/h. This equates to a relative speed difference of 4 km/h between the shipment and the cyclist as the shipment passes the cyclist. The cyclist is assumed to be located at 1.5 m from the side of the passing shipment. Once the UFTP shipment has passed, the cyclist's speed is assumed to increase to match that of the UFTP shipment and follow the shipment at a distance of 10 m from the UFTP over a 1 km distance.

The cyclist is assumed to be exposed to 2 shipments per year. An illustration of this scenario is provided in Figure 17, below. Additional details are provided in Appendix B.10 under the activity "Cyclist along Urban Road".

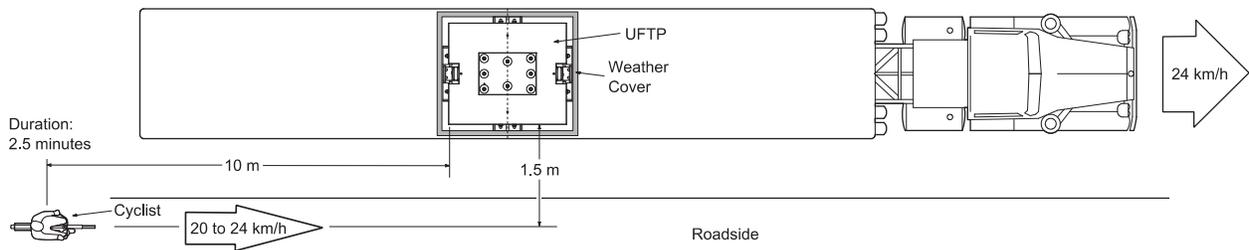


Figure 17: Cyclist along Urban Road

4.5.1.2 Dose to Cyclist along Urban Road

The dose received by the cyclist per occurrence is the sum of the dose received from the passing shipment and the dose received while following the shipment. In the described scenario, the dose to the cyclist due to the passing shipment is calculated to be 0.00000589 mSv and the dose received while following the shipment at 10 m from the package for 2.5 minutes is 0.0000067 mSv giving a total dose per shipment of 0.0000126 mSv. For two occurrences annually, the total dose received by the cyclist is 0.000025 mSv (see Appendix B.10).

4.5.1.3 Discussion – Cyclist along Urban Road

The annual dose received by a cyclist is very low, approximately 40 000 times below the regulatory limit or equal to an annual FED of 23 seconds.

4.5.2 Cyclist on Highway

4.5.2.1 Scenario Description

Cyclists may be present along highways, but are prohibited on controlled access highways such as the 400 series highways in Ontario. In this scenario, a cyclist is assumed to be riding along the side of the highway as traffic passes by. The cyclist is assumed to be travelling at a speed of 30 km/h. This speed is representative of an accomplished rider (the average speed for a Tour-de-France rider is approximately 40 km/h). Assuming a high speed for the cyclist is reasonable as it results in conservative dose calculations (a higher cyclist speed results in a lower relative speed between the cyclist and the UFTP shipment thereby increasing the exposure time).

The posted speed limits on Ontario highways are typically 80 km/h or 90 km/h, however the passing UFTP shipment is assumed to have reduced its speed to 70 km/h. This results in a relative passing speed of 40 km/h. The cyclist is assumed to be located at 1.5 m from the side of the passing shipment.

Cyclists travelling along the Trans-Canada Highway may be on the road for several weeks. In the analysed scenario, the cyclist is assumed to be exposed to 30 shipments per year (two shipments per day for a period of three weeks). An illustration of this scenario is provided in Figure 18, below. Additional details are provided in Appendix B.11 under the activity “Cyclist along Highway”.

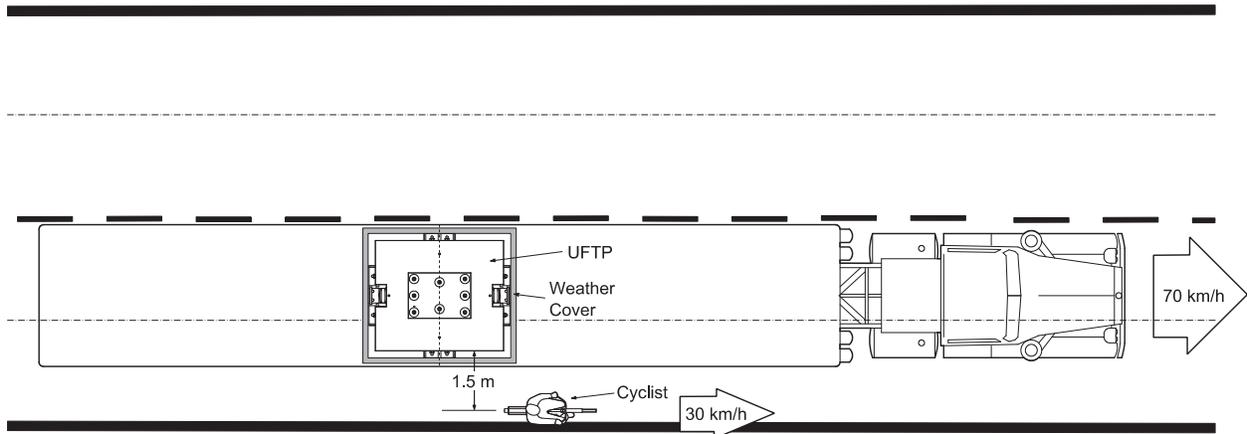


Figure 18: Cyclist along Highway

4.5.2.2 Dose to Cyclist on Highway

The dose received by the cyclist per occurrence is simply the dose received by the cyclist as the shipment passes by. This dose is calculated to be 0.000000401 mSv. For 30 occurrences annually, the total dose received by the cyclist is 0.000012 mSv (see Appendix B.11).

4.5.2.3 Discussion – Cyclist on Highway

The annual dose received by a cyclist is very low, approximately 83 000 times below the regulatory limit or equal to an annual FED of 11 seconds.

4.6 VEHICLE OCCUPANT

Members of the public may be exposed to the UFTP as occupants of vehicles while sharing the route with a UFTP shipment. An occupant of a vehicle may be travelling in front of, beside, or behind the UFTP shipment. This section examines scenarios placing vehicle occupants in the proximity of a UFTP shipment travelling along urban roads, highways, and controlled access highways.

The geometry of the UFTP shipment dictates that only vehicle occupants travelling beside or behind the UFTP shipment need be considered. The UFTP is positioned near the centre of the trailer, placing it approximately 5 m from the rear bumper of the trailer and approximately 13 m from the front bumper of the tractor. As a result, a vehicle occupant travelling behind the shipment will be in closer proximity to the UFTP than a vehicle occupant travelling in front of the shipment. Doses calculated for vehicle occupants travelling behind the shipment will be higher and bound those for vehicle occupants travelling in front of the shipment. Additionally, the tractor itself will provide significant shielding for vehicle occupants travelling in front of the shipment and the space between the shipment and the vehicle in front can be controlled by the NWMO driver.

The following scenarios are evaluated in this section:

- 1) Vehicle Occupant on Urban Road
 - a. travelling beside the UFTP shipment (Section 4.6.1); and
 - b. travelling behind the UFTP shipment (Section 4.6.2).
- 2) Vehicle Occupant on Highway or Controlled Access Highway
 - a. travelling behind and passing the UFTP shipment (Section 4.6.3).
- 3) Vehicle Occupant in Congested Traffic
 - a. travelling behind the UFTP shipment on Highway (Section 4.6.4);
 - b. travelling behind the UFTP shipment on Controlled Access Highway (Section 4.6.5); and
 - c. travelling beside the UFTP shipment on Controlled Access Highway (Section 4.6.6).

In normal traffic on highways and controlled access highways, vehicles are assumed to approach the UFTP shipment from behind and, within a short period of time, pass the UFTP shipment and continue their journey. The situation where a vehicle is unable to pass the UFTP shipment for an extended period of time is examined in Section 4.6.4, Vehicle Occupant on Highway – Congested Traffic. Similarly, congested traffic conditions on controlled access highways are examined in Sections 4.6.5 and 4.6.6. As the traffic speed in these sections is assumed to be slow (more typical of urban traffic), these scenarios also capture congested traffic conditions along urban roadways.

It should be noted that the minimum distance between the UFTP and the vehicle occupant is assumed to be 2.3 m. This assumption captures the minimum distance between the vehicle occupant and the UFTP regardless of their position in the vehicle, whether they are the driver, or a passenger. Motorcycle riders are also included as no credit for additional shielding offered by a vehicle is assumed.

4.6.1 Vehicle Occupant on Urban Road – Beside UFTP Shipment

4.6.1.1 Scenario Description

In this scenario, a UFTP shipment is assumed to be stopped at a traffic signal. A vehicle and occupant approach the UFTP shipment and stop directly adjacent to the UFTP. The signal cycle time is assumed to be 1½ minutes. During the stop, the vehicle occupant is assumed to be located at a distance of 2.3 m from the UFTP. As the UFTP shipment is heavy (a gross vehicle weight of around 56 tonnes) and acceleration from a stopped position is slow, the vehicle occupant approach and departure speed is assumed to be 5 km/h. The vehicle occupant is assumed to encounter this scenario twice per year. The scenario is illustrated in Figure 19, below. Additional details are provided in Appendix B.12 under the activity “Vehicle Occupant on Urban Road – Beside UFTP Shipment”.

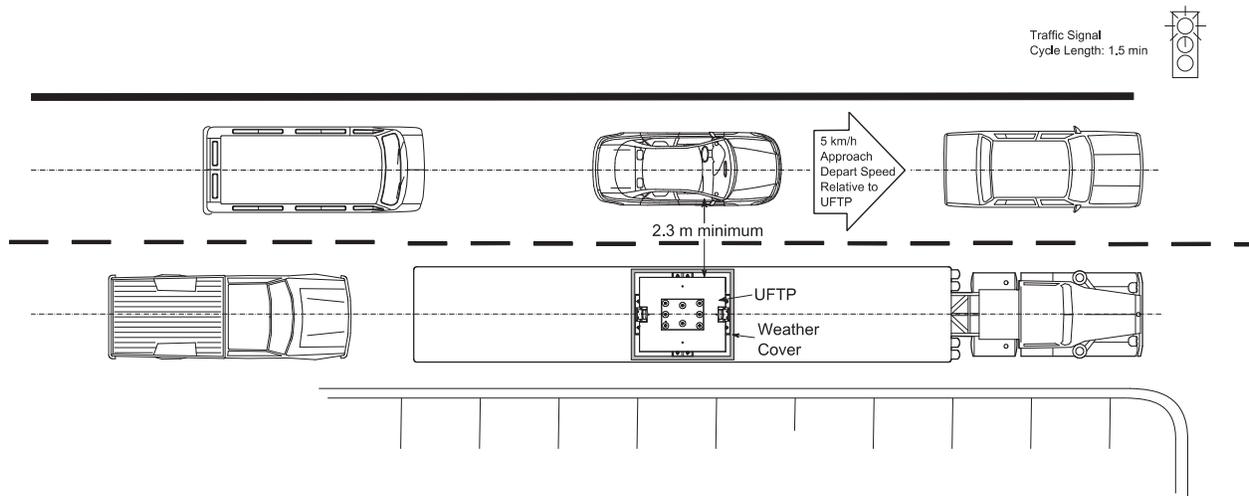


Figure 19: Vehicle Occupant on Urban Road beside UFTP Shipment

4.6.1.2 Dose to Vehicle Occupant on Urban Road – Beside UFTP Shipment

The dose received by the vehicle occupant per occurrence is the sum of the dose received during the approach to and departure from the UFTP shipment and the dose received while stopped next to the UFTP. The dose received during approach to and departure from the shipment at a minimum distance of 2.3 m is calculated to be 0.00000390 mSv. The dose received during the 1½ minute stop next to the UFTP at 2.3 m away is calculated to be 0.0000675 mSv. The dose per occurrence is 0.0000714 mSv. For two occurrences per year, the annual dose would be 0.00014 mSv per year (see Appendix B.12).

4.6.1.3 Discussion – Vehicle Occupant on Urban Road – Beside UFTP Shipment

The annual dose received by a vehicle occupant travelling beside a UFTP shipment on an urban road is low; approximately 7000 times below the regulatory limit or equal to an annual FED of 2 minutes and 9 seconds. In fact, the received dose may be lower. The cycle time of most signals on major routes is less than 1½ minutes and the relative difference in speed between the vehicle and the UFTP shipment will likely be much greater than 5 km/h, a typical walking speed. Since this scenario is assumed to only occur twice per year to the same individual, peak dose rates, rather than average dose rates are used in the calculations. Additionally, shielding provided by vehicle the occupant is in is not credited.

4.6.2 Vehicle Occupant on Urban Road – Behind UFTP Shipment

4.6.2.1 Scenario Description

In this scenario, a vehicle and occupant are assumed to approach the UFTP shipment from behind at a relative speed of 5 km/h and then travel behind a UFTP shipment for a period of 2½ minutes. The UFTP shipment is then stopped at a traffic signal for 1½ minutes with the vehicle occupant positioned behind the UFTP shipment. When the traffic signal turns green, the vehicle and occupant pass the UFTP shipment. While following the shipment, the vehicle occupant is assumed to be located 18 m behind the UFTP. During the signal stop, the vehicle occupant is assumed to be 10 m away from the UFTP. While passing, the minimum distance between the vehicle occupant and the UFTP is assumed to be 2.3 m. This scenario is assumed to be representative of an urban community near the repository site and a given vehicle occupant is assumed to experience it 8 times per year. The scenario is illustrated in Figure 20, below. Additional details are provided in Appendix B.13 under the activity “Vehicle Occupant on Urban Road – Behind UFTP Shipment”.

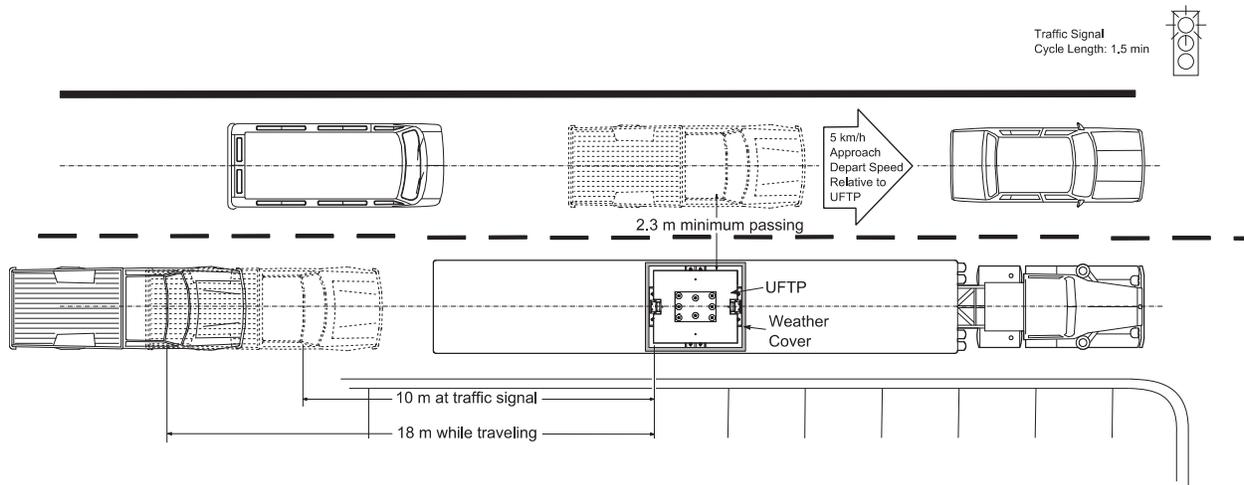


Figure 20: Vehicle Occupant on Urban Road behind UFTP Shipment

4.6.2.2 Dose to Vehicle Occupant on Urban Road – Behind UFTP Shipment

The dose received by the vehicle occupant per occurrence is the sum of the dose received during the approach to and departure from the UFTP shipment, the dose received while travelling behind the UFTP and the dose received while stopped behind to the UFTP. The dose received during approach to and departure from the shipment at a minimum distance of 2.3 m is calculated to be 0.00000289 mSv. The dose received during the 2½ minutes travelling behind the UFTP at 18 m away is calculated to be 0.00000208 mSv. The dose received during the 1½ minute stop behind the UFTP at 10 m away is calculated to be 0.00000336 mSv. The dose per occurrence is 0.00000834 mSv. For eight occurrences per year, the annual dose would be 0.000067 mSv per year (see Appendix B.13).

4.6.2.3 Discussion – Vehicle Occupant on Urban Road – Behind UFTP Shipment

The annual dose received by a vehicle occupant travelling behind a UFTP shipment on an urban road is low; approximately 15 000 times below the regulatory limit or equal to an annual FED of 60 seconds. The received dose may be lower. The cycle time of most signals on major

routes is less than 1½ minutes and the relative difference in speed between the vehicle and the UFTP shipment will likely be much greater than 5 km/h, a typical walking speed. Additionally, shielding provided by vehicle the occupant is in is not credited.

4.6.3 Vehicle Occupant – Passing UFTP Shipment on Highway

Vast stretches of Ontario highways consist of two lanes of traffic, one in each direction. In many cases, a vehicle occupant may be required to follow a slower moving vehicle for some time before a safe passing opportunity arises. On highways such as the Trans-Canada Highway, passing lanes have been incorporated, usually along uphill stretches, to allow traffic to pass slower moving vehicles. Controlled access highways are usually multi-lane, thus passing is more straight-forward and may be accomplished by changing lanes and passing the slower moving vehicle. Traffic travelling at posted highway speeds (typically 80 to 100 km/h) necessitates a safe separation distance between vehicles. At highway speeds, this separation distance is typically greater than 30 m (assuming the two-second rule for maintaining a safe separation distance, a vehicle travelling at 80 km/h for 2 seconds covers a distance of 44 m), hence the dose received by a vehicle occupant following a UFTP shipment, even for an extended period of time, is negligible. Separation distances will be reduced during congested traffic. Congested traffic scenarios are examined in Sections 4.6.4, 4.6.5 and 4.6.6.

4.6.3.1 Scenario Description

In this scenario a vehicle occupant is assumed to be following and then passing a UFTP shipment while travelling along the highway. As the opportunity to pass presents itself, the vehicle occupant is assumed to approach and overtake the shipment at a relative speed of 5 km/h. While passing, the vehicle occupant is assumed to be located at a minimum distance of 2.3 m from the UFTP. An illustration of this scenario is provided in Figure 21, below. The vehicle occupant is assumed to encounter 10% of all shipments or 62 shipments per year. This scenario is applicable to highways and controlled access highways. Additional details are provided in Appendix B.14 under the activity “Vehicle Occupant passing UFTP Shipment”.

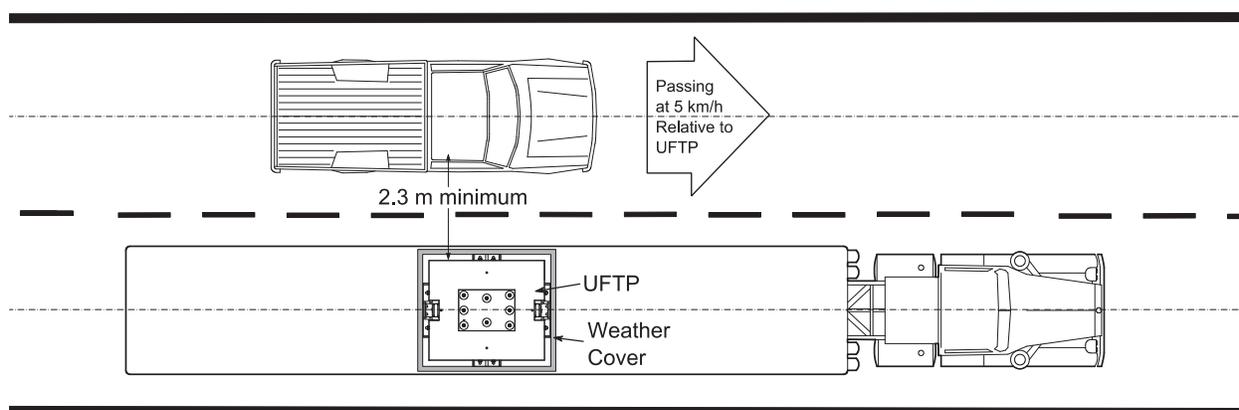


Figure 21: Vehicle Occupant passing UFTP Shipment

4.6.3.2 Dose to Vehicle Occupant – Passing UFTP Shipment

The dose received by the vehicle occupant per occurrence is simply the dose received while passing the UFTP shipment. The dose received while passing the shipment at a minimum

distance of 2.3 m is calculated to be 0.00000289 mSv. For 62 occurrences per year, the annual dose would be 0.00018 mSv per year (see Appendix B.14).

4.6.3.3 Discussion – Vehicle Occupant – Passing UFTP Shipment

The annual dose received by a vehicle occupant along a highway is low; approximately 5600 times below the regulatory limit or equal to an annual FED of 2 minutes and 41 seconds. In fact, the received dose may be lower. The relative difference in speed between the vehicle and the UFTP shipment will likely be much greater than 5 km/h, a typical walking speed. Additionally, shielding provided by vehicle the occupant is in is not credited.

4.6.4 Vehicle Occupant in Congested Traffic – Behind UFTP Shipment

4.6.4.1 Scenario Description

This scenario is similar to the one described in Section 4.6.2 above. A vehicle occupant is assumed to be following a UFTP shipment in stop-and-go traffic for a period of 30 minutes. Due to traffic congestion, the separation distances between the UFTP and the vehicle occupant are assumed to be similar to those encountered in urban traffic rather than the ones typical of highway traffic. The vehicle occupant is assumed to be behind the UFTP shipment at a distance of 10 m from the UFTP for a period of 5 minutes and at a distance of 18 m for the remaining 25 minutes. Once the congestion has cleared, the vehicle occupant is assumed to pass the UFTP shipment at a relative speed of 5 km/h and a minimum distance of 2.3 m from the UFTP. An illustration of this scenario is provided in Figure 22, below. The vehicle occupant is assumed to encounter this congestion for 1% of all shipments or 6 shipments per year. This scenario is applicable to all three categories of roads. Additional details are provided in Appendix B.15 under the activity “Vehicle Occupant in Congested Traffic – Behind UFTP Shipment”.

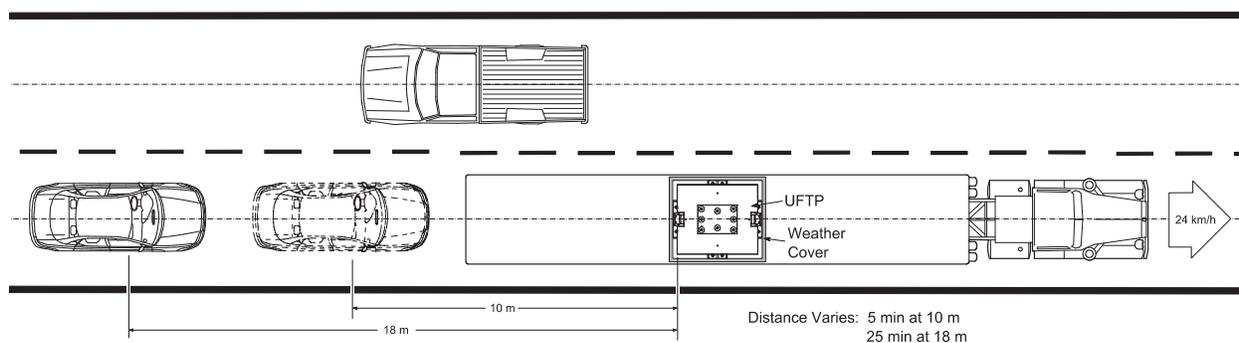


Figure 22: Vehicle Occupant in Congested Traffic behind UFTP Shipment

4.6.4.2 Dose to Vehicle Occupant in Congested Traffic – Behind UFTP Shipment

The dose received by the vehicle occupant per occurrence is the sum of the dose received at 18 m from the shipment for a period of 25 minutes, the dose received at 10 m from the shipment for a period of 5 minutes and the dose received while passing the UFTP shipment. Per occurrence, the dose received at 18 m for 25 minutes is 0.000021 mSv, at 10 m for 5 minutes, the dose received is 0.000011 mSv and while passing the shipment at a minimum distance of 2.3 m the dose is calculated to be 0.00000289 mSv. The total dose per occurrence is

calculated to be 0.000035 mSv. For 6 occurrences per year, the annual dose would be 0.00021 mSv per year (see Appendix B.15).

4.6.4.3 Discussion – Vehicle Occupant in Congested Traffic – Behind UFTP Shipment

The annual dose received by a vehicle occupant along a highway during congested traffic travelling behind the UFTP shipment is low; approximately 4800 times below the regulatory limit or equal to an annual FED of 3 minutes and 9 seconds. In fact, the received dose may be lower. Traffic is fluid with the positions of vehicles changing continuously, even during congested traffic. It is unlikely that over the course of the one hour congestion the relative positions between the vehicle occupant and the UFTP will remain as static as described. The relative difference in speed between the vehicle and the UFTP shipment will likely be much greater than 5 km/h, a typical walking speed. Additionally, shielding provided by vehicle the occupant is in is not credited.

4.6.5 Vehicle Occupant in Congested Traffic on Controlled Access Highway – Behind UFTP Shipment

4.6.5.1 Scenario Description

This scenario is very similar to the scenario of congested traffic on a highway as described in 4.6.4, above, but because access to the highway is controlled, there is less opportunity for a vehicle to exit the route. Again, the separation distance between the vehicle occupant and the UFTP is assumed to be reduced. In this case, the traffic congestion is assumed to last one hour. During that time, the vehicle occupant is assumed to be stopped behind the UFTP shipment at 10 m from the UFTP for a period of 5 minutes and is assumed to be travelling behind UFTP at a distance of 24 m (a larger separation distance is assumed in this scenario due to the increased speed limit on the controlled access highway) for the remaining 55 minutes. After the congestion has cleared, the vehicle occupant is assumed to pass the UFTP shipment at a relative speed of 5 km/h and a minimum distance of 2.3 m from the UFTP. An illustration of this scenario is provided in Figure 23, below. This scenario is considered to be a singular annual event for a given vehicle occupant. Additional details are provided in Appendix B.16 under the activity “Vehicle Occupant in Congested Traffic on Controlled Access Highway – Behind UFTP Shipment”.

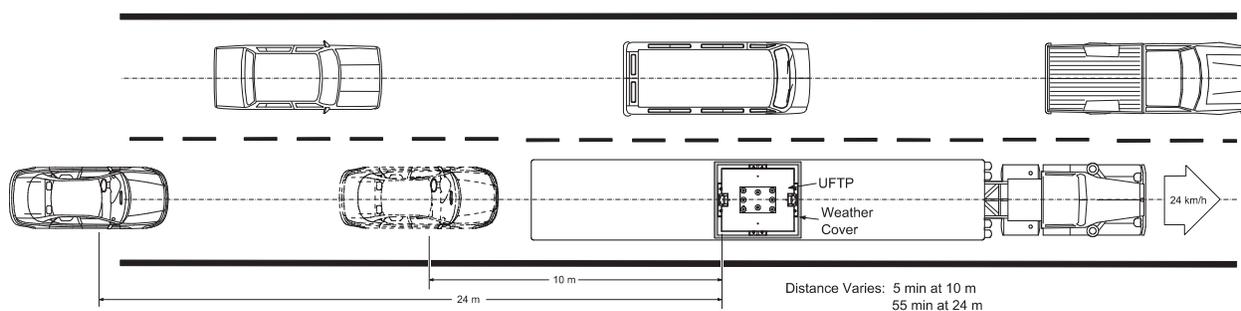


Figure 23: Vehicle Occupant in Congested Traffic on Controlled Access Highway behind UFTP Shipment

4.6.5.2 Dose to Vehicle Occupant on Controlled Access Highway – Behind UFTP Shipment

The dose received by the vehicle occupant per occurrence is the sum of the dose received at 24 m from the shipment for a period of 55 minutes, the dose received at 10 m from the shipment for a period of 5 minutes and the dose received while passing the UFTP shipment. Per occurrence, the dose received at 24 m for 55 minutes is 0.000029 mSv, at 10 m for 5 minutes, the dose received is 0.000013 mSv and while passing the shipment at a minimum distance of 2.3 m the dose is calculated to be 0.00000390 mSv. The total dose per occurrence is calculated to be 0.000047 mSv (see Appendix B.16).

4.6.5.3 Discussion – Vehicle Occupant on Controlled Access Highway – Behind UFTP Shipment

The annual dose received by a vehicle occupant along a controlled access highway during congested traffic travelling behind the UFTP shipment is low; approximately 21 000 times below the regulatory limit or equal to an annual FED of 42 seconds. In fact, the received dose may be lower. Traffic is fluid with the positions of vehicles changing continuously, even during congested traffic. It is unlikely that over the course of the one hour congestion the relative positions between the vehicle occupant and the UFTP will remain as static as described. The relative difference in speed between the vehicle and the UFTP shipment will likely be much greater than 5 km/h, a typical walking speed. Additionally, shielding provided by vehicle the occupant is in is not credited.

4.6.6 Vehicle Occupant in Congested Traffic on Controlled Access Highway – Beside UFTP Shipment

4.6.6.1 Scenario Description

This scenario is very similar to the scenario of congested traffic on a highway as described in 4.5.5, above, however in this case, the vehicle occupant is assumed to be travelling in the lane next to the UFTP shipment. Again, the traffic congestion is assumed to last one hour. During that time, the vehicle occupant is assumed to be travelling alongside the UFTP shipment at 10 m from the UFTP for a period of 55 minutes and is assumed to be located directly beside the UFTP at a distance of 2.3 m for the remaining 5 minutes. After the congestion has cleared, the vehicle occupant is assumed to pass the UFTP shipment at a relative speed of 5 km/h. An illustration of this scenario is provided in Figure 24, below. This scenario is considered to be a singular annual event for a given vehicle occupant. Additional details are provided in Appendix B.17 under the activity “Vehicle Occupant in Congested Traffic on Controlled Access Highway – Beside UFTP Shipment”.

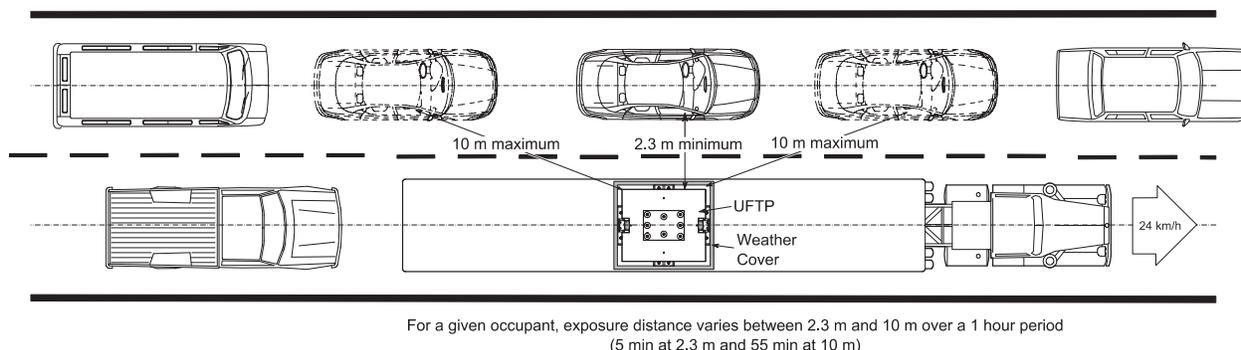


Figure 24: Vehicle Occupant in Congested Traffic on Controlled Access Highway beside UFTP Shipment

4.6.6.2 Dose to Vehicle Occupant on Controlled Access Highway – Beside UFTP Shipment

The dose received by the vehicle occupant per occurrence is the sum of the dose received at 10 m from the shipment for a period of 55 minutes, the dose received at 2.3 m from the shipment for a period of 5 minutes and the dose received while passing the UFTP shipment. Per occurrence, the dose received at 10 m for 55 minutes is 0.0000148 mSv, at 2.3 m for 5 minutes, the dose received is 0.000225 mSv and while passing the shipment at a minimum distance of 2.3 m the dose is calculated to be 0.00000390 mSv. The total dose per occurrence is calculated to be 0.00038 mSv (see Appendix B.17).

4.6.6.3 Discussion – Vehicle Occupant on Controlled Access Highway – Beside UFTP Shipment

The annual dose received by a vehicle occupant along a controlled access highway during congested traffic travelling beside the UFTP shipment is low; approximately 2700 times below the regulatory limit or equal to an annual FED of 5 minutes and 39 seconds. In fact, the received dose may be lower. Traffic is fluid with the positions of vehicles changing continuously, even during congested traffic. It is unlikely that over the course of the one hour congestion the relative positions between the vehicle occupant and the UFTP will remain as static as described. The relative difference in speed between the vehicle and the UFTP shipment will likely be much greater than 5 km/h, a typical walking speed. Additionally, shielding provided by vehicle the occupant is in is not credited.

4.6.7 Summary of Estimated Annual Dose to Vehicle Occupant sharing Transport Route

Table 6 summarizes the estimated annual dose received by vehicle occupants sharing the transport route in the various traffic scenarios discussed in Sections 4.6.1 to 4.6.6, above. In all cases, the dose estimated to be received by a resident is many orders of magnitude below the regulatory dose limit of 1 mSv per year for members of the public.

Table 6: Summary of Estimated Annual Dose to Vehicle Occupant sharing Transport Route

Vehicle Occupant	Estimated Annual Dose	Factor to Dose Limit (1 mSv/year)	FED (rounded)
On Urban Road beside UFTP Shipment	0.00014 mSv	7000	2¼ minutes
On Urban Road behind UFTP Shipment	0.000067 mSv	15 000	1 minute
Passing UFTP Shipment on Highway	0.00018 mSv	5600	2¾ minutes
In Congested Traffic behind UFTP Shipment	0.00021 mSv	4800	3¼ minutes
In Congested Traffic on Controlled Access Highway behind UFTP Shipment	0.000047 mSv	21 000	42 seconds
In Congested Traffic on Controlled Access Highway beside UFTP Shipment	0.00038 mSv	2700	5¾ minutes

5. PUBLIC ACTIVITIES AT STOPS ALONG THE TRANSPORT ROUTE

UFTP shipments will need to stop en-route for the transport crew to get food, relief, and to refuel the vehicle. Unplanned stops due to equipment breakdowns and minor incidents are also expected. Dose to individuals present near a UFTP shipment stopped en-route for any of these reasons is examined in this section.

5.1 INDIVIDUAL AT REST STOP

Rest and relief stops are required during any lengthy journey. Based on information provided by commercial trucking firms, rest and relief stops are typically 30 minutes in length and are made approximately every 400 km or 4 hours of driving time.

5.1.1 Scenario Description

Planned stops will typically be made at truck stops along the transport route. The transport crew will be trained to not to park in high traffic areas. However, members of the public could be present in the proximity of the stopped UFTP shipment.

In this scenario, a member of the public (such as a driver of a vehicle parked nearby) is assumed to approach the UFTP shipment on foot (4 km/h) and be present at a distance of 20 m during the entire 30 minutes of the rest stop. At the end of the 30 minutes, the UFTP shipment is assumed to depart at walking speed. For a given individual, this scenario is assumed to occur twice per year. An illustration of this scenario is provided in Figure 25, below. Additional details are provided in Appendix B.18 under the activity “Individual at Rest Stop”.

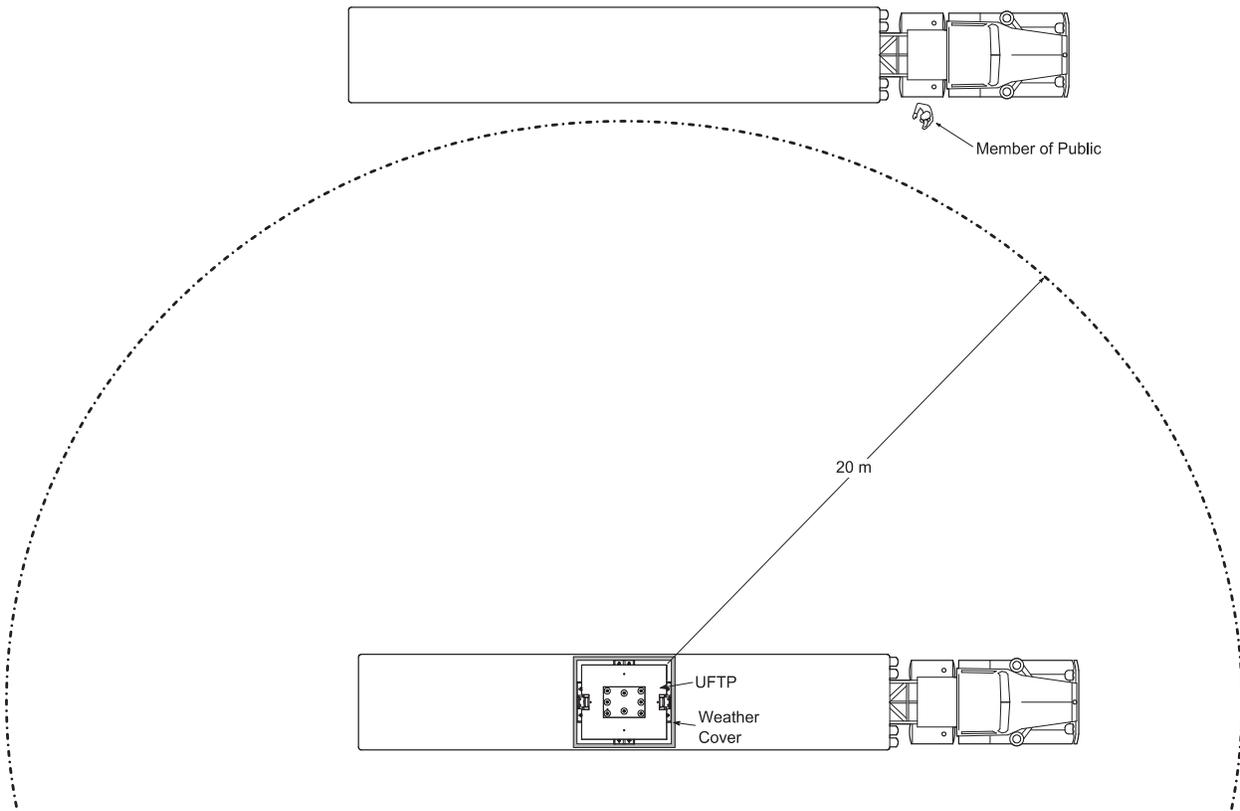


Figure 25: Individual at Rest Stop

5.1.2 Dose to Individual at Rest Stop

The dose received by the individual per occurrence is the sum of the doses received during approach and departure and the dose received during the duration of the stop. The dose due to approach and departure is calculated to be 0.000000603 mSv. The dose received by the individual at 20 m from the UFTP over the 30 minute stop is calculated to be 0.000024 mSv. The dose per occurrence is 0.000025 mSv. For 2 occurrences per year, the annual dose received by the individual is 0.000049 mSv (see Appendix B.18).

5.1.3 Discussion – Individual at Rest Stop

The annual dose received by an individual in the proximity of a UFTP shipment at a rest stop is very low, approximately 20 000 times below the regulatory limit or equal to an annual FED of 44 seconds.

5.2 COMMERCIAL DRIVER AT REFUELLING STOP

All efforts will be made to keep refuelling of a loaded UFTP shipment to a minimum. However, refuelling of loaded UFTP shipments will be required. A typical tractor trailer can travel approximately 1400 km on a full load of diesel. Thus, refuelling of the tractor will only be required on trips greater than 1400 km in length. Based on information provided by commercial trucking firms, it typically takes 20 minutes to fill the fuel tanks on a tractor.

5.2.1 Scenario Description

Refuelling stops will be made at truck stops along the transport route. The transport crew will be trained to avoid popular refuelling times such as in the morning. However, commercial drivers (members of the public) could be present refuelling their vehicles in the proximity of the UFTP shipment while it is being refueled.

In this scenario, a commercial driver (such as a driver of a vehicle parked nearby) is assumed to be refuelling a vehicle at a distance of 4 m from the loaded UFTP during the entire 20 minutes of the refuelling stop plus an additional 10 minutes for miscellaneous record keeping activities. Dose received by the commercial driver during approach and departure of the UFTP shipment is also considered. For a given commercial driver, this scenario is assumed to be a singular event in any given year. An illustration of this scenario is provided in Figure 26, below. Additional details are provided in Appendix B.19 under the activity “Commercial Driver at Refuelling Stop”.

5.2.2 Dose to Commercial Driver at Refuelling Stop

The dose received by the commercial driver is the sum of the dose received during approach and departure and the dose received during the duration of the refuelling stop. The dose due to approach and departure is calculated to be 0.00000251 mSv. The dose received by the commercial driver at 4 m from the UFTP for a time of 20 minutes is calculated to be 0.00050 mSv resulting in a dose of 0.00050 mSv per occurrence (see Appendix B.19).

5.2.3 Discussion – Commercial Driver at Refuelling Stop

The annual dose received by the commercial driver near a UFTP shipment during a refuelling stop is low; approximately 2000 times below the regulatory limit or equal to an annual FED of 7½ minutes. The dose received by the commercial driver will likely be less than this calculated amount. In this scenario, the commercial driver is assumed to be located at the fuel pump in close proximity of the loaded UFTP during the entire time the vehicle is being refueled. Fuel pumps at truck stops have locks on the pump handles allowing the pump to be locked in an on position while pumping diesel fuel. This frees the driver to perform other activities during the approximately 20 minute refuelling period. It is very unlikely that a commercial driver will spend

the entire refuelling time at the pump. This scenario also assumes that trucks can enter refuelling stations from both directions. This is not possible at all refuelling stations. The two trucks facing the same direction at the refuelling station would position the commercial driver at a greater distance from the UFTP than assessed in this scenario. Additionally, the UFTP shipment transport crew would be trained to advise members of the public, including commercial drivers, to minimize their time in close proximity of a loaded UFTP shipment.

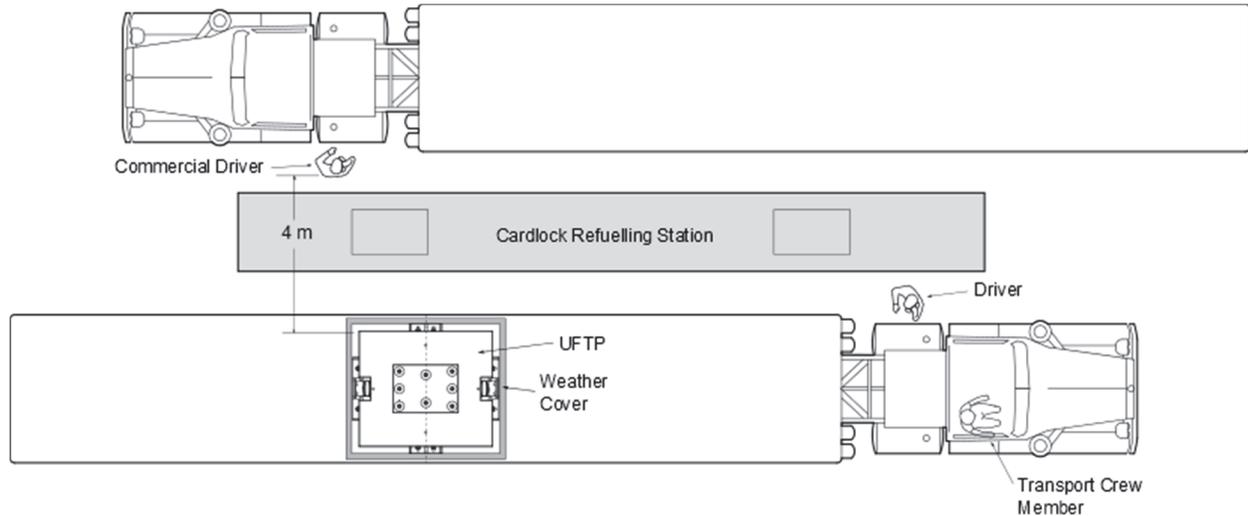


Figure 26: Commercial Driver at Refuelling Stop

5.3 UNPLANNED STOP

The UFTP tractor and trailer fleet will be maintained to the highest standards to minimize the likelihood of unplanned incidents. However, unplanned incidents are expected and must be taken into consideration.

5.3.1 Scenario Description

In this scenario, a UFTP shipment is stopped by the side of the road due to an unplanned incident. The shipment is assumed to be stopped for a period of 6 hours. The shipment is also assumed to be stopped in the proximity of a building. A building set-back distance of 25 m is assumed (see discussion on building set-back in Section 4.1). It is also assumed that a member of the public is present in or around the building during the entire unplanned stop. Conservatively, a 4 km/h walking speed approach and departure of the individual or the truck is also considered. As unplanned stops can happen anywhere and are not expected to occur frequently, a given individual is assumed to only experience one unplanned stop in a given year. An illustration of this scenario is provided in Figure 27, below. Additional details are provided in Appendix B.20 under the activity “Individual at Unplanned Stop”.

5.3.2 Dose to Individual during Unplanned Stop

The dose received by the individual is the sum of the dose received during approach and departure and the dose received during the duration of the unplanned stop. The dose due to approach and departure is calculated to be 0.000000456 mSv. The dose received by the individual located 25 m from the UFTP for a time of 6 hours is calculated to be 0.00017 mSv resulting in a dose of 0.00017 mSv per occurrence (see Appendix B.20).

5.3.3 Discussion – Individual during Unplanned Stop

The annual dose received by an individual during an unplanned stop is low; approximately 5700 times below the regulatory limit or equal to an annual FED of 2 minutes and 37 seconds. Shielding provided by buildings or other sources is not credited, but will reduce dose exposure to the individual.

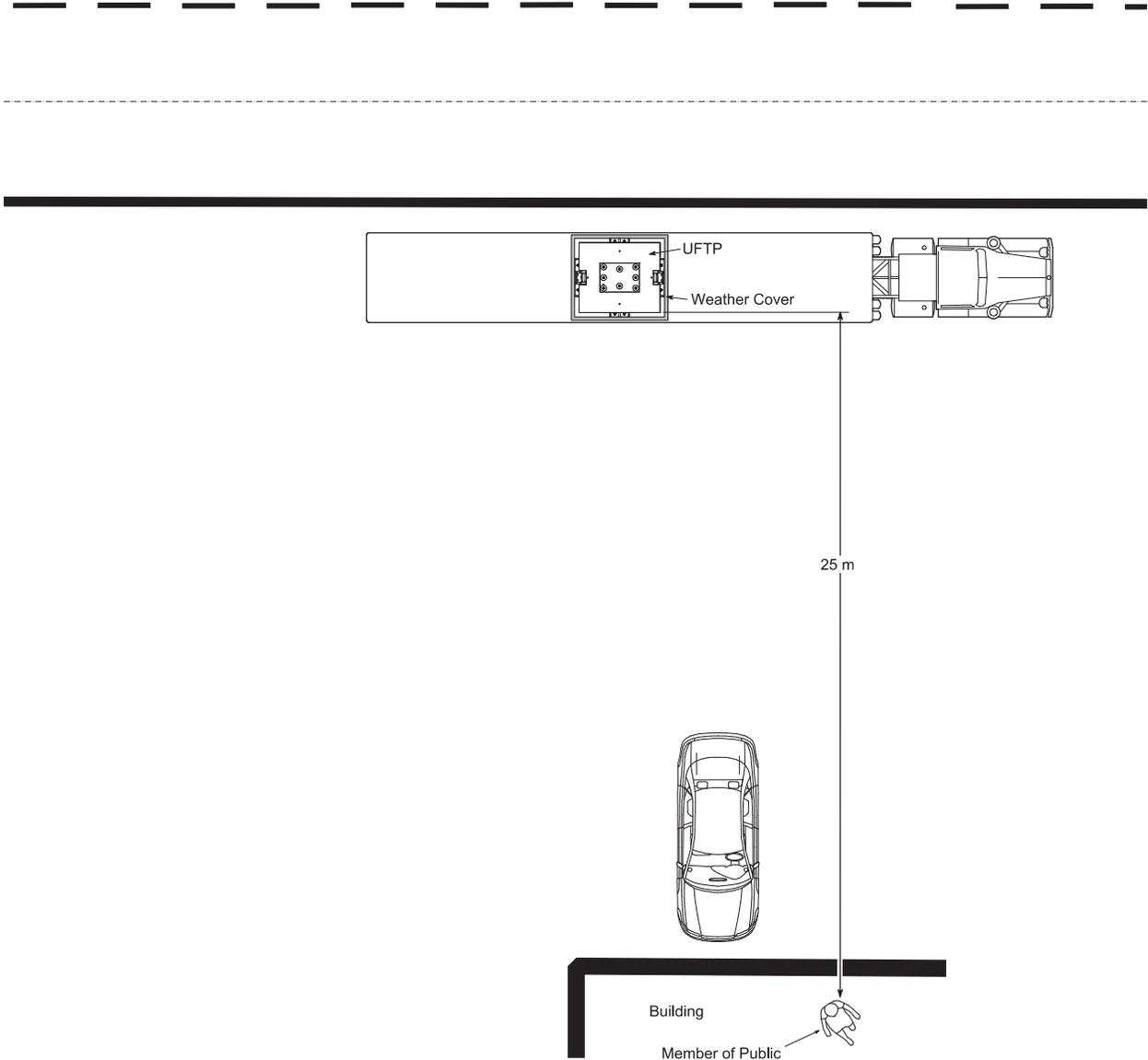


Figure 27: Individual at Unplanned Stop

6. WORKER ACTIVITIES DUE TO USED FUEL TRANSPORTATION

In 2014, the NWMO prepared a report which assessed the radiological dose to workers associated with the transportation of used nuclear fuel using the UFTP (Stahmer, 2014). The 2014 worker dose assessment has been incorporated into this report for completeness (no

additional analysis was done for this report), thereby providing a complete assessment of public and worker doses due to used nuclear fuel transportation using the UFTP.

The occupational dose due to used fuel transport is dependent on several factors which include:

- radioactivity of the radiological source (the used fuel);
- shielding present around the source (the transportation package, in this case the UFTP);
- duration of exposure;
- proximity to the radiological source; and
- frequency of occurrence.

The first two factors, radioactivity and shielding, are determined by configuration and package design and therefore do not vary in this study. Thus differences in occupational dose for a given package configuration becomes a function of the remaining three: exposure time, distance and frequency. To calculate occupational dose, activities placing a worker in the vicinity of the package must be determined. For each activity, the activity duration, the worker's distance from the package, and the frequency at which a specific activity is carried out must be established. These data are then used to calculate the dose that a worker may receive during that activity. The dose for any given activity is the product of the dose rate at the given distance, the duration of the activity at that distance, and the frequency of occurrence. The total dose the worker will receive is the sum of the doses of all activities the worker engages in. The total dose value is calculated based on a one-year period, to allow comparison with the allowable limits as shown in Table 1.

Activities associated with the transport of used fuel can be divided into three categories:

- pre-shipment activities (preparation for shipment at the interim storage site);
- activities en-route (during used fuel transport); and
- activities post receipt at the eventual repository site (inspections, removal of package from trailer, etc.).

The list of activities associated with used fuel transport and the workers conducting each of these activities are itemized in Table 7 below.

Note: As stated in Section 1.2, this assessment focuses on activities associated with the physical transport of used nuclear fuel. Activities occurring at the nuclear facilities at the point of origin and destination, such as the loading and unloading of the UFTP to and from the transport vehicle, are conducted by workers within these facilities covered by the facility licences and are not part of this work.

As noted in Section 1.3 (e) above, return shipments do not contain used fuel (do not emit radiation) and thus are not considered to contribute to occupational dose.

Additionally, the scope of occupational dose calculations is limited to workers within a 30 m radius of the package. The basis for this is the calculation that a worker located at 30 m from a fully loaded UFTP during an entire 2000 hour work year would receive a dose of approximately 0.03 mSv or approximately 3% of the regulatory public dose limit or 0.15% of the dose limit for NEWs (see Appendix A).

For each activity and worker listed in Table 7 below, information was obtained from appropriate resources (such as logistics companies, mobile repair services, trucking related associations, etc.) to collect real-world time, distance and frequency scenario data in a Canadian context. These data were analyzed and used to calculate radiological dose for each activity and subsequently for each worker. Data obtained from the sources is included in Appendix C.

Table 7: Transportation Activities and Associated Workers

Pre-shipment	En-route	Upon Receipt
<ul style="list-style-type: none"> connecting tractor to trailer vehicle condition inspection documentation check 	<ul style="list-style-type: none"> time in transit (driving) vehicle inspections by driver rest / relief stops refuelling stops en-route transport inspections (weigh scales) breakdown stops – minor en-route repair / tire change 	<ul style="list-style-type: none"> disconnect tractor from trailer post-shipment debrief and documentation filing
Associated Workers		
<ul style="list-style-type: none"> Driver 	<ul style="list-style-type: none"> Driver Commercial vehicle inspector Commercial weigh scale operator Mechanic / tow truck operator 	<ul style="list-style-type: none"> Driver

6.1 TRANSPORT CREW

6.1.1 Scenario Description

As stated in CNSC Regulatory Guide G-208, Transportation Security Plans for Category I, II or III Nuclear Material (CNSC, 2003), the transport crew required for a used nuclear fuel shipment consists of, as a minimum, a driver and an escort. The driver is responsible for the operation of the vehicle and the escort is responsible for on-board communications and surveillance of the shipment. For this study the driver and the escort are assumed to travel in the tractor.

During driving and rest stops, the transport crew is assumed to be equidistant from the UFTP. However, non-driving activities performed by the driver, such as connecting and disconnecting the trailer, conducting en-route vehicle condition inspections, and refuelling the tractor routinely place the driver in closer proximity to the UFTP than the escort. During these activities, the driver will receive a greater dose than the escort. In reality, some of the driver's activities may be shared by the transport crew.

At this early stage in transport logistics planning, determination of the exact activities of the escort and any work sharing that may occur is premature. However, it is reasonable to assume that the dose received by the escort will not exceed the dose received by the driver. For calculation purposes, only the dose to the driver is assessed.

Dose received by the transport crew is a function of pre- and post-shipment activities, number and duration of the stops along the route, and the time spent driving. As the eventual repository

site is still unknown, a spectrum of trip lengths is considered. Each of the activities conducted by the transport crew is described in more detail below. In this assessment, the transport crew is assumed to be assigned to the same return trip, i.e.: Darlington to Ignace, over a one year period.

To obtain information on driving practices, members of the transportation logistics groups at Ontario Power Generation and at Caravan Logistics were interviewed.

6.1.1.1 Pre-Driving Activities

Based on the information provided by the carriers interviewed, pre-shipment activities for the transport crew can be categorized into 3 groups:

- a) connecting the tractor to the trailer;
- b) conducting a vehicle condition inspection; and
- c) a documentation check.

Each of these activities is discussed in more detail below.

a) Connecting the tractor and trailer

Connecting the tractor to the trailer includes the following activities (see Figure 28):

1. checking the 5th wheel on the tractor to ensure it is sufficiently lubricated (this activity is conducted prior to arrival);
2. backing the tractor under the trailer to engage and lock the kingpin and the 5th wheel together;
3. ensuring that a positive connection has been made;
4. applying tractor brake;
5. inspecting the kingpin and 5th wheel and ensuring the release arm has moved into the locked position;
6. attaching the glad-hands (airlines) and electrical connections; and
7. raising the landing gear on the trailer.

This activity typically takes 5 minutes. Additional details on the location of the transport crew are provided in Appendix C.1 under the activity “Tractor-Trailer Hookup / Unhook”.

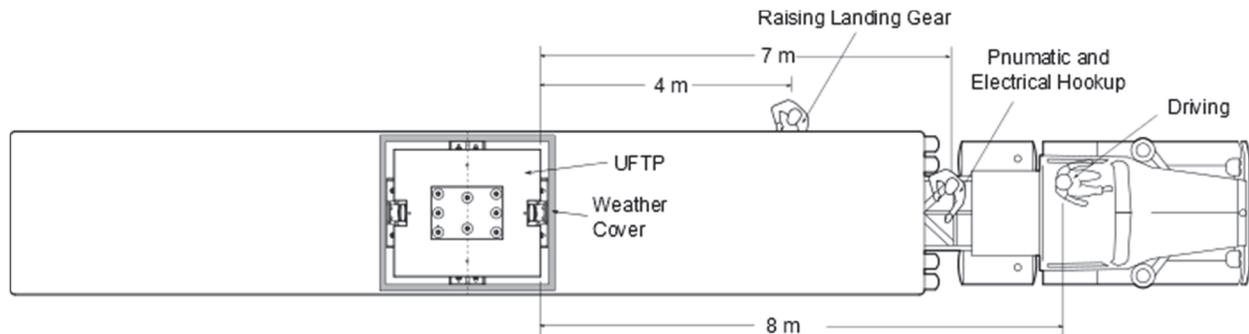


Figure 28: Driver Connecting Tractor to Trailer

b) Vehicle Condition Inspection

After hookup, the transport crew conducts a circle check of the vehicle as required by the Ministry of Transportation of Ontario (MTO). This check consists of a general condition inspection of the vehicle including: ensuring correct load securement, placards and labels, lights operational, etc. The vehicle condition inspection typically takes 10 minutes. Additional details on the position of the transport crew are provided in Appendix C.6 under the activity “Vehicle Inspections”. Note: any more detailed inspection of the vehicle prior to departure, such as a full Commercial Vehicle Safety Alliance (CVSA) Level VI inspection (specific to radioactive materials shipments) is assumed to be conducted by a qualified inspector, and not by the transport crew.

c) Documentation Check

Prior to departure, the transport crew is briefed by the transportation staff and the transport crew checks the documentation accompanying the shipment, as required. This activity typically takes 15 minutes and could take place away from the loaded trailer. For calculation purposes, the transport crew is assumed to be in the tractor during this time (to maximize dose to the transport crew).

6.1.1.2 En-route Activities

6.1.1.2.1 Driving

Driving time must be established to estimate radiological dose to the transport crew. The time required to complete one shipment cycle (a round trip shipment – UFTP loaded with used fuel from the interim storage site to the repository and an empty UFTP on the return trip) is the sum of times for all activities performed by the transport crew over the course of the trip.

a) Transport Crew Location

The NWMO UFTP Mobile Display tractor-trailer configuration is assumed to be typical of the configuration that will be used once transport operations begin. In this configuration, the distance between the package and leading edge of the trailer is 6.6 m, and the distance between the front wall of the UFTP and the rear wall of the tractor sleeper berth is approximately 8 m. Tractors with sleeper berths are typically longer than those without, placing the transport crew’s position during driving at a further distance from the UFTP. Conservatively, for calculation purposes, the transport crew is assumed to be located at 8 m from the UFTP as shown in Figure 29. No credit is given for any shielding provided by the sleeper or tractor walls. Additional details on the position of the transport crew are provided in Appendix C.5 under the activity “En-route Transport”.

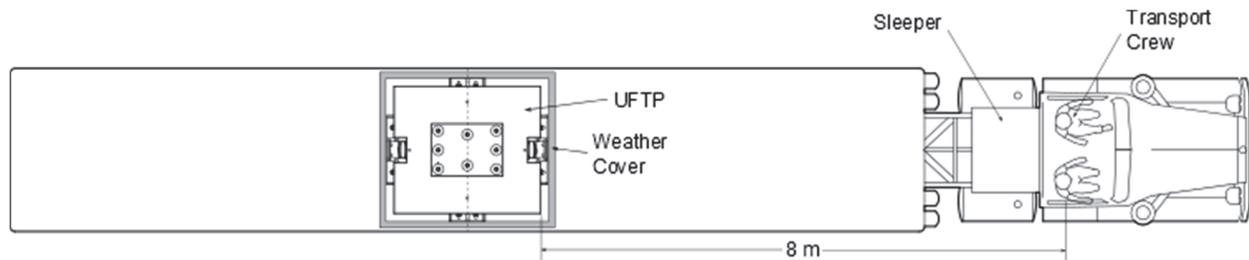


Figure 29: Transport Crew in Tractor during Driving

b) Trip Length

As the repository site location is unknown, various trip lengths are considered. Nine communities are currently in the site selection program (one west of Thunder Bay, three between Thunder Bay and Sault Ste. Marie, two near Elliot Lake, and three in southwestern Ontario). To characterize transport between the interim storage locations and these communities, four representative trip lengths ranging from 50 km to 1700 km are considered. These trip lengths, detailed further in Section 6.1.1.2.2, have been selected to represent typical distances from the existing interim storage sites to potential repository sites. For calculation purposes, three of the trips assume the representative point of origin to be the Darlington nuclear facility, as transport from Darlington maximizes travel through densely populated areas. The 4th trip assumes the trip origin to be the Bruce Nuclear facility and the destination a representative site in southwestern Ontario approximately 50 km away.

c) Population Density

Transport speed along a road or regional highway is dependent to a degree on the population density of the area through which the road travels. For example, rural highway speed limits are often reduced in areas where the highway passes through a town. To account for this, population centres along representative trips are examined.

Statistics Canada defines, *“A population centre as area with a population of at least 1,000 and a density of 400 or more people per square kilometre. All areas outside population centres will continue to be defined as rural area.”* (Statistics Canada, 2011). However, these two divisions are too broad for the purposes of this investigation.

To account for the numerous small towns with populations less than 1000 and posted speed limits less than highway speed, population densities in this assessment have been broken into three ranges: urban, suburban and rural. These densities were selected to allow identification of areas of reduced speed limits along roadways (see Figure 30). The population densities are classified as:

- Urban: more than 650 persons per km²;
- Suburban: 50 to 650 persons per km²; and
- Rural: less than 50 persons per km².

This division is similar to the population density classifications used in the radiological assessment code RADTRAN (Weiner et al., 2009). Note that the suburban range (50 to 650 persons per km²) straddles Statistics Canada’s value of 400 persons per km² for the urban/suburban boundary.

Population densities in Ontario were obtained using Statistics Canada data from the 2011 census (Statistics Canada, 2011). A map showing the population densities in Ontario is provided in Figure 30.

Each of the four trips identified in 6.1.1.3 b) above is broken down into segments based on the population density it passes through. The distance of each segment is calculated and an associated transport speed is assigned. For each trip, the total distance through each population density zone is determined.

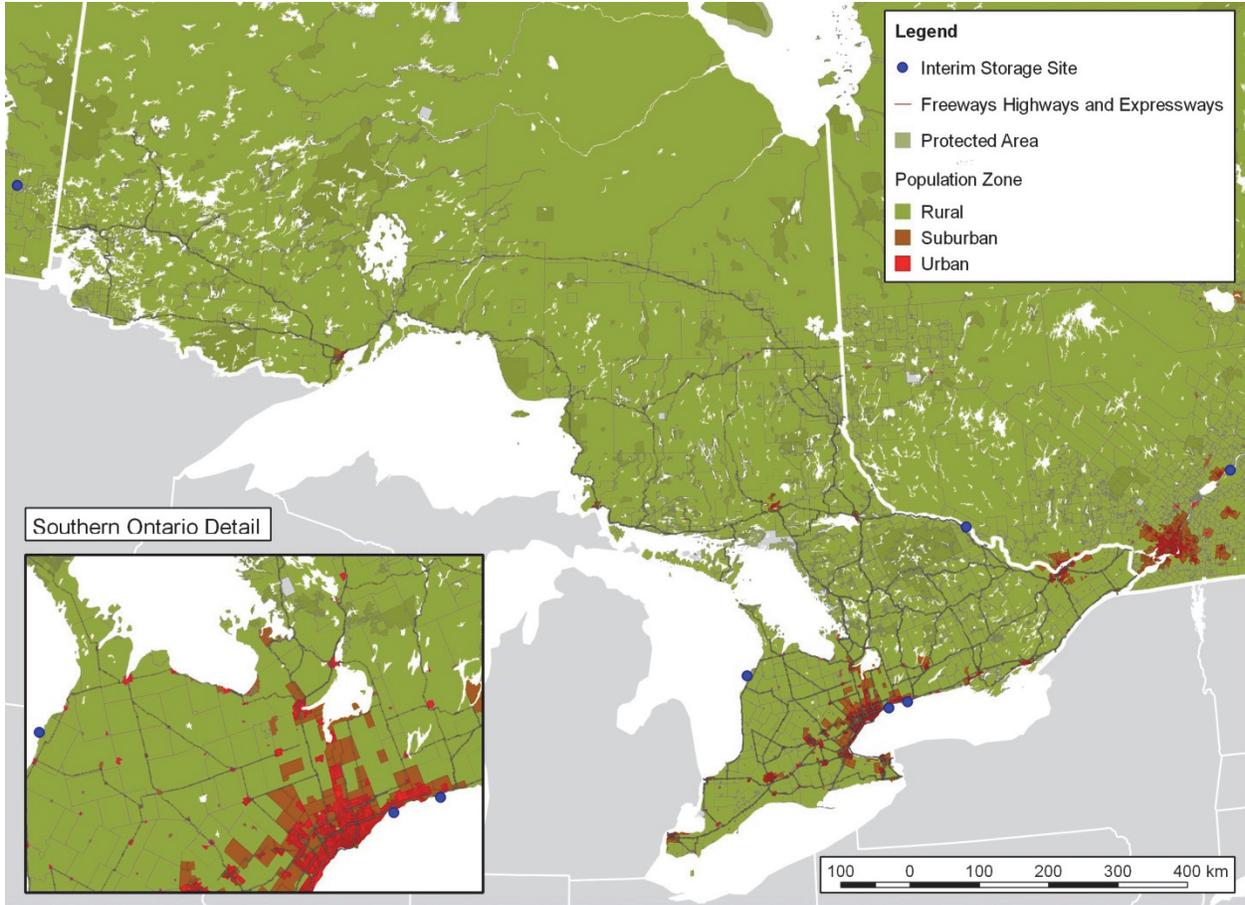


Figure 30: Sample Population Density Zone Map

d) Transport Speed in Population Density Zones

Typical posted transport speed limits through population density zones are provided in Table 8 below. Although use of highways and controlled access highways (through large population areas) is assumed, average transport speeds are frequently lower than the posted speed limits due to traffic congestion. For example, the average speed of commuting through Toronto is 42 km/h (HDR, 2008), hence this speed is assumed for all urban segments. A speed of 45 km/h is assumed for suburban segments and a speed of 70 km/h for rural segments. These assumptions fall within the range of average speeds published by the Transportation Association of Canada (TAC) (Kingston, 2011).

e) Transport Distance and Time

For each trip, distances through the three population density zones: urban, suburban and rural, are calculated (see Table 9). The communities presented in this table are selected solely to provide a range of possible transport distances. Using the transport speeds in Table 8, the travel time in each population density zone is calculated and summed to obtain a total travel time. Note that travel time does not include stops along the route. Stops during driving are addressed in the next section.

Table 8: Transport Speed Limits in Population Density Zones

Population Density	Typical Posted Speed Limit	Speed Assumed in Calculations
Urban (≥ 650 persons per km ²)	100 km/h (controlled access highway) 50 km/h (city street)	42 km/h*
Suburban (< 650 persons per km ² and ≥ 50 persons per km ²)	80 to 100 km/h (highway)	45 km/h**
Rural (< 50 persons per km ²)	80 to 90 km/h (highway)	70 km/h**

* Reference: HDR, 2008

** Reference: Kingston, 2011

6.1.1.2.2 Stops during Driving

Carriers, such as Caravan Logistics and Ontario Power Generation, were contacted to provide information on typical activities of the transport crew during routine trips. Frequencies of the activities were also provided. Stops are divided into three categories: rest and relief, en-route vehicle condition inspections, and refuelling. Each is described in more detail in Sections (a) to (c) below.

Table 9: Distances and Travel Times through Population Density Zones

Representative Trip	Distance	Distance and Travel Time in Zone			Total Travel Time
		Urban	Suburban	Rural	
Bruce to South Bruce	50 km	0 km 00:00 h	3 km 00:04 h	47 km 00:40 h	00:44 h
Darlington to South Bruce	250 km	86 km 02:02 h	47 km 01:03 h	117 km 01:40 h	04:45 h
Darlington to Elliot Lake	600 km	82 km 01:57 h	64 km 01:25 h	454 km 06:29 h	09:51 h
Darlington to Ignace	1700 km	99 km 02:21 h	98 km 02:11 h	1503 km 21:28 h	26:00 h

a) Rest and Relief Stops

Rest and relief stops are required during any lengthy journey. Based on information provided by commercial trucking firms, rest and relief stops are typically 30 minutes in length and are made approximately every 400 km or 4 hours of driving time. All trips greater than 300 km in length are assumed to have at least one stop for rest or relief (Note: it is assumed that rest stops are not taken during 50 km and 250 km shipments). As traffic congestion and unplanned traffic slowdowns or stoppages cannot be predicted, for dose calculation purposes, rest and relief stops are based on travel distance and not driving time.

Although it is expected that each member of the transport crew will leave the tractor over the course of the stop, for dose calculation purposes, the transport crew is assumed to remain in the tractor during each rest stop for its entirety (to maximize dose to the transport crew).

Additional details on the position of the transport crew are provided in Appendix C.3 under the activity “Rest / Relief Stop”.

b) En-route Vehicle Condition Inspections

Regulations require that the condition of a commercial vehicle is monitored by the transport crew during transport. This requirement is met through en-route vehicle condition inspections. These inspections carried out by the transport crew are typically conducted every 200 km and are similar to the pre-shipment vehicle condition inspection discussed in Section 6.1.1.1 (b) (Note: it is assumed that there are no en-route vehicle inspection stops for trips less than 300 km in length). Additional details on the position of the transport crew are provided in Appendix C.6 under the activity “Vehicle Inspections”. For dose calculation purposes, the driver is assumed to conduct all vehicle condition inspections, placing him or her in close proximity to the package more frequently than any other transport crew member.

c) Refuelling Stops

Refuelling stops of a tractor-trailer loaded with used nuclear fuel should be kept to a minimum. It is assumed that the fuel tanks on the tractor are full at the point of origin. The range of a tractor-trailer is approximately 1400 km, thus only trips greater than 1400 km in length will require refuelling. The time to refuel takes approximately 20 minutes.

Refuelling is assumed to take place at a commercial cardlock station such as the one shown in Figure 31. Cardlock stations can support the refuelling of multiple vehicles at the same time. The assumed configuration of the cardlock station along with the time and distance assumptions used in the dose calculations is presented in Appendix C.4. For calculation purposes, the transport crew is assumed to be located 6 m from the UFTP during refuelling.



Figure 31: Commercial Cardlock Station on Highway 17

6.1.1.2.3 Post-Driving Activities

Upon arrival at the destination, the transport crew disconnects the tractor from the trailer. This is essentially the reverse of the activities listed in Section 6.1.1.1 (a) and requires the same amount of time (5 minutes). Last, the transport crew prepares documentation for filing into a

records management system and is debriefed by the transportation manager. This activity typically takes 15 minutes and would typically take place away from the trailer. For calculation purposes, this is assumed to take place at 8 m from the UFTP (to maximize dose to the transport crew).

6.1.1.3 Transport Crew Activity Summary

a) Pre- and Post-Driving Activity Summary

The calculation of total driving time includes pre- and post-shipment activities. Typical activities for the transport crew detailed in Appendix C are summarized in Table 10 below. Typically, pre-shipment activities performed by the transport crew require 30 minutes and post-shipment activities require 20 minutes.

Table 10: Pre- and Post-Shipment Activities

Activity	Duration	Performed by
Tractor Hookup to Trailer	5 min	Driver – Pre-Shipment
Vehicle Condition Inspection	10 min	Driver – Pre-Shipment
Documentation Preparation and Check	15 min	Transport Crew – Pre-Shipment
Unhook Tractor from Trailer	5 min	Driver – Post-Shipment
Documentation Submission and Debrief	15 min	Transport Crew – Post-Shipment

b) En-route Activity Summary

Parameters used to determine the number of and total time for stops along the trip are summarized in Table 11 below.

Table 11: Stop Durations and Frequencies

Stop Type	Duration	Frequency
Rest / Relief	30 min	Every 400 km or 4 hours All trips over 300 km have at least one rest stop
Vehicle Condition Inspection	10 min	Every 200 km for trips greater than 300 km
Refuelling	20 min	Every 1400 km

6.1.1.4 Time per Shipment and Maximum Annual Shipments per Transport Crew

The total time per shipment is the sum of all pre- and post-shipment activities, all stops, and time in transit. Shipment times for each of the four representative trips are summarized in Table 12, below.

Used fuel delivery from the reactor sites where it is currently stored to the repository site will require approximately 620 UFTP shipments per year. Using the representative trip lengths

presented in Table 9, a given transport crew is only able to perform a fraction of this total. The maximum number of annual shipments for a given transport crew can be estimated by dividing the number of available work hours by the total time for a return shipment (a 2000 hour work year is assumed: 40 working hours per week, 50 weeks per year) and is presented in Table 12. In the case of the 50 km trip (Bruce site to repository site in Southwestern Ontario), the maximum number of annual trips is calculated to be 636. However, current transport logistics estimates (Stahmer, 2009) indicate that the maximum number of annual shipments originating from the Bruce site is 295. In this case, the number of annual shipments for the transport crew has been reduced from the calculated number (636) to the number provided in current transport logistics estimates (295).

Due to hours of service requirements, trips over 600 km in length may require multiple transport crews or overnight stops. Addressing of these logistics decisions is premature and out of scope for this analysis; however, trip length has minimal impact on annualized transport crew dose. See Section 6.1.3.1 for discussion on data sensitivity.

Table 12: Maximum Annual Shipments per Transport Crew

Activity	Trip Length			
	50 km	250 km	600 km	1700 km*
Pre-Shipment	00:30 h	00:30 h	00:30 h	00:30 h
Rest / Relief Stops	00:00 h (0 stops)	00:30 h (1 stop)	00:30 h (1 stop)	02:00 h (4 stops)
Vehicle Condition Inspection Stops	00:00 h (0 stops)	00:00 h (0 stops)	00:20 h (2 stops)	01:20 h (8 stops)
Refuelling Stops	00:00 h (0 stops)	00:00 h (0 stops)	00:00 h (0 stops)	00:20 h (1 stop)
Driving Time	00:44 h	04:45 h	09:51 h	26:00 h
Post-Shipment	00:20 h	00:20 h	00:20 h	00:20 h
Total Time per Shipment (one way)	01:34 h	06:05 h	11:31 h	30:30 h
Maximum Annual Shipments	295**	164	86	32

* Multiple transport crews or overnight stops will be required to meet Hours of Service requirements.

** The number of annual shipments originating from the Bruce site. See NWMO TR-2009-21.

6.1.2 Dose to Transport Crew

The total dose to the transport crew is calculated as the sum of all doses received during pre-shipment, en-route, and post-shipment activities. These activities are dependent on many factors including traffic conditions, road conditions, vehicle speed, trip length, population density, en-route condition inspection, and rest stop frequencies, etc.

Each transport crew activity was identified and assessed individually to determine transport crew location and time. This data was then used to calculate the maximum number of shipments a transport crew could make in a given year. Once this was established, per-shipment and annual dose to the transport crew was calculated. The results for the four different trip lengths discussed in Section 6.1.1.2.2 are summarised in Table 13 below. Detailed calculations and assumptions for each activity are presented in Appendix C.1 through C.4 and are summarized in Appendix C.5.

6.1.3 Discussion – Transport Crew

Radiological dose received by the transport crew for a given shipment is largely a function of shipment length. The dose received by a transport crew varies from 0.0009 mSv for a 50 km shipment to a dose of 0.011 mSv for a 1700 km shipment. However, as a given transport crew on a short route will make many more shipments during a given year than a transport crew on a long route, the annualized doses received by a transport crew end up varying very little. As presented in Table 13, the lowest annual dose is 0.27 mSv per year for a transport crew on the 50 km route while the dose for a transport crew on the 1700 km route is only 0.35 mSv per year, approximately 2.8 times below the regulatory limit or equal to an annual FED of 88.5 hours. In comparison, the annual FED for a flight crew is typically around 700 hours.

Occupational dose to the transport crew under normal transport conditions is calculated to be below the dose limit for a member of the public (1 mSv per year); and, by extension well below that of 20 mSv per year for NEWs (the regulatory dose limit of 100 mSv averaged over five years for Nuclear Energy Workers).

Dose rates and resulting occupational doses received by the transport crew have been calculated in this report and are not based on measured values. Dose monitoring of occupational activities for the transport crew should be established as the radiation protection program is developed, prior to the operational start-up of the used fuel transportation program.

6.1.3.1 Data Sensitivity

As mentioned in Section 6.1.1, transport crew dose is dependent on many factors. To determine the sensitivity of the annualized dose to the various inputs, calculations were repeated with varying inputs. For example, the calculated dose received by a transport crew in the base assumption ranges from 0.27 mSv per year to 0.35 mSv per year. This assumes average transport speeds of 42 km/h for urban areas, 45 km/h for suburban areas and 70 km/h for rural areas. See Base Assumption in Table 14 below.

Recalculating transport crew dose using typical posted speed limits of 100 km/h for urban areas, 50 km/h for suburban areas and 80 km/h for rural areas only marginally affects the annual transport crew dose. For this data, the dose range is 0.25 to 0.39 mSv per year. See the column "Posted Speed" in Table 14 below.

Using typical posted speed limits of 100 km/h for urban areas, 50 km/h for suburban areas and 80 km/h for rural areas in Southern Ontario (trips of 50 and 250 km in length) and 90 km/h for rural areas in Northern Ontario and extending the rest stop length from 30 to 45 minutes in length, the dose range is 0.26 to 0.38 mSv per year. See the last column in Table 14 below.

Table 13: Transport Crew Dose Summary

Shipment Length	50 km	250 km	600 km	1700 km
Per-shipment Dose by Activity (all doses in mSv)				
Pre-shipment	0.00066	0.00066	0.00066	0.00066
Driving	0.00015	0.00095	0.0020	0.0052
Rest Stops	0.00	0.00010	0.00010	0.00040
Condition Inspections	0.00	0.00	0.0012	0.0046
Refuelling	0.00	0.00	0.00	0.00012
Post-Shipment	0.000088	0.000088	0.000088	0.000088
Per-Shipment Dose	0.0009	0.0018	0.0040	0.011
Annual Dose by Activity (all doses in mSv)				
Pre-shipment	0.20	0.11	0.057	0.021
Driving	0.044	0.16	0.17	0.17
Rest Stops	0.00	0.016	0.009	0.013
Condition Inspections	0.00	0.00	0.099	0.15
Refuelling	0.00	0.00	0.00	0.004
Post-Shipment	0.026	0.014	0.008	0.003
Annual Dose	0.27	0.30	0.34	0.35

Note: All doses rounded to 2 significant digits.

Table 14: Data Sensitivity to Transport Speed and Rest Stop Length

	Base Assumption	Posted Speed	Posted Speed – Longer Rest Stop
Transport Speed			
Urban	42 km/h	100 km/h	100 km/h
Suburban	45 km/h	50 km/h	50 km/h
Rural	70 km/h	80 km/h	80 or 90 km/h
Rest Stop Length	30 min	30 min	45 min
Annual Transport crew Dose	0.27 mSv – 0.35 mSv	0.25 mSv – 0.39 mSv	0.26 mSv – 0.38 mSv

This consistency in transport crew dose can be readily explained. Varying the transport speed, rest stop and en-route inspection frequencies, or pre- and post-shipment activities all end up affecting the number of shipments per year. A faster shipment cycle means more shipments by the transport crew; a slower shipment cycle means fewer shipments. However since the length of the work year and hours of service remain fixed, the impact of dose to the transport crew is minimal, because the time spent by the transport crew in front of the package remains similar.

Conservatively, the transport crew was assumed to remain in the tractor during the documentation check (both pre- and post-shipment) and during all the rest stops. In reality, the crew is not restricted to remain in the tractor during these activities. For all transport distances, occupational dose is dominated by dose received while performing activities other than documentation checks and rest stops. The annual dose range for the transport crew was unaffected when the doses were recalculated assuming virtually zero dose during these activities.

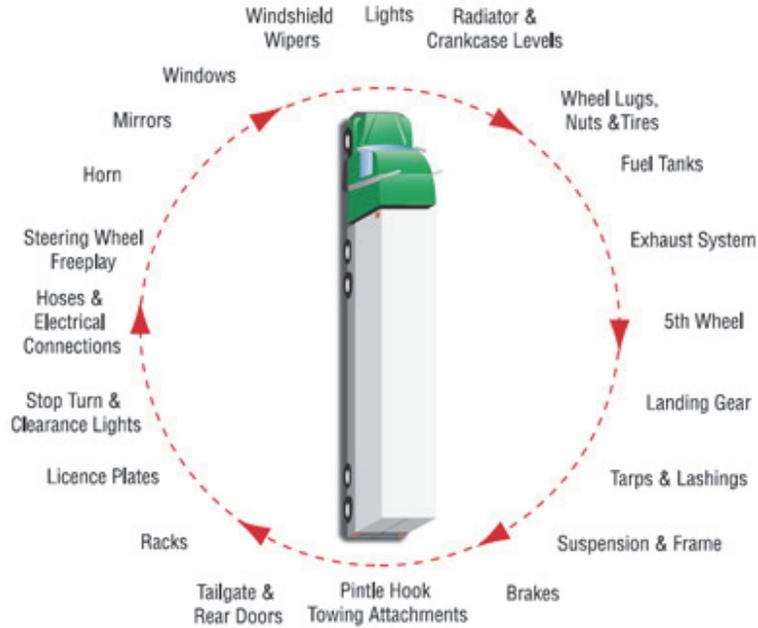
A simple reality check can be made by assuming that the transport crew spends the entire working year in the tractor. For 1000 hours of the 2000 hour work year, the crew would be driving a vehicle carrying a loaded package (emitting dose) and the other 1000 hours would be spent driving a vehicle carrying an unloaded package (emitting no dose). From Figure 6, the dose rate at 6 m from the UFTP is approximately 0.0035 mSv/h. The calculated annual dose of 0.35 mSv per year is equivalent to the transport crew spending 1000 hours at an average of 6 m from the package. This check fits well within expectations as the transport crew will spend some time closer to the package than only in the driving position at 8 m from the UFTP.

6.2 PROVINCIAL COMMERCIAL VEHICLE INSPECTOR

Provincial commercial vehicle inspectors ensure that commercial vehicles are in compliance with acts, regulations, and safety standards. Their role is to visually inspect vehicles and load securing systems to look for defects. They also review documentation, examine driver licenses and log books, commercial vehicle licenses, insurance documents, and permits for compliance with applicable acts and regulations.

Through the Commercial Vehicle Safety Alliance (CVSA), commercial vehicle inspections have been harmonized between provinces. There are several levels of inspection ranging from a comprehensive (Level I) inspection that evaluates both the driver and vehicle, to ones with a more specific area of focus, such as for hazardous or radioactive materials (Level VI). Inspections and affixing of CVSA decals must be performed by certified inspectors. The term "certified" means the government employee performing inspections and/or affixing CVSA decals must have successfully completed a training program approved by the CVSA. Vehicle inspection standards are established by the CVSA and compliance inspections are conducted, in Ontario, by the Ministry of Transportation (MTO).

Vehicle inspections typically follow a similar pattern termed the circle check (see Figure 32) placing the inspector at various distances from the package during the course of the inspection. Inspection durations will vary depending on the comprehensiveness of the inspection, but the inspections typically consist of an inspector performing a circle check by walking around the conveyance, and at times, going underneath and on to the vehicle deck to inspect the various components and features (e.g. brakes and tie-downs). Inspections to the various CVSA levels range in completion time from approximately one hour for a CVSA Level I inspection, a half-hour for a CVSA Level II inspection, and one-and-a-half hours for a CVSA Level VI inspection.



Source: Ontario Ministry of Transportation (MTO)

Figure 32: Commercial Vehicle Circle Check

6.2.1 Scenario Description

To address the issue of varying distance from the package, the area around the vehicle was divided into 1 m² parcels and the inspector was assumed to be in each of the 46 parcels an equivalent amount of time. This methodology is described in further detail in Appendix C.6 and was applied to all vehicle inspections: both CVSA and en-route vehicle condition inspections performed by the transport crew.

Data provided by MTO indicates that government inspectors inspect approximately 110,000 commercial vehicles per year across all inspection levels. This is only a small fraction of the number of shipments made. For dose calculation purposes, the MTO agreed that inspection of 5% of all UFTP shipments was reasonable (or 31 shipments per year). For additional conservatism, all of these inspections are assumed to be conducted by the same inspector. Details on the proximity and duration of the inspector to the vehicle for the different inspection levels are provided in Appendix C.6 under the activity "Vehicle Inspections".

6.2.2 Dose to Commercial Vehicle Inspector

A summary of the dose calculation results for the CVSA inspections is provided in Table 15, below.

Table 15: Commercial Vehicle Inspector Dose

Inspection Level	Dose per Inspection [mSv]	Number of Inspections by given Inspector	Annual Dose [mSv]	Annual FED
CVSA Level I	0.0035	31	0.11	26¾ hours
CVSA Level II	0.0017	31	0.054	13½ hours
CVSA Level VI	0.0052	31	0.16	40¼ hours

Note: All doses rounded to 2 significant digits.

The potential dose to a commercial vehicle inspector varies from 0.054 mSv for an inspector inspecting 31 shipments annually to CVSA Level II standards to 0.16 mSv for an inspector inspecting 31 shipments annually to CVSA Level VI standards.

6.2.3 Discussion – Commercial Vehicle Inspector

Although dose for a singular inspection is low, ranging from an annual FED of 26 minutes to 1¼ hours, caution and awareness of potential dose exposure are advisable for all detailed inspections. According to CVSA, most employers require dosimeters as part of the personal protective equipment worn by inspectors conducting Level VI inspections. All Level VI qualified inspectors interviewed were qualified to inspect hazardous materials shipments. The transport crew will be equipped with dose monitoring equipment and will be trained to minimize exposure by conducting work (when possible) at a greater distance from a loaded package. Dose received by each inspector would be measured and tracked to ensure that no inspector would receive more than the 1 mSv limit for members of the public.

6.3 COMMERCIAL WEIGH SCALE OPERATOR

Regulations require that commercial vehicles be weighed periodically. Weighing typically takes place at either government or commercial weigh stations along highways, but may also be performed en-route by ministry inspectors using portable scales.

Commercial vehicle scales at weigh stations vary in size. Some have scales that can only weigh axle groupings while others can weigh the entire vehicle at once. Depending on the weigh station, the time required to weigh a vehicle will vary. Additionally, Ministry inspectors have portable scales that can be used to weigh a vehicle along a roadway (see Figure 33). These variances were considered in calculating dose to a weigh scale operator.



Figure 33: MTO Weigh Station and MTO Officer using a Portable Scale

6.3.1 Scenario Description

During the weighing, a weigh scale operator may be in proximity of a loaded UFTP. With information provided by the MTO, placement of weigh scale operators was established for both stationary and portable scales. Dose received by the weigh scale operator will vary depending on the type of scale that is being used to weigh the vehicle. A typical stationary weigh scale configuration is shown in Figure 34 below. Additional details for the different scale configurations are provided in Appendices C.7 and C.8 under the activities “Weighing at Weigh Station” and “Weighing with Portable Weigh Scale”.

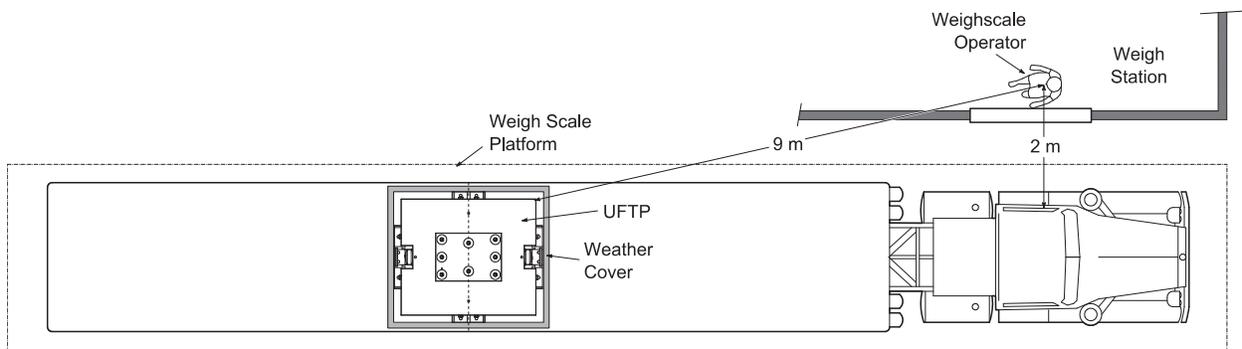


Figure 34: UFTP Shipment in Stationary Weigh Scale

6.3.2 Dose to Commercial Weigh Scale Operator

For operators at stationary scales, the methodology applied in dose calculations was similar. The operator was assumed to be in a fixed position during the weighing activity. For a large scale, only one fixed position (operator near tractor) was considered. For small scales, a

second fixed position placing the operator in closer proximity with the rear axle grouping was added. In both cases, dose received during vehicle approach and departure was included (see Appendix C.7).

Weighing a vehicle using portable scales requires two scale units, one for each side of the vehicle. One axle is weighed at a time. The scales are placed on the ground in front of the wheels and the vehicle is driven forward onto the scales. The axle weight is the sum of the weights of each scale. Weighing of a tractor-trailer in this manner typically takes 15 minutes. Equal time is assumed to be required at each axle location. The dose to the inspector is calculated to be the sum of the dose received at each axle location during the total weighing activity (see Appendix C.8).

Based on information provided by the Ontario Ministry of Transportation (MTO), any given operator was assumed to be present for 5% of all 620 annual shipments (31 shipments). The dose received by weigh scale operators is summarized in Table 16 below.

Table 16: Weigh Scale Operator Dose

Scale Type	Operator Dose per Weighing [mSv]	Number of Inspections by given Inspector	Annual Dose [mSv]	Annual FED
Stationary – Large Platform	0.0000084	31	0.00026	4 minutes
Stationary – Small Platform	0.000089	31	0.0028	41½ minutes
Portable	0.00040	31	0.012	3 hours

Note: All doses rounded to 2 significant digits.

The potential annual dose received by a weigh scale operator ranges from 0.00026 mSv for an operator at a stationary weigh scale to 0.012 mSv for the operator of a portable scale assuming MTO data that suggests that approximately 5% of all trucks are weighed.

6.3.3 Discussion – Commercial Weigh Scale Operator

The annual doses received by commercial weigh scale operators range from a low annual FED of 4 minutes for an operator of a large platform stationary scale to a high annual FED of 3 hours for the operator of portable scales.

The doses calculated for stationary scale operators are conservative because of the distance assumptions made (2 m away from side of truck is a low estimate) and that the shielding provided by the structure they are in is not credited. Even with these conservative assumptions, if all 620 UFTP shipments were to be weighed by the same operator (a highly unlikely scenario), the total received dose would range from 0.005 mSv (an annual FED of 1¼ hours) for an operator at a stationary large platform weigh scale to 0.06 mSv (an annual FED of 13¾ hours) for the operator at a small platform weigh scale.

Weighings using portable scales are typically conducted by MTO officers who have stopped a commercial vehicle for potential safety infractions alongside the roadway. As the weight of the UFTP shipments will be very consistent and the MTO will be aware of the UFTP transportation

program, the assumption that 31 UFTP shipments will be weighed a given officer is very conservative.

6.4 MECHANIC – MOBILE REPAIR SERVICE OPERATOR

UFTP transportation equipment will be maintained to the highest standards and will be inspected prior to departure as well as en-route and upon arrival at the destination. However, breakdowns of equipment may occur. Mobile repair services will be at times required to fix flat tires or make minor repairs to the tractor-trailer while it is en-route. Depending on the nature of the breakdown, the repair work may place a mechanic or tow truck operator close to a loaded UFTP.

Mobile breakdown services were contacted and typical repairs that may be required during transit were established. Breakdowns in two categories were identified: tire replacement and brake chamber replacement. Replacement of the inner tire of a dual tire group and the repair of a maxipot brake chamber were considered to be typical roadside repairs. In either case, the repair time and distance from the UFTP is assumed to be similar.

6.4.1 Scenario Description

To be conservative, the repair of components on the axle located directly under the UFTP is considered. For a given mechanic, this scenario is assumed to be a singular event. The mechanic is assumed to be positioned in close proximity (approximately 0.4 m, alongside the weather cover) to the UFTP for the entire duration of the repair. Roadside repairs such as these typically take between 30 minutes to one hour to complete. The scenario is illustrated in Figure 35, below. Additional details are provided in Appendix C.9 under the activity “Minor Breakdown or Tire Repair”.

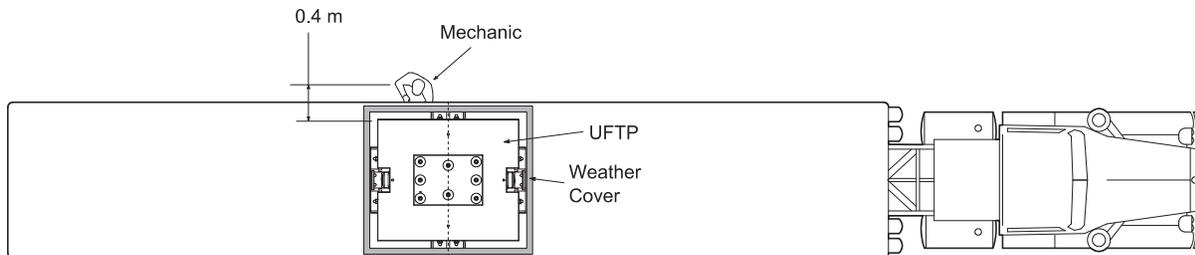


Figure 35: Mechanic Repairing Tire

6.4.2 Dose to Mechanic – Mobile Repair Service Operator

The dose received by the mechanic is calculated as the dose received from the UFTP during the duration of the repair. (Note, in this case the dose received during repair is much larger than the dose received during approach and departure from the UFTP, thus only the dose received during the repair is considered). In the described scenario, the dose to the mechanic at 0.4 m for one hour is calculated to be 0.017 mSv (see Appendix C.9).

6.4.3 Discussion – Mechanic – Mobile Repair Service Operator

The annual dose received by a mechanic is approximately 59 times below the regulatory limit or equal to an annual FED of 4¼ hours. This assumes that the repair required is in very close proximity to the UFTP (0.4 m). In fact, the received dose may be lower. As it is assumed that a tire repair for a given mechanic is a singular event, peak burnup is assumed in the calculations.

Additionally, the dose received by the mechanic is very dependent on location. For example, conducting the same repair on the rear axle 4 m from the UFTP, the dose received by the mechanic drops to 0.001 mSv; approximately equal to an annual FED of 15 minutes. The transport crew will be equipped with dose monitoring equipment and will be trained to instruct the mechanic to minimize exposure by conducting work (when possible) at a greater distance from a loaded package.

6.5 CONCLUSIONS

Activities placing members of the public in the proximity of a UFTP shipment were identified and exposure time, distance, and frequency relationships were assessed. The identified members of the public were grouped into the following eight categories:

1. Resident – a member of the public living or working along a UFTP transport route;
2. Pedestrian – a member of the public present along the roadside of a passing UFTP shipment;
3. Hitchhiker – a member of the public on the roadside soliciting a ride from passing vehicles as a UFTP shipment passes by;
4. Roadside Worker – a member of the public working along the roadside as a UFTP shipment passes by;
5. Cyclist – a member of the public cycling along the roadside as a UFTP shipment passes by;
6. Vehicle Occupant – a member of the public in a vehicle sharing the road with a UFTP shipment;
7. Traveler at a Stop – a member of the public present near a UFTP shipment during an en-route stop; and
8. Driver at a Refuelling Stop – a member of the public refuelling a vehicle in the proximity of a refuelling UFTP shipment.

One or more exposure scenarios were created for members of the public in each group. These scenarios represented both typical and limiting scenarios for dose calculations. The time, distance, and frequency data collected by Carleton University was then used to calculate potential annual radiological dose within a Canadian context to members of the public due to the transportation of used fuel using the UFTP.

For completeness, dose to transportation workers reported in (Stahmer, 2014) was also included. The worker dose assessment looked at individuals that would come into contact with a UFTP shipment as a result of their occupation. The following workers were included:

1. Transport Crew – the driver and security escort for the UFTP shipment;
2. Commercial Vehicle Inspector – an inspector (typically working for the ministry of transportation) conducting a detailed safety inspection of the UFTP shipment;
3. Mechanic – a mobile repair service operator who may make a minor roadside repair to a UFTP shipment; and
4. Commercial Weigh Scale Operator – an operator at a commercial vehicle weigh scale. As the vehicle weight will be very consistent from one shipment to the next, vehicle weights will likely only be made at ministry scales.

Using dose rate data calculated to be emitted by a UFTP loaded with 192 bundles of 30 year out-of-reactor CANDU fuel (Batters, et al., 2012), radiological doses to members of the public and transportation workers in the proximity of UFTP shipments were calculated. Annual dose to members of the public and workers for the identified activities was calculated. These results are summarized in Table 17 and Table 18, below.

All doses to members of the public and transportation workers were determined to be well below the regulatory dose limit of 1 mSv per year set by the CNSC for members of the public. The dose to members of the public ranged from 0.0000013 mSv per year for a hitchhiker standing along a highway experiencing 6 UFTP shipments passing by to 0.00054 mSv per year for a traffic control person experiencing 260 shipments per year. The dose to transportation workers ranged from 0.00026 mSv per year for a weigh scale operator (large scale) weighing 31 shipments to 0.35 mSv per year for member of the transport crew.

The doses by group for both members of the public and transportation workers are graphically illustrated in Figure 36 and Figure 37, below. For comparison, the calculated doses are presented alongside the public dose limit set by the CNSC and the average annual background dose for Canadians. A detailed breakdown of the dose calculated for each identified activity is provided in Table 17 and Table 18. For context, the annual FED for each activity is included in Column 5 of the table.

In all cases, the calculated annual dose to members of the public with a possibility of being in the proximity of a UFTP were orders of magnitude below the regulatory dose limit of 1 mSv per year. As described in Stahmer (2014) the occupational dose to transport workers under normal transport conditions was assessed to be below the dose limit for a member of the public (1 mSv per year). Since this occupational dose remains below the regulatory public dose limit of 1 mSv per year, the assessment concluded that transportation workers would not need to be designated as NEWs.

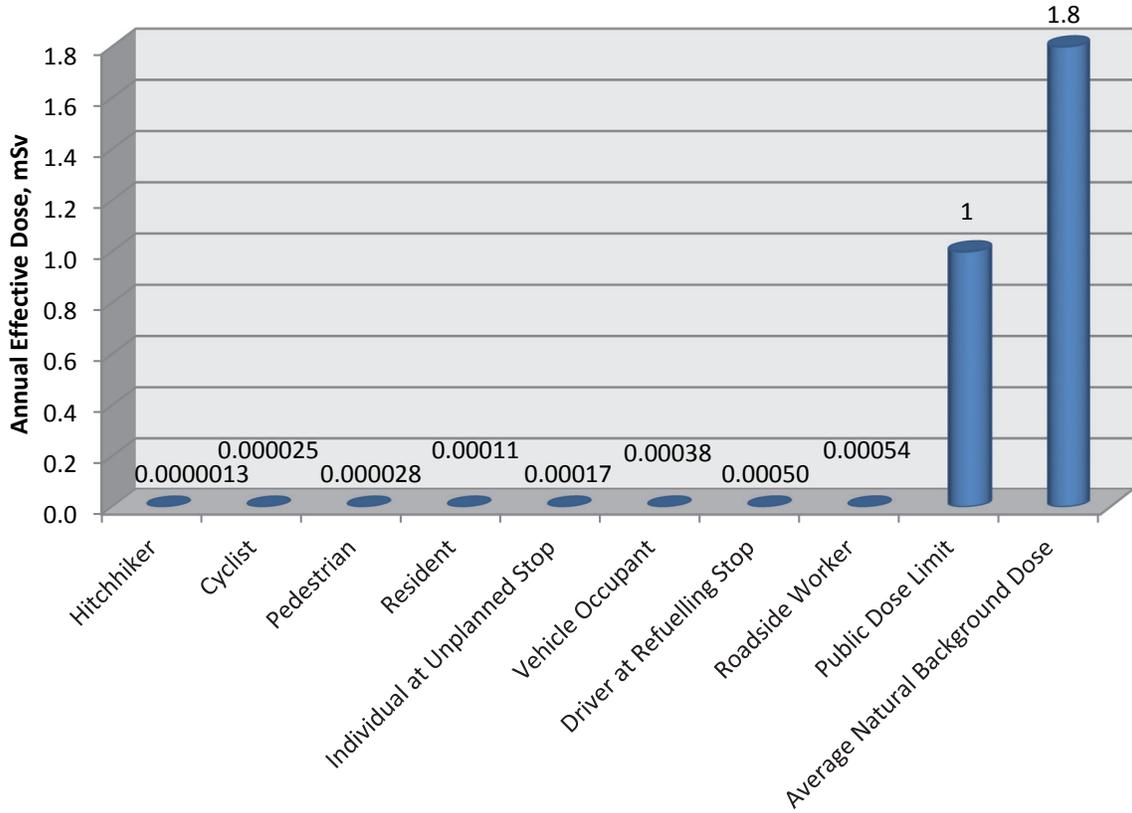


Figure 36: Comparison of Public Dose

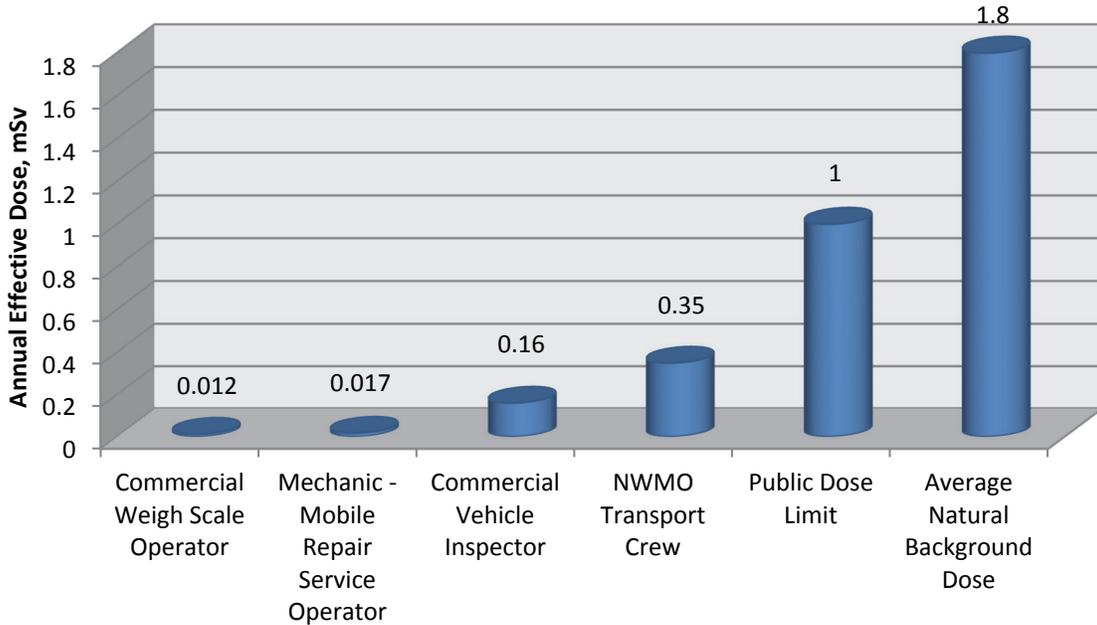


Figure 37: Comparison of Worker Dose

The doses calculated in this assessment serve as an estimate of the radiological impact the used fuel transportation package may have on members of the public and on transportation workers. Dose emitted by transportation packages is design and content specific; in this case the dose is specific to the UFTP carrying 192 bundles of 30 year old used fuel. Dose estimates may change with changes to the UFTP design or the use of other transportation packages. A more comprehensive dose assessment may be required once details of the Canadian used fuel transportation program are finalized.

It should be noted that the dose estimates to members of the public and transportation workers presented in this assessment have been calculated.

Requirements for dose monitoring of the transportation packages and occupational activities to validate these calculations will be assessed as the radiation protection program is developed to support operational start-up of the used fuel transportation program. This will include decisions on the use of dosimeters worn by the workers to measure and verify the doses estimated in this assessment.

Driving operations (team driving (straight through) vs. driving with overnight stops) have not been optimized as the eventual repository site destination and associated transport routes are unknown. Transport crew dose calculations should be re-examined once more detailed route information becomes available.

Transportation activities assessed in this report focus on members of the public and workers involved with a UFTP shipment departing the facility at the point of origin to arriving at the destination facility. Specifically the scope of the assessment covers activities in the public domain, from the time a used fuel shipment is loaded on the trailer, departing from the reactor sites to when the trailer arrives at the APM repository site receiving bay and is disconnected. Activities conducted within the boundaries of the associated facilities to prepare a shipment for transport and to process a shipment at the repository site after arrival are not included in the scope of this report (i.e., loading of fuel into the UFTP, on-site transfers of the UFTP, UFTP inspection and testing, loading, securing of the UFTP onto transport trailer at the point of origin, and unloading of UFTP at the destination).

Table 17: Estimated Annual Dose to Members of the Public due to the Transportation of Used Fuel

Section	Member of the Public	Estimated Annual Dose	Factor to Dose Limit* (1 mSv/year)	FED** (rounded)
4.4.2	Traffic Control Person	0.00054 mSv	1900	8 minutes
5.2	Commercial Driver Refuelling Truck	0.00050 mSv	2000	7½ minutes
4.6.6	Vehicle Occupant on Controlled Access Highway (beside UFTP in congested traffic)	0.00038 mSv	2700	5¾ minutes
4.6.4	Vehicle Occupant on Highway (behind UFTP in congested Traffic)	0.00021 mSv	4800	3¼ minutes
4.6.3	Vehicle Occupant passing UFTP	0.00018 mSv	5600	2¾ minutes
5.3	Public at Unplanned Stop	0.00017 mSv	5700	2½ minutes
4.6.1	Vehicle Occupant on Urban Road beside UFTP	0.00014 mSv	7000	2¼ minutes
4.1.3	Resident in Urban Area – Sensitivity Case B	0.00011 mSv	8900	1¾ minutes
4.4.1	Worker along Highway	0.000095 mSv	10 000	1½ minutes
4.6.2	Vehicle Occupant on Urban Road behind UFTP	0.000067 mSv	15 000	60 seconds
4.1.2	Resident in Urban Area – Sensitivity Case A	0.000065 mSv	15 000	58 seconds
5.1	Individual at Rest Stop	0.000049 mSv	20 000	44 seconds
4.6.5	Vehicle Occupant on Controlled Access Highway (behind UFTP in congested traffic)	0.000047 mSv	21 000	42 seconds
4.1.1	Resident along Urban Road – Typical	0.000032 mSv	31 000	29 seconds
4.2	Pedestrian along Road	0.000028 mSv	35 000	26 seconds
4.5.1	Cyclist on Urban Road	0.000025 mSv	40 000	23 seconds
4.5.2	Cyclist on Highway	0.000012 mSv	83 000	11 seconds
4.1.4	Resident along Highway	0.0000096 mSv	100 000	9 seconds
4.1.5	Resident along Controlled Access Highway	0.0000080 mSv	120 000	7 seconds
4.3	Hitchhiker along Highway	0.0000013 mSv	780 000	1 second

* The factor the estimated annual dose is below the regulatory dose limit of 1 mSv/y for members of the public. Note: Factor to Dose Limit values are rounded to two significant digits.

** The dose received travelling in a jet airplane at an altitude of 10 000 m is approximately 0.004 mSv/h. The time listed in this column represents the flight-time equivalent dose (FED), the time in an airplane at 10 000 m required to receive a dose equivalent to the dose received during transportation-related activity listed in Column 2.

Table 18: Estimated Annual Dose to Transportation Workers due to the Transportation of Used Fuel

Section	Member of the Public	Estimated Annual Dose	Factor to Dose Limit* (1 mSv/year)	FED** (rounded)
6.1	Transport Crew	0.35 mSv	2.8	88½ hours
6.2	Inspector (Level VI)	0.16 mSv	6.2	40 hours
6.2	Inspector (Level I)	0.11 mSv	9.3	26¾ hours
6.2	Inspector (Level II)	0.054 mSv	19	13½ hours
6.4	Mechanic (tire repair)	0.017 mSv	59	4¼ hours
6.3	Portable Scale Operator	0.012 mSv	82	3 hours
6.3	Weigh Scale Operator (small scale)	0.0028 mSv	360	41½ minutes
6.3	Weigh Scale Operator (large scale)	0.00026 mSv	3900	4 minutes

* The factor the estimated annual dose is below the regulatory dose limit of 1 mSv/y for members of the public. Note: Factor to Dose Limit values are rounded to two significant digits.

** The dose received travelling in a jet airplane at an altitude of 10 000 m is approximately 0.004 mSv/h. The time listed in this column represents the flight-time equivalent dose (FED), the time in an airplane at 10000 m required to receive a dose equivalent to the dose received during transportation-related activity listed in Column 2.

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APPENDIX A: RATIONALE FOR LIMITING SCOPE TO INDIVIDUALS WITHIN 30 M OF PACKAGE

Assumptions:

- Worker is present at 30 m from UFTP every work day for the entire day
- Worker works 8 h per day, 5 days per week, 50 weeks per year = 2000 h/y

Data:

- | | | | | | | | | | |
|--|--|----------------|------------------------|---------|--------------|---------------|--------------|------------------|--|
| <ul style="list-style-type: none"> • Dose from UFTP at 30 m (220 MWh/kgU) • Regulatory limit for non-NEW • Regulatory limit for NEW | <table border="0"> <tr> <td style="padding-right: 10px;">0.000015 mSv/h</td> <td>(Batters et al., 2012)</td> </tr> <tr> <td>1 mSv/y</td> <td>(CNSC, 2000)</td> </tr> <tr> <td>100 mSv / 5 y</td> <td>(CNSC, 2000)</td> </tr> <tr> <td>50 mSv/y maximum</td> <td></td> </tr> </table> | 0.000015 mSv/h | (Batters et al., 2012) | 1 mSv/y | (CNSC, 2000) | 100 mSv / 5 y | (CNSC, 2000) | 50 mSv/y maximum | |
| 0.000015 mSv/h | (Batters et al., 2012) | | | | | | | | |
| 1 mSv/y | (CNSC, 2000) | | | | | | | | |
| 100 mSv / 5 y | (CNSC, 2000) | | | | | | | | |
| 50 mSv/y maximum | | | | | | | | | |
| <ul style="list-style-type: none"> • Annualized dose limit for NEWs¹ | <table border="0"> <tr> <td>20 mSv/y</td> <td></td> </tr> </table> | 20 mSv/y | | | | | | | |
| 20 mSv/y | | | | | | | | | |

Calculation:

Annual dose to worker at 30 m from UFTP	= 0.000015 mSv/h x 2000 h
	= 0.03 mSv/y

Comparisons:

Dose to worker from UFTP at 30 m is approximately equivalent to:

- 3% of regulatory limit for the general public
- 0.15% of dose limit for Nuclear Energy Workers

Conclusions:

The annual dose to a worker situated 30 m from a UFTP every day for the entire workday is estimated to be 0.03 mSv/y or 3% of the regulatory limit for the general public. Thus the radiological dose due to the transport of used nuclear fuel to workers engaged in activities at distances greater than 30 m from the UFTP is considered negligible. As the probability that a member of the public will spend as much time in close proximity to a loaded UFTP is highly unlikely, only activities placing individuals at distances within 30 m of the UFTP are included in this assessment.

References:

Batters, S., K. Tsang and U. Stahmer. 2012. Generic transportation dose assessment. Prepared by AMEC NSS for the Nuclear Waste Management Organization. Nuclear Waste Management Organization Report NWMO TR-2012-06. Toronto, Canada.

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¹ For the purpose of this assessment, doses to workers are compared to a dose limit of 20 mSv per year for NEWs (i.e., the regulatory dose limit of 100 mSv averaged over five years for Nuclear Energy Workers).

APPENDIX B: PUBLIC ACTIVITIES AND DOSE CALCULATIONS**CONTENTS**

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B.1 RESIDENT ALONG URBAN ROAD – TYPICAL

Description: An individual is present in or around a building or residence along an urban road as a UFTP shipment passes by. See Figure B-1 below.

Shipment Speed: 24 km/h. The UFTP shipment is assumed to pass the resident at a speed of 24 km/h. This is the average speed of traffic in an urban center and accounts for minor traffic congestion and for traffic signal stops.

Distance: 20 m and 25 m. The resident is assumed to be present at 20 m for 10% of all shipments and at 25 m for 50% of all shipments (see Figure B-1).

Frequency: 372 shipments. The resident is assumed to be present for 60% of all 620 shipments.

Time, distance and frequency references: Khan, et al., (2015).

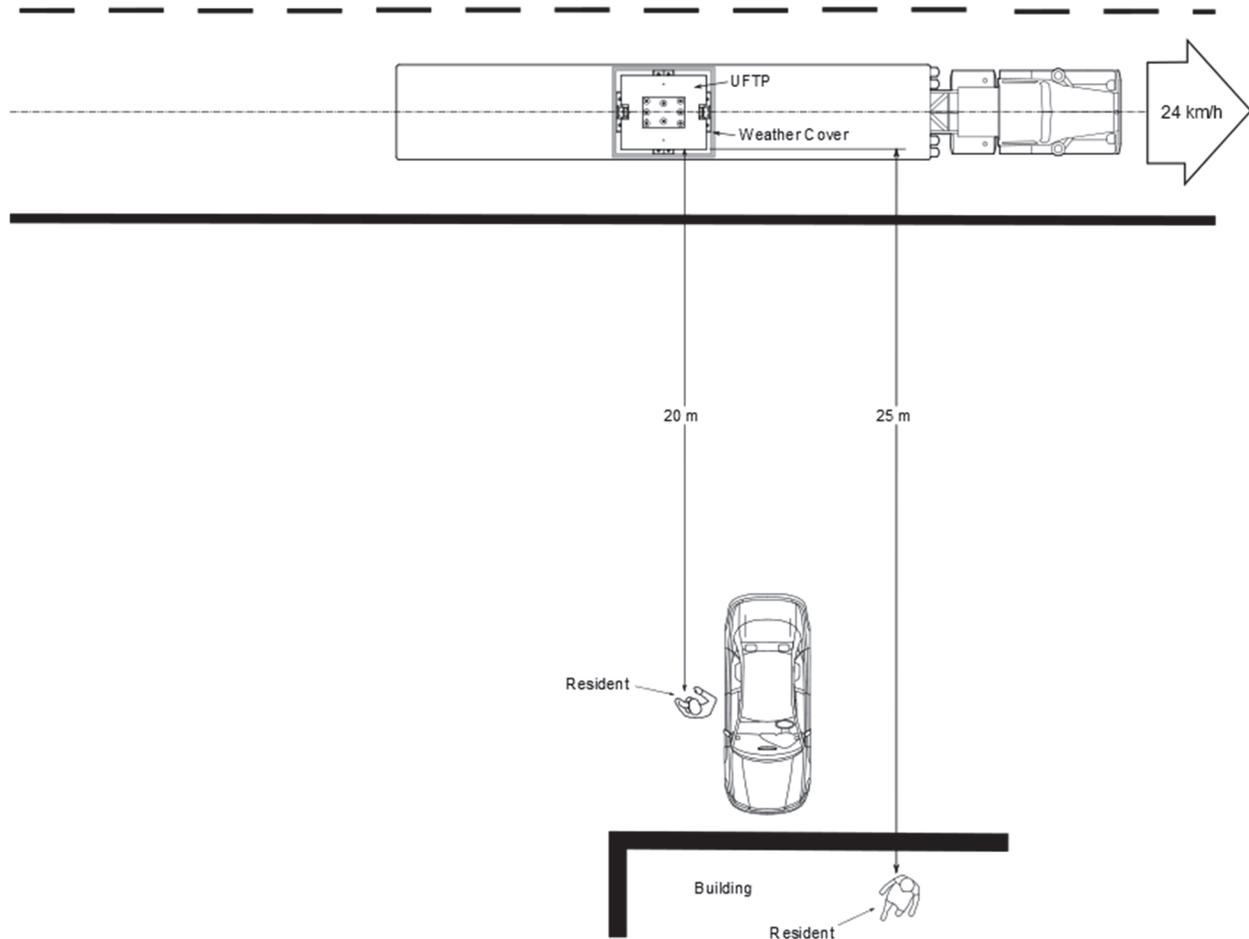


Figure B-1: A Resident along an Urban Road at 20 m and 25 m from the UFTP Shipment

Resident Dose Calculation

A resident may receive a dose from a UFTP shipment as it passes by.

Dose received from UFTP shipment passing at 20 m away

Dose received by a stationary receptor from moving source is presented in Appendix D. Using the method described, the dose received by the resident at 20 m from side of the truck as it passes at 24 km/h is 1.05×10^{-7} mSv.

Dose received from UFTP shipment passing at 25 m away

Dose received by a stationary receptor from moving source is presented in Appendix D. Using the method described, the dose received by the resident at 25 m from side of the truck as it passes at 24 km/h is 8.18×10^{-8} mSv.

Annual Dose received from 62 shipments (10% of all shipments) at 20 m from UFTP Shipment

$$\begin{aligned} \text{Dose} &= \text{dose} \times \text{frequency} \\ &= 1.05 \times 10^{-7} \text{ mSv} \times 62 \text{ shipments} \\ &= 6.51 \times 10^{-6} \text{ mSv} \end{aligned}$$

Annual Dose received from 310 shipments (50% of all shipments) at 25 m from UFTP Shipment

$$\begin{aligned} \text{Dose} &= \text{dose} \times \text{frequency} \\ &= 8.18 \times 10^{-8} \text{ mSv} \times 310 \text{ shipments} \\ &= 2.54 \times 10^{-5} \text{ mSv} \end{aligned}$$

Annual Dose to Resident

$$\begin{aligned} \text{Dose} &= \text{annual dose at 20 m} + \text{annual dose at 25 m} \\ &= 6.51 \times 10^{-6} \text{ mSv} + 2.54 \times 10^{-5} \text{ mSv} \\ &= 0.000032 \text{ mSv} \end{aligned}$$

Conclusions

The annual dose due to used fuel transportation estimated to be received by a resident in an urban area is 0.000032 mSv. This dose is orders of magnitude lower than the regulatory dose limit for the public of 1 mSv per year. The annual dose to an urban resident is approximately equal to an annual FED of 29 seconds.

B.2 RESIDENT ALONG URBAN ROAD – SENSITIVITY CASE A

Description: An individual is present in or around a building or residence along an urban road as a UFTP shipment passes by. See Figure B-2 below.

Shipment Speed: 24 km/h. The UFTP shipment is assumed to pass the resident at a speed of 24 km/h. This is the average speed of traffic in an urban center and accounts for minor traffic congestion and for traffic signal stops.

Distance: 8 m. The resident is assumed to be present at 8 m for 50% of all shipments (see Figure B-2).

Frequency: 310 shipments. The resident is assumed to be present for 50% of all 620 shipments.

Time, distance and frequency references: Khan, et al., (2015).

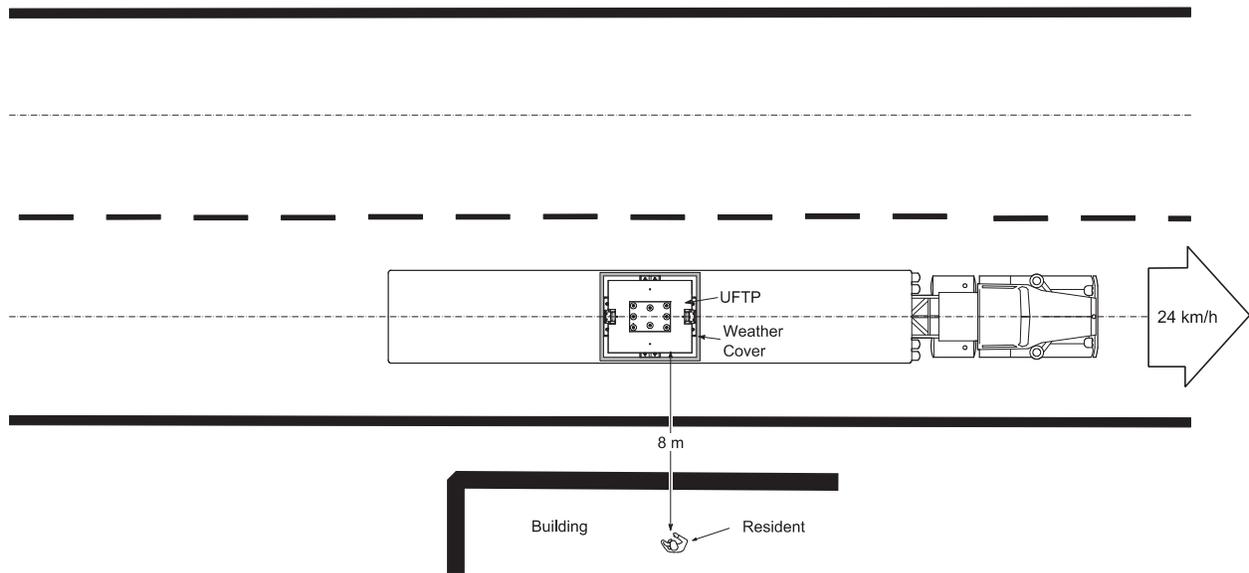


Figure B-2: A Resident along an Urban Road at 8 m from the UFTP Shipment

Resident Dose Calculation

A resident may receive a dose from a UFTP shipment as it passes by.

Dose received from UFTP shipment passing at 8 m away

Dose received by a stationary receptor from moving source is presented in Appendix D. Using the method described, the dose received by the resident at 8 m from side of the truck as it passes at 24 km/h is 2.09×10^{-7} mSv.

Annual Dose received from 310 shipments (50% of all shipments) at 8 m from UFTP Shipment

$$\begin{aligned} \text{Dose} &= \text{dose} \times \text{frequency} \\ &= 2.09 \times 10^{-7} \text{ mSv} \times 310 \text{ shipments} \\ &= 0.000065 \text{ mSv} \end{aligned}$$

Conclusions

The annual dose due to used fuel transportation estimated to be received by a resident in an urban area at 8 m from the UFTP shipment for 310 shipments is 0.000065 mSv. This dose is orders of magnitude lower than the regulatory dose limit for the public of 1 mSv per year. The annual dose to an urban resident in this sensitivity case is approximately equal to an annual FED of 58 seconds.

B.3 RESIDENT ALONG URBAN ROAD – SENSITIVITY CASE B

Description: An individual is present in front of a building or residence along an urban road as a UFTP shipment passes by. See Figure B-3 below.

Shipment Speed: 5 km/h and 30 km/h. During through traffic, the UFTP shipment is assumed to pass the resident at a speed of 30 km/h. While approaching a red traffic signal, and departing from a newly green traffic signal, the UFTP shipment is assumed to pass the resident at 5 km/h.

Distance: 5 m. The resident is assumed to be present at 5 m for 50% of all shipments (see Figure B-3).

Frequency: 118 shipments. This scenario is specific to rural towns in southwestern Ontario. Only the shipments originating from the Bruce site are considered. The resident is assumed to be present for 40% of all 295 shipments originating from the Bruce site. Of these, 75% (88 shipments) are assumed to pass by at 30 km/h. The remaining 25% (30 shipments) are assumed to be stopped by the traffic signal. The signal cycle time is assumed to be 1½ minutes in length. Of the 30 shipments stopped at the signal, three shipments are assumed to stop directly in front of the resident, placing the resident at 5 m from the UFTP for the entire 1½ minutes of the signal cycle time. The remaining 27 shipments stopped at the signal are assumed to be stopped with the UFTP more than 30 m away from the resident.

Time, distance and frequency references: Khan, et al., (2015).

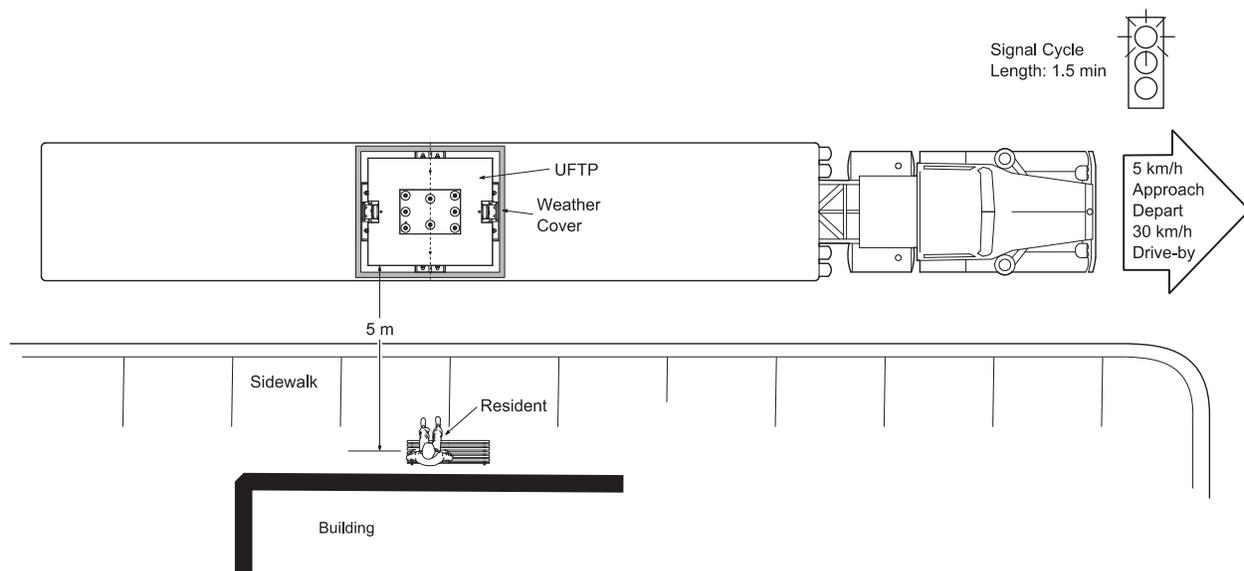


Figure B-3: A Resident along an Urban Road at 8 m from the UFTP Shipment

Resident Dose Calculation

A resident may receive a dose from a UFTP shipment as it passes by.

Dose received from UFTP shipment passing at 30 km/h

Dose received by a stationary receptor from moving source is presented in Appendix D. Using the method described, the dose received by the resident at 5 m from side of the truck as it passes at 30 km/h is 2.72×10^{-7} mSv.

Dose received from UFTP shipment passing at 5 km/h (approach and departure)

Dose received by a stationary receptor from moving source is presented in Appendix D. Using the method described, the dose received by the resident at 5 m from side of the truck as it passes at 5 km/h is 1.63×10^{-6} mSv.

Dose received during traffic signal stop

$$\begin{aligned} \text{Dose rate at 5 m} &= 0.00052 \text{ mSv/h (see Figure 6 in main report)} \\ \text{Dose} &= \text{dose rate} \times \text{duration} \\ &= 0.00052 \text{ mSv/h} \times (1.5 \text{ min}) \\ &= 1.30 \times 10^{-5} \text{ mSv} \end{aligned}$$

Annual Dose received from 88 drive by shipments at 5 m from UFTP Shipment

$$\begin{aligned} \text{Dose} &= \text{dose} \times \text{frequency} \\ &= 2.72 \times 10^{-7} \text{ mSv} \times 88 \text{ shipments} \\ &= 2.39 \times 10^{-5} \text{ mSv} \end{aligned}$$

Annual Dose received from 30 slow shipments at 5 m from UFTP Shipment

$$\begin{aligned} \text{Dose} &= \text{dose} \times \text{frequency} \\ &= 1.63 \times 10^{-6} \text{ mSv} \times 30 \text{ shipments} \\ &= 4.89 \times 10^{-5} \text{ mSv} \end{aligned}$$

Annual Dose received from 3 stopped shipments at 5 m from UFTP Shipment

$$\begin{aligned} \text{Dose} &= \text{dose} \times \text{frequency} \\ &= 1.30 \times 10^{-5} \text{ mSv} \times 3 \text{ shipments} \\ &= 3.9 \times 10^{-5} \text{ mSv} \end{aligned}$$

Annual Dose received from 118 shipments

$$\begin{aligned} \text{Dose} &= \text{drive through dose} + \text{approach and depart dose} + \text{signal stop dose} \\ &= 2.39 \times 10^{-5} \text{ mSv} + 4.89 \times 10^{-5} \text{ mSv} + 3.9 \times 10^{-5} \text{ mSv} \\ &= 0.00011 \text{ mSv} \end{aligned}$$

Conclusions

The annual dose due to used fuel transportation estimated to be received by a resident in an urban area at 5 m from the UFTP shipment for 118 shipments is 0.00011 mSv. This dose is orders of magnitude lower than the regulatory dose limit for the public of 1 mSv per year. The annual dose to an urban resident in this sensitivity case is approximately equal to an annual FED of 1 minute and 41 seconds.

B.4 RESIDENT ALONG HIGHWAY

Description: An individual is present in or around a building or residence along a highway as a UFTP shipment passes by. See Figure B-4 below.

Shipment Speed: 80 km/h. The UFTP shipment is assumed to pass the resident at a speed of 80 km/h.

Distance: 20 m and 25 m. The resident is assumed to be present at 20 m for 10% of all shipments and at 25 m for 50% of all shipments (see Figure B-4).

Frequency: 372 shipments. The resident is assumed to be present for 60% of all 620 shipments.

Time, distance and frequency references: Khan, et al., (2015).

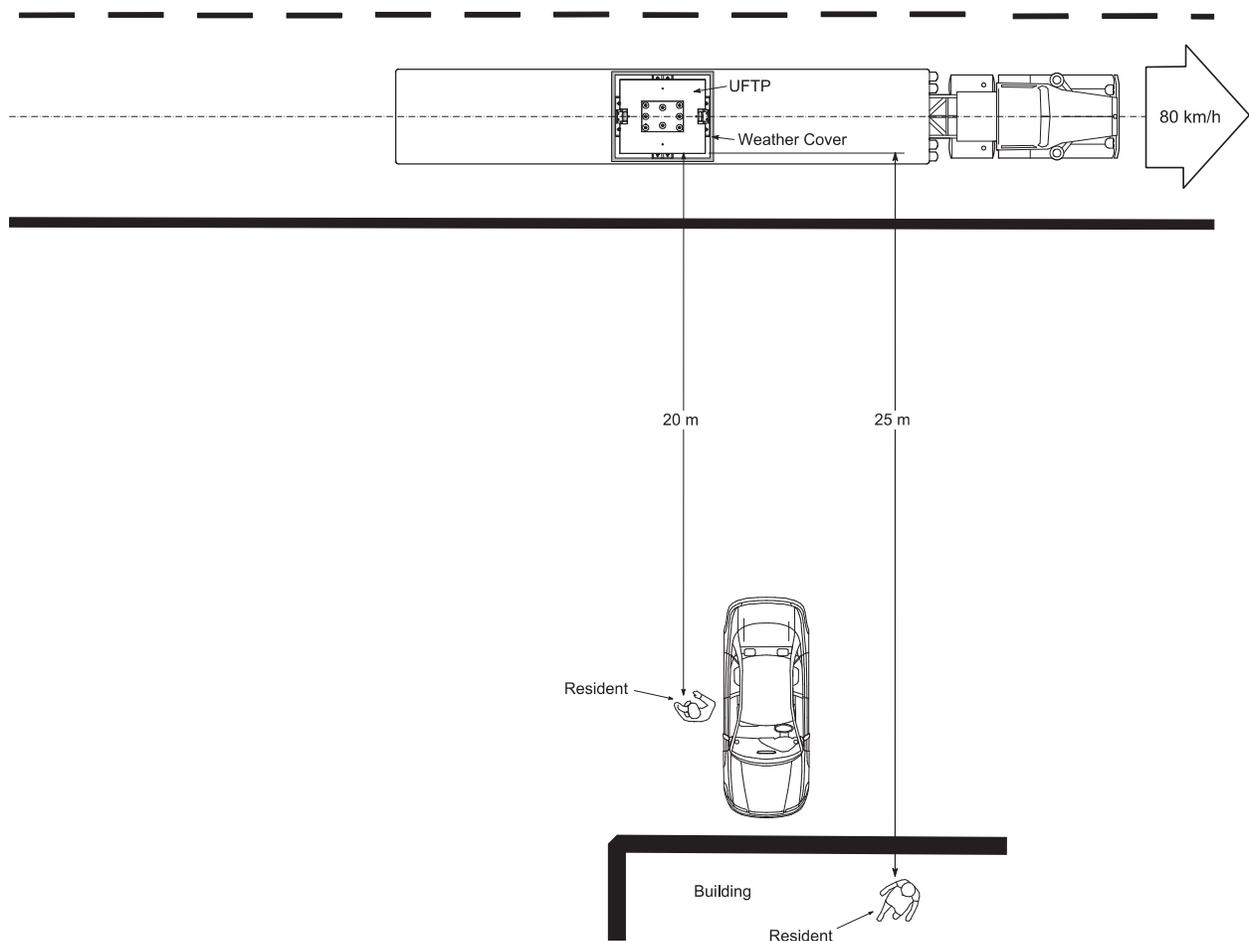


Figure B-4: A Resident along a Highway at 20 m and 25 m from the UFTP Shipment

Resident Dose Calculation

A resident may receive a dose from a UFTP shipment as it passes by.

Dose received from UFTP shipment passing at 20 m away

Dose received by a stationary receptor from moving source is presented in Appendix D. Using the method described, the dose received by the resident at 20 m from side of the truck as it passes at 80 km/h is 3.14×10^{-8} mSv.

Dose received from UFTP shipment passing at 25 m away

Dose received by a stationary receptor from moving source is presented in Appendix D. Using the method described, the dose received by the resident at 25 m from side of the truck as it passes at 80 km/h is 2.45×10^{-8} mSv.

Annual Dose received from 62 shipments (10% of all shipments) at 20 m from UFTP Shipment

$$\begin{aligned} \text{Dose} &= \text{dose} \times \text{frequency} \\ &= 3.14 \times 10^{-8} \text{ mSv} \times 62 \text{ shipments} \\ &= 1.95 \times 10^{-6} \text{ mSv} \end{aligned}$$

Annual Dose received from 310 shipments (50% of all shipments) at 25 m from UFTP Shipment

$$\begin{aligned} \text{Dose} &= \text{dose} \times \text{frequency} \\ &= 2.45 \times 10^{-8} \text{ mSv} \times 310 \text{ shipments} \\ &= 7.61 \times 10^{-6} \text{ mSv} \end{aligned}$$

Annual Dose to Resident

$$\begin{aligned} \text{Dose} &= \text{annual dose at 20 m} + \text{annual dose at 25 m} \\ &= 7.61 \times 10^{-6} \text{ mSv} + 1.95 \times 10^{-6} \text{ mSv} \\ &= 0.0000096 \text{ mSv} \end{aligned}$$

Conclusions

The annual dose due to used fuel transportation estimated to be received by a resident along a highway is 0.0000096 mSv. This dose is orders of magnitude lower than the regulatory dose limit for the public of 1 mSv per year. The annual dose to a resident along a highway is approximately equal to an annual FED of 9 seconds.

B.5 RESIDENT ALONG CONTROLLED ACCESS HIGHWAY

Description: An individual is present in or around a building or residence along a controlled access highway as a UFTP shipment passes by. See Figure B-5 below.

Shipment Speed: 24 km/h and 100 km/h. 10% of the UFTP shipments are assumed to pass the resident at a speed of 24 km/h. The remaining 90% of the shipments are assumed to pass at 100 km/h. This takes traffic slowdowns into account.

Distance: 25 m. The resident is assumed to be present at 25 m for 50% of all shipments (see Figure B-5).

Frequency: 310 shipments. The resident is assumed to be present for 50% of all 620 shipments.

Time, distance and frequency references: Khan, et al., (2015).

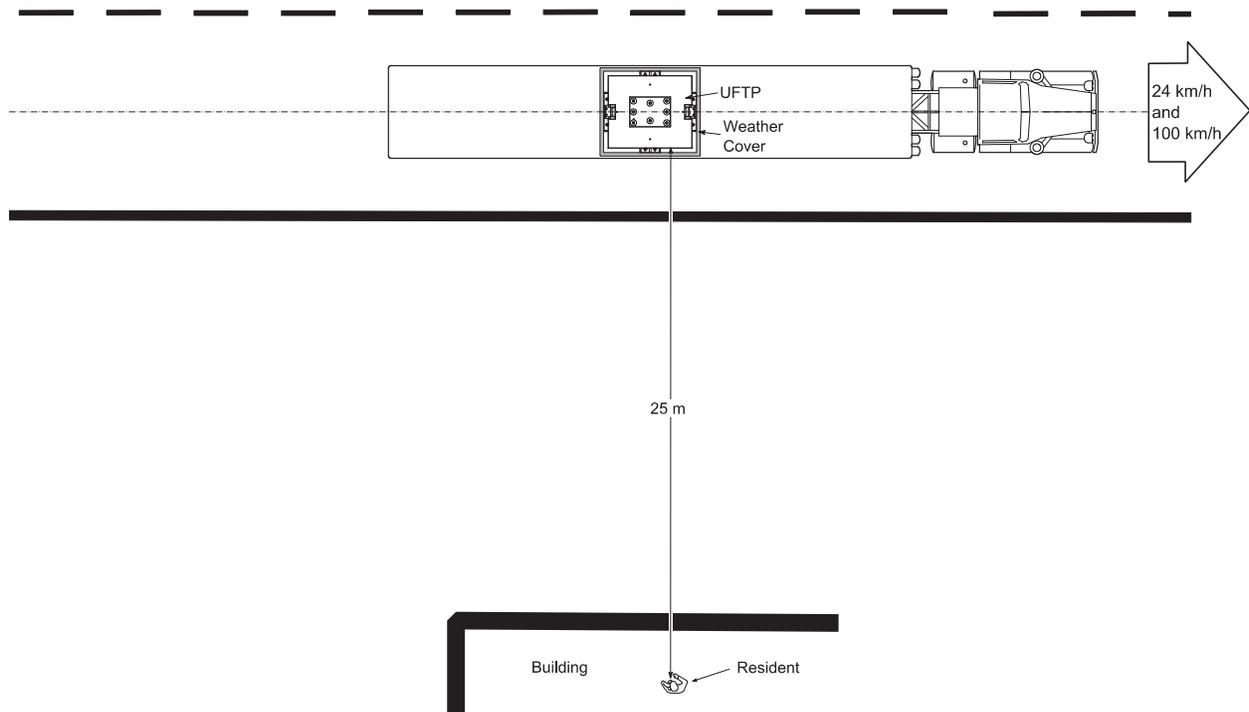


Figure B-5: A Resident along a Controlled Access Highway at 25 m from the UFTP Shipment

Resident Dose Calculation

A resident may receive a dose from a UFTP shipment as it passes by.

Dose received from UFTP shipment passing at 25 m away at 24 km/h

Dose received by a stationary receptor from moving source is presented in Appendix D. Using the method described, the dose received by the resident at 25 m from side of the truck as it passes at 24 km/h is 8.18×10^{-8} mSv.

Dose received from UFTP shipment passing at 25 m away at 100 km/h

Dose received by a stationary receptor from moving source is presented in Appendix D. Using the method described, the dose received by the resident at 25 m from side of the truck as it passes at 100 km/h is 1.96×10^{-8} mSv.

Annual Dose received from 31 shipments (10% of shipments) at 25 m from UFTP Shipment at 24 km/h

$$\begin{aligned} \text{Dose} &= \text{dose} \times \text{frequency} \\ &= 8.18 \times 10^{-8} \text{ mSv} \times 31 \text{ shipments} \\ &= 2.54 \times 10^{-6} \text{ mSv} \end{aligned}$$

Annual Dose received from 279 shipments (90% of shipments) at 25 m from UFTP Shipment at 100 km/h

$$\begin{aligned} \text{Dose} &= \text{dose} \times \text{frequency} \\ &= 1.96 \times 10^{-8} \text{ mSv} \times 279 \text{ shipments} \\ &= 5.47 \times 10^{-6} \text{ mSv} \end{aligned}$$

Annual Dose to Resident

$$\begin{aligned} \text{Dose} &= \text{annual dose at 20 m} + \text{annual dose at 25 m} \\ &= 2.54 \times 10^{-6} \text{ mSv} + 5.47 \times 10^{-6} \text{ mSv} \\ &= 0.0000080 \text{ mSv} \end{aligned}$$

Conclusions

The annual dose due to used fuel transportation estimated to be received by a resident along a controlled access highway is 0.0000080 mSv. This dose is orders of magnitude lower than the regulatory dose limit for the public of 1 mSv per year. The annual dose to a resident along a controlled access highway is approximately equal to an annual FED of 7 seconds.

B.6 PEDESTRIAN

Description: A pedestrian is present along an urban road as a UFTP shipment passes by. See Figure B-6 below.

Shipment Speed: 24 km/h. The UFTP shipment is assumed to pass the pedestrian at a speed of 24 km/h. This is the average speed of traffic in an urban center and accounts for minor traffic congestion and for traffic signal stops.

Distance: 3.5 m. The pedestrian is assumed to be present at 3.5 m from the passing UFTP shipment (see Figure B-6).

Frequency: 62 shipments. The pedestrian is assumed to be present for 10% of all 620 shipments.

Time, distance and frequency references: Khan, et al., (2015).

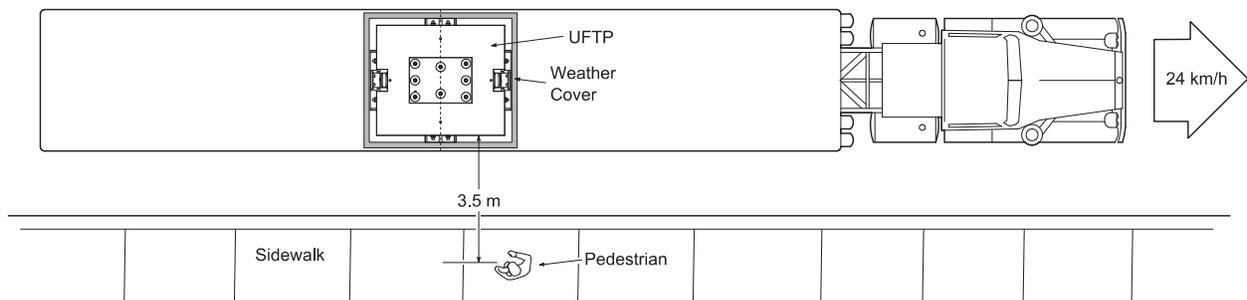


Figure B-6: A Pedestrian along an Urban Road at 3.5 m from the UFTP Shipment

Pedestrian Dose Calculation

A pedestrian may receive a dose from a UFTP shipment as it passes by.

Dose received from UFTP shipment passing at 3.5 m away at 24 km/h

Dose received by a stationary receptor from moving source is presented in Appendix D. Using the method described, the dose received by the pedestrian at 3.5 m from side of the truck as it passes at 24 km/h is 4.58×10^{-7} mSv.

Annual Dose to Pedestrian

$$\begin{aligned} \text{Dose} &= \text{dose at 3.5 m} \times \text{frequency} \\ &= 4.58 \times 10^{-7} \text{ mSv} \times 62 \text{ shipments} \\ &= 0.000028 \text{ mSv} \end{aligned}$$

Conclusions

The annual dose due to used fuel transportation estimated to be received by a pedestrian along an urban road is 0.000028 mSv. This dose is orders of magnitude lower than the regulatory dose limit for the public of 1 mSv per year. The annual dose to a pedestrian along an urban road is approximately equal to an annual FED of 26 seconds.

B.7 HITCHHIKER

Description: A hitchhiker is present along a highway as a UFTP shipment passes by. See Figure B-7 below.

Shipment Speed: 50 km/h. The UFTP shipment is assumed to pass the hitchhiker at a speed of 50 km/h. The hitchhiker is assumed to be standing at the town limits prior to the increase in highway speed limit.

Distance: 3.1 m. The hitchhiker is assumed to be present at 3.1 m from the passing UFTP shipment (see Figure B-7).

Frequency: 6 shipments. The hitchhiker is assumed to be present for 1% of all 620 shipments.

Time, distance and frequency references: Khan, et al., (2015).

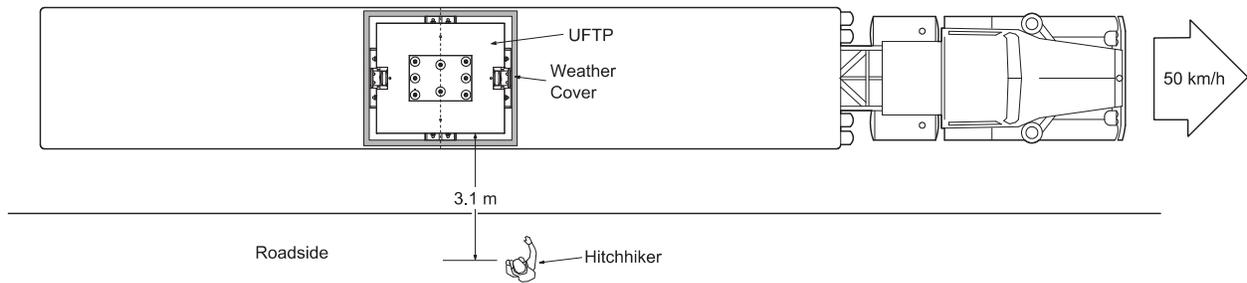


Figure B-7: A Hitchhiker along a Highway at 3.1 m from the UFTP Shipment

Hitchhiker Dose Calculation

A hitchhiker may receive a dose from a UFTP shipment as it passes by.

Dose received from UFTP shipment passing at 3.1 m away at 50 km/h

Dose received by a stationary receptor from moving source is presented in Appendix D. Using the method described, the dose received by the hitchhiker at 3.1 m from side of the truck as it passes at 50 km/h is 2.14×10^{-7} mSv.

Annual Dose to Hitchhiker

$$\begin{aligned}\text{Dose} &= \text{dose at 3.1 m} \times \text{frequency} \\ &= 2.14 \times 10^{-7} \text{ mSv} \times 6 \text{ shipments} \\ &= 0.0000013 \text{ mSv}\end{aligned}$$

Conclusions

The annual dose due to used fuel transportation estimated to be received by a hitchhiker along a highway is 0.0000013 mSv. This dose is orders of magnitude lower than the regulatory dose limit for the public of 1 mSv per year. The annual dose to a hitchhiker along a highway is approximately equal to an annual FED of 1 second.

B.8 CONSTRUCTION WORKER ALONG HIGHWAY

Description: A construction worker is present along a highway as a UFTP shipment passes by. See Figure B-8 below.

Shipment Speed: 24 km/h. The UFTP shipment is assumed to pass the construction worker at a speed of 24 km/h.

Distance: 3.1 m and 5 m. The construction worker is assumed to be present at 3.1 m and 5 m from the passing UFTP shipment (see Figure B-8). The construction worker is assumed to be at 3.1 m from the passing UFTP for 25% of the shipments (65 shipments) and at 5 m from the passing UFTP for the remaining 75% of the shipments (195 shipments).

Frequency: 260 shipments. The construction worker is assumed to be present for 2 shipments per day, 5 days per week for a construction period of 26 weeks.

Time, distance and frequency references: AECON.

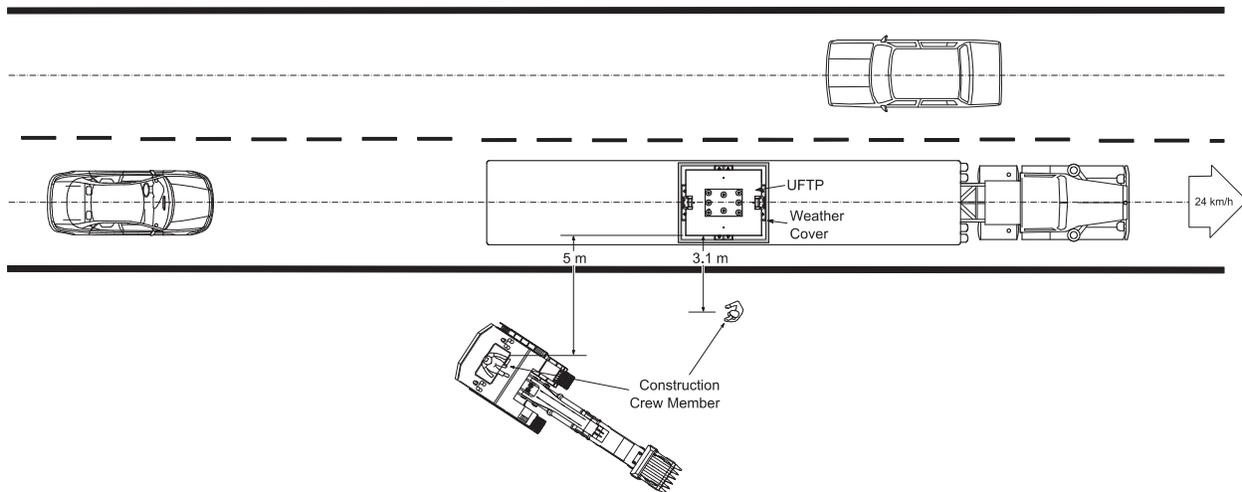


Figure B-8: Construction Workers along a Highway at 3.1 m and 5 m from the UFTP Shipment

Construction Worker Dose Calculation

A construction worker may receive a dose from a UFTP shipment as it passes by.

Dose received from UFTP shipment passing at 3.1 m away at 24 km/h

Dose received by a stationary receptor from moving source is presented in Appendix D. Using the method described, the dose received by the construction worker at 3.1 m from side of the truck as it passes at 24 km/h is 4.46×10^{-7} mSv.

Dose received from UFTP shipment passing at 5 m away at 24 km/h

Dose received by a stationary receptor from moving source is presented in Appendix D. Using the method described, the dose received by the construction worker at 5 m from side of the truck as it passes at 24 km/h is 3.40×10^{-7} mSv.

Annual Dose received from 65 shipments at 3.1 m from UFTP Shipment at 24 km/h

$$\begin{aligned} \text{Dose} &= \text{dose} \times \text{frequency} \\ &= 4.46 \times 10^{-7} \text{ mSv} \times 65 \text{ shipments} \\ &= 2.90 \times 10^{-5} \text{ mSv} \end{aligned}$$

Annual Dose received from 195 shipments at 5 m from UFTP Shipment at 24 km/h

$$\begin{aligned} \text{Dose} &= \text{dose} \times \text{frequency} \\ &= 3.40 \times 10^{-7} \text{ mSv} \times 195 \text{ shipments} \\ &= 6.63 \times 10^{-5} \text{ mSv} \end{aligned}$$

Annual Dose to Construction Worker

$$\begin{aligned} \text{Dose} &= \text{dose at 3.1 m} + \text{dose at 5 m} \\ &= 2.90 \times 10^{-5} \text{ mSv} + 6.63 \times 10^{-5} \text{ mSv} \\ &= 0.000095 \text{ mSv} \end{aligned}$$

Conclusions

The annual dose due to used fuel transportation estimated to be received by a construction worker along a highway is 0.000095 mSv. This dose is orders of magnitude lower than the regulatory dose limit for the public of 1 mSv per year. The annual dose to a construction worker along a highway is approximately equal to an annual FED of 1 minute and 26 seconds.

B.9 TRAFFIC CONTROL PERSON ALONG HIGHWAY

- Description:** A traffic control person is present along a highway as a UFTP shipment passes by. See Figure B-9 below.
- Time:** 5 minutes. Traffic stopped by the traffic control person is assumed to be stopped for a period of 5 minutes.
- Shipment Speed:** 5 km/h and 24 km/h. When being stopped, the UFTP shipment is assumed to approach and depart the traffic control person at a speed of 5 km/h. When being waved through without stopping, the UFTP shipment is assumed to pass the traffic control person at a speed of 24 km/h.
- Distance:** 2 m, 5 m and 14 m. The traffic control person is assumed to be 2 m from the side of the UFTP shipment for stopped shipments. When the UFTP is positioned first in queue, the traffic control person is assumed to be located 14 m from the UFTP (See Figure B-9). For shipments waved through without stopping, the traffic control person is assumed to be located 5 m from the passing shipment (see Figure B-9).
- Frequency:** 260 shipments. The construction worker is assumed to be present for 2 shipments per day, 5 days per week for a construction period of 26 weeks. 50% of the shipments are assumed to be stopped by the traffic control person. The UFTP shipment is assumed to be first in queue for 10% of these.
- Time, distance and frequency references:** AECON.

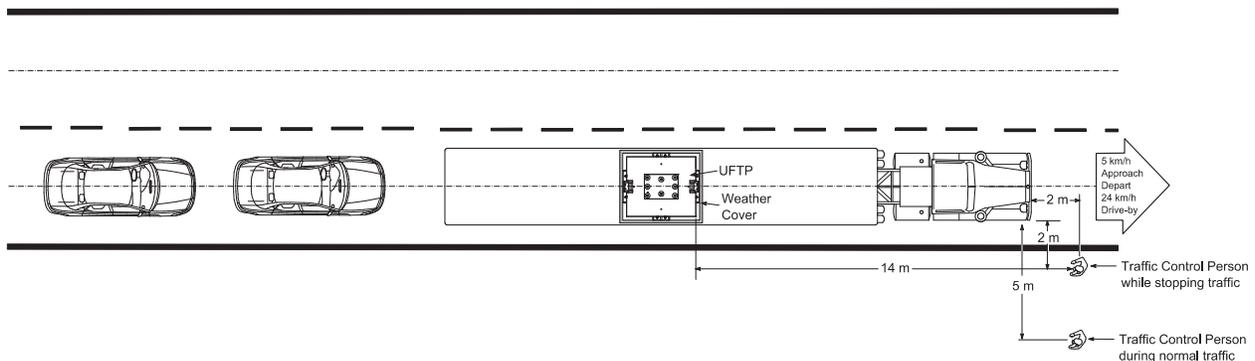


Figure B-9: A Traffic Control Person along a Highway at 2 m and 5 m from the UFTP Shipment

Traffic Control Person Dose Calculation

A traffic control person may receive a dose from a UFTP shipment as it passes by.

Dose received from UFTP shipment passing at 2 m away at 5 km/h

Dose received by a stationary receptor from moving source is presented in Appendix D. Using the method described, the dose received by the traffic control person at 2 m from side of the truck as it passes at 5 km/h is 3.04×10^{-6} mSv.

Dose received from UFTP shipment passing at 5 m away at 24 km/h

Dose received by a stationary receptor from moving source is presented in Appendix D. Using the method described, the dose received by the construction worker at 5 m from side of the truck as it passes at 24 km/h is 3.40×10^{-7} mSv.

Dose received during 5 minute stoppage period at 14 m from UFTP

$$\begin{aligned} \text{Dose} &= \text{dose rate at 14 m} \times \text{time} \\ &= 0.00009 \text{ mSv/h} \times 5 \text{ minutes} \\ &= 7.50 \times 10^{-6} \text{ mSv} \end{aligned}$$

Annual Dose received from 130 (50%) of shipments waved through at 2 m from UFTP Shipment at 5 km/h

$$\begin{aligned} \text{Dose} &= \text{dose} \times \text{frequency} \\ &= 3.04 \times 10^{-6} \text{ mSv} \times 130 \text{ shipments} \\ &= 3.95 \times 10^{-4} \text{ mSv} \end{aligned}$$

Annual Dose received from 130 (50%) of shipments waved through at 5 m from UFTP Shipment at 24 km/h

$$\begin{aligned} \text{Dose} &= \text{dose} \times \text{frequency} \\ &= 3.40 \times 10^{-7} \text{ mSv} \times 130 \text{ shipments} \\ &= 4.42 \times 10^{-5} \text{ mSv} \end{aligned}$$

Annual Dose received from stopped shipments first in queue at 14 m from UFTP

$$\begin{aligned} \text{Dose} &= \text{dose} \times \text{frequency} \\ &= 7.50 \times 10^{-6} \text{ mSv} \times 13 \text{ shipments} \\ &= 9.75 \times 10^{-5} \text{ mSv} \end{aligned}$$

Annual Dose to Traffic Control Person

$$\begin{aligned} \text{Dose} &= \text{dose at 2 m} + \text{dose at 5 m} + \text{dose due to stop} \\ &= 3.95 \times 10^{-4} \text{ mSv} + 4.42 \times 10^{-5} \text{ mSv} + 9.75 \times 10^{-5} \text{ mSv} \\ &= 0.00054 \text{ mSv} \end{aligned}$$

Conclusions

The annual dose due to used fuel transportation estimated to be received by a traffic control person along a highway is 0.00054 mSv. This dose is orders of magnitude lower than the regulatory dose limit for the public of 1 mSv per year. The annual dose to a traffic control person along a highway is approximately equal to an annual FED of 8 minutes and 4 seconds.

B.10 CYCLIST ALONG URBAN ROAD

Description: A cyclist is present along an urban road as a UFTP shipment passes by. See Figure B-10 below.

Speed: 20 km/h (cyclist) and 24 km/h (shipment). The UFTP shipment is assumed to pass the cyclist at a relative speed of 4 km/h.

Distance: 1.5 m and 10 m. The cyclist is assumed to be present at 1.5 m from the passing UFTP shipment (see Figure B-10). After the shipment passes, the cyclist is assumed to draft behind the shipment at a distance of 10 m from the UFTP for a period of 2½ minutes.

Frequency: 2 shipments. The cyclist is assumed to be present for 2 shipments per year.

Time, distance and frequency references: Khan, et al., (2015).

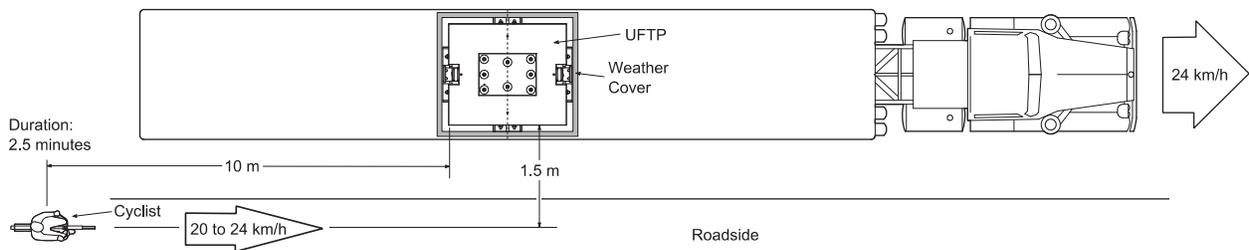


Figure B-10: A Cyclist along an Urban Road 1.5 m from the UFTP Shipment

Cyclist along Urban Road Dose Calculation

A cyclist may receive a dose from a UFTP shipment as it passes by. As the occurrence frequency of the cyclist is low, the UFTP is assumed to contain peak burnup fuel (higher dose to the cyclist).

Dose received from UFTP shipment passing at 4 km/h at 1.5 m away

In this case, the cyclist is assumed to be a stationary receptor with the shipment passing the receptor at the relative speed difference between the cyclist and the UFTP shipment. Dose received by a stationary receptor from moving source is presented in Appendix D. Using the method described, the dose received by the cyclist at 1.5 m from side of the truck as it passes at 4 km/h is 5.89×10^{-6} mSv.

Dose received while drafting behind shipment at 10 m from UFTP for 2½ minutes

$$\begin{aligned} \text{Dose} &= \text{dose rate at 10 m} \times \text{time} \\ &= 0.00016 \text{ mSv/h} \times 2.5 \text{ minutes} \\ &= 6.71 \times 10^{-6} \text{ mSv} \end{aligned}$$

Dose per occurrence

$$\begin{aligned} \text{Dose} &= \text{dose due to passing} + \text{dose due to drafting} \\ &= 5.89 \times 10^{-6} \text{ mSv} + 6.71 \times 10^{-6} \text{ mSv} \\ &= 1.26 \times 10^{-5} \text{ mSv} \end{aligned}$$

Annual Dose received by Cyclist

$$\begin{aligned} \text{Dose} &= \text{dose} \times \text{frequency} \\ &= 1.26 \times 10^{-5} \text{ mSv} \times 2 \text{ shipments} \\ &= 0.000025 \text{ mSv} \end{aligned}$$

Conclusions

The annual dose due to used fuel transportation estimated to be received by a cyclist on an urban road is 0.000025 mSv. This dose is orders of magnitude lower than the regulatory dose limit for the public of 1 mSv per year. The annual dose to a cyclist on an urban road is approximately equal to an annual FED of 23 seconds.

B.11 CYCLIST ALONG HIGHWAY

Description: A cyclist is present along a highway as a UFTP shipment passes by. See Figure B-11 below.

Speed: 30 km/h (cyclist) and 70 km/h (shipment). The UFTP shipment is assumed to pass the cyclist at a relative speed of 40 km/h. For conservatism, the cyclist is assumed to travel at 30 km/h. This reduces the relative speed between the cyclist and the UFTP shipment, thus maximizing the dose to the cyclist.

Distance: 1.5 m. The cyclist is assumed to be present at 1.5 m from the passing UFTP shipment (see Figure B-11).

Frequency: 30 shipments. The cyclist is assumed to be present for 2 shipments per day 5 days per week for a period of 3 weeks.

Time, distance and frequency references: Khan, et al., (2015).

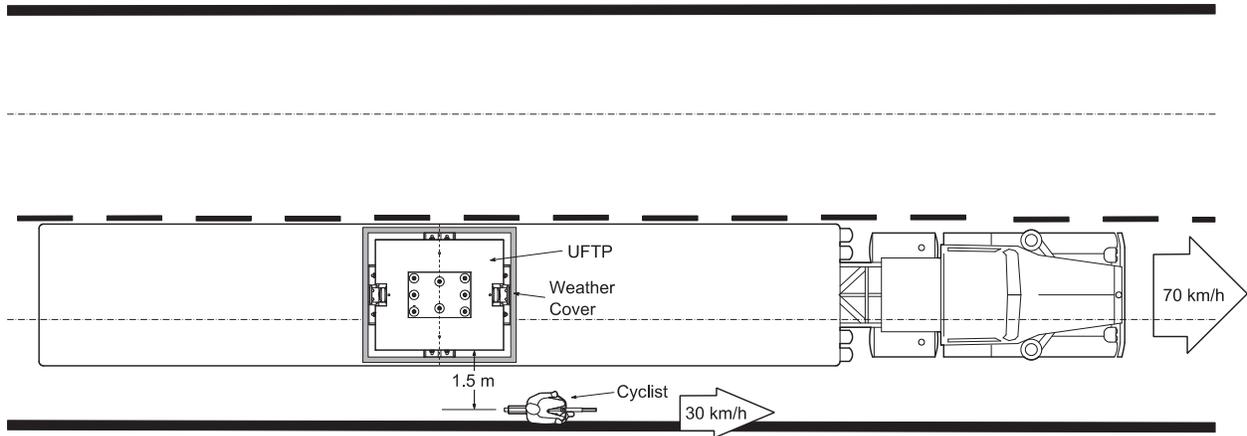


Figure B-11: A Cyclist along a Highway 1.5 m from the UFTP Shipment

Cyclist along Urban Road Dose Calculation

A cyclist may receive a dose from a UFTP shipment as it passes by.

Dose received from UFTP shipment passing at 40 km/h at 1.5 m away

In this case, the cyclist is assumed to be a stationary receptor with the shipment passing the receptor at the relative speed difference between the cyclist and the UFTP shipment. Dose received by a stationary receptor from moving source is presented in Appendix D. Using the method described, the dose received by the cyclist at 1.5 m from side of the truck as it passes at 40 km/h is 4.01×10^{-7} mSv.

Annual Dose received by Cyclist

$$\begin{aligned} \text{Dose} &= \text{dose} \times \text{frequency} \\ &= 4.01 \times 10^{-7} \text{ mSv} \times 30 \text{ shipments} \\ &= 0.000012 \text{ mSv} \end{aligned}$$

Conclusions

The annual dose due to used fuel transportation estimated to be received by a cyclist on a highway is 0.000012 mSv. This dose is orders of magnitude lower than the regulatory dose limit for the public of 1 mSv per year. The annual dose to a cyclist on a highway is approximately equal to an annual FED of 11 seconds.

B.12 VEHICLE OCCUPANT ON URBAN ROAD – BESIDE UFTP SHIPMENT

- Description:** An occupant in a vehicle in the passing lane of an urban road approaches a UFTP shipment, stops next to the UFTP at a traffic signal and then passes the UFTP shipment. See Figure B-12 below.
- Speed:** 5 km/h. The relative speed between the slow-moving UFTP shipment and the vehicle occupant is assumed to be 5 km/h. The vehicle occupant is assumed to approach the UFTP shipment which is stopped at a traffic signal. The vehicle occupant is assumed to be positioned directly beside the UFTP during the entire 1.5 minute traffic signal duration and then the vehicle occupant is assumed to finish passing the UFTP shipment at a relative speed of 5 km/h.
- Distance:** 2.3 m. The vehicle occupant is assumed to be present at 2.3 m when positioned directly beside the UFTP (see Figure B-12).
- Frequency:** 2 shipments. The vehicle occupant is assumed to be exposed to 2 shipments per year.
- Time, distance and frequency references:** Khan, et al., (2015).

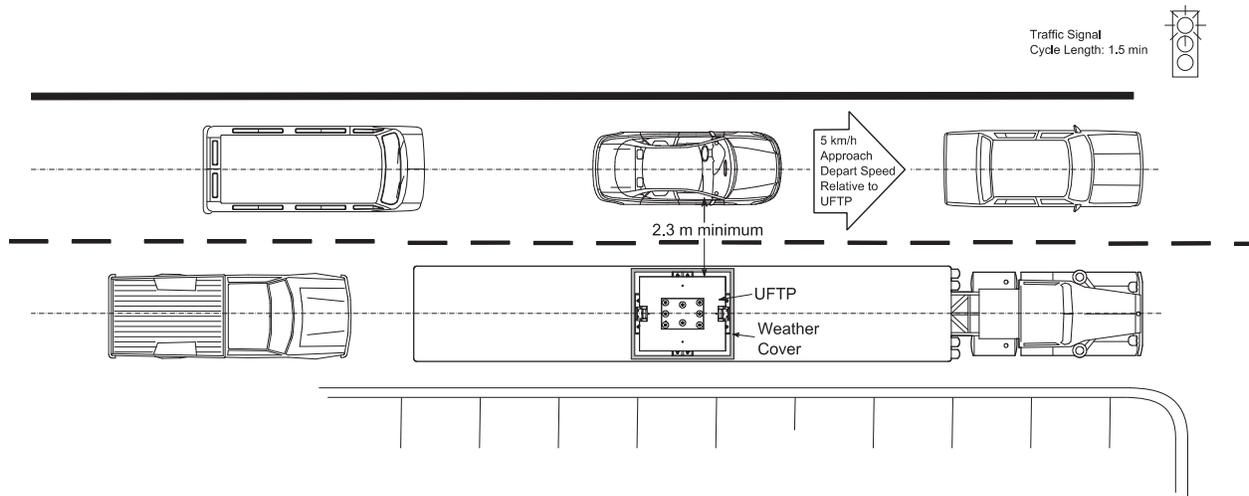


Figure B-12: Vehicle Occupant on Urban Road – Beside UFTP Shipment

Vehicle Occupant on Urban Road beside UFTP Shipment Dose Calculation

A vehicle occupant may receive a dose from a UFTP shipment as it is being passed. As the occurrence frequency of the vehicle occupant is low, the UFTP is assumed to contain peak burnup fuel (higher dose to the vehicle occupant).

Dose received from UFTP shipment while passing at 5 km/h at 2.3 m away

In this case, the UFTP is assumed to be a stationary receptor while the vehicle occupant passes the shipment at a relative speed difference of 5 km/h between the vehicle and the UFTP shipment. Dose received by a stationary receptor from moving source is presented in Appendix D. Using the method described, the dose received by the vehicle occupant at 2.3 m from side of the truck as it passes at 5 km/h is 3.90×10^{-6} mSv.

Dose received during 1½ minute signal stop at 2.3 m from UFTP

$$\begin{aligned} \text{Dose} &= \text{dose rate at 2.3 m} \times \text{time} \\ &= 0.0027 \text{ mSv/h} \times 1.5 \text{ minutes} \\ &= 6.75 \times 10^{-5} \text{ mSv} \end{aligned}$$

Dose per occurrence

$$\begin{aligned} \text{Dose} &= \text{dose due to passing} + \text{dose due to signal stop} \\ &= 3.90 \times 10^{-6} \text{ mSv} + 6.75 \times 10^{-5} \text{ mSv} \\ &= 7.14 \times 10^{-5} \text{ mSv} \end{aligned}$$

Annual Dose received by Vehicle Occupant

$$\begin{aligned} \text{Dose} &= \text{dose} \times \text{frequency} \\ &= 7.14 \times 10^{-5} \text{ mSv} \times 2 \text{ shipments} \\ &= 0.00014 \text{ mSv} \end{aligned}$$

Conclusions

The annual dose due to used fuel transportation estimated to be received by a cyclist on a highway is 0.00014 mSv. This dose is orders of magnitude lower than the regulatory dose limit for the public of 1 mSv per year. The annual dose to a cyclist on a highway is approximately equal to an annual FED of 2 minutes and 9 seconds.

B.13 VEHICLE OCCUPANT ON URBAN ROAD – BEHIND UFTP SHIPMENT

Description: An occupant in a vehicle on an urban road approaches a UFTP shipment from behind, travels behind the shipment for a period of 2½ minutes, stops behind the shipment at a traffic signal for a period of 1½ minutes and then passes the UFTP shipment. See Figure B-13 below.

Speed: 5 km/h. The relative speed between the slow-moving UFTP shipment and the vehicle occupant is assumed to be 5 km/h. The vehicle occupant is assumed to approach the UFTP shipment which is stopped at a traffic signal. The vehicle occupant is assumed to be positioned directly beside the UFTP during the entire 1.5 minute traffic signal duration and then the vehicle occupant is assumed to finish passing the UFTP shipment at a relative speed of 5 km/h.

Distance: 2.3 m, 10 m and 18 m. The vehicle occupant is assumed to be present at 18 m when travelling behind the UFTP shipment, at 10 m when stopped behind the UFTP shipment and at 2.3 m when passing the UFTP shipment (see Figure B-13).

Frequency: 8 shipments. The vehicle occupant is assumed to be exposed to 8 shipments per year.

Note: The exposure frequency presented in Khan, et al., (2015) is two exposures per year along the access roads leading from the Darlington facility. As only approximately 25% of the annual shipments originate from Darlington, a frequency of 8 shipments per year has been assumed for the access road to the DGR facility to take all shipments into account.

Time, distance and frequency references: Khan, et al., (2015).

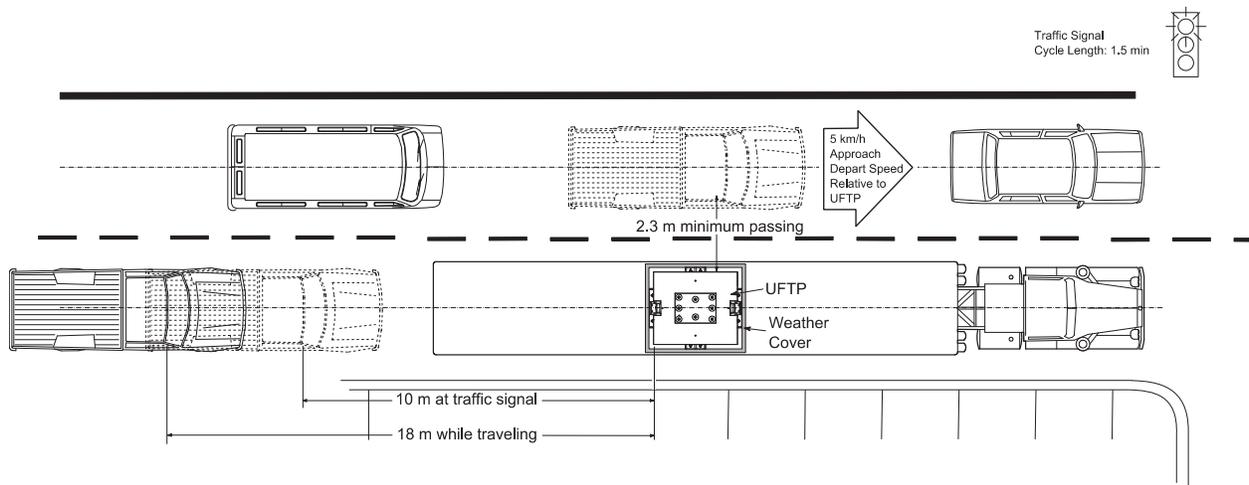


Figure B-13: Vehicle Occupant on Urban Road – Behind UFTP Shipment

Vehicle Occupant on Urban Road behind UFTP Shipment Dose Calculation

A vehicle occupant may receive a dose from a UFTP shipment as it is being passed.

Dose received from UFTP shipment while passing at 5 km/h at 2.3 m away

In this case, the UFTP is assumed to be a stationary receptor while the vehicle occupant passes the shipment at a relative speed difference of 5 km/h between the vehicle and the UFTP shipment. Dose received by a stationary receptor from moving source is presented in Appendix D. Using the method described, the dose received by the vehicle occupant at 2.3 m from side of the truck as it passes at 5 km/h is 2.89×10^{-6} mSv.

Dose received while following UFTP at 18 m for 2½ minutes

$$\begin{aligned} \text{Dose} &= \text{dose rate at 18 m} \times \text{time} \\ &= 0.000050 \text{ mSv/h} \times 2.5 \text{ minutes} \\ &= 2.08 \times 10^{-6} \text{ mSv} \end{aligned}$$

Dose received during 1½ minute signal stop at 10 m from UFTP

$$\begin{aligned} \text{Dose} &= \text{dose rate at 10 m} \times \text{time} \\ &= 0.000135 \text{ mSv/h} \times 1.5 \text{ minutes} \\ &= 3.36 \times 10^{-6} \text{ mSv} \end{aligned}$$

Dose per occurrence

$$\begin{aligned} \text{Dose} &= \text{dose due to passing} + \text{dose due to following} + \text{dose due to signal stop} \\ &= 2.89 \times 10^{-6} \text{ mSv} + 2.08 \times 10^{-6} \text{ mSv} + 3.36 \times 10^{-6} \text{ mSv} \\ &= 8.34 \times 10^{-6} \text{ mSv} \end{aligned}$$

Annual Dose received by Vehicle Occupant

$$\begin{aligned} \text{Dose} &= \text{dose} \times \text{frequency} \\ &= 8.34 \times 10^{-6} \text{ mSv} \times 8 \text{ shipments} \\ &= 0.000067 \text{ mSv} \end{aligned}$$

Conclusions

The annual dose due to used fuel transportation estimated to be received by an occupant of a vehicle occupant on an urban road travelling behind a UFTP shipment is 0.000067 mSv. This dose is orders of magnitude lower than the regulatory dose limit for the public of 1 mSv per year. The annual dose to a vehicle occupant on an urban road travelling behind a UFTP shipment is approximately equal to an annual FED of 60 seconds.

B.14 VEHICLE OCCUPANT – PASSING UFTP SHIPMENT ON HIGHWAY

- Description:** An occupant in a vehicle on a highway approaches a UFTP shipment from behind and then passes the UFTP shipment. See Figure B-14 below.
- Speed:** 5 km/h. The relative speed between the UFTP shipment and the vehicle occupant is assumed to be 5 km/h.
- Distance:** 2.3 m. The vehicle occupant is assumed to be present at 2.3 m when passing the UFTP shipment (see Figure B-14).
- Frequency:** 62 shipments. The vehicle occupant is assumed to be exposed to 10% of all 620 annual shipments.
- Time, distance and frequency references:** Khan, et al., (2015).

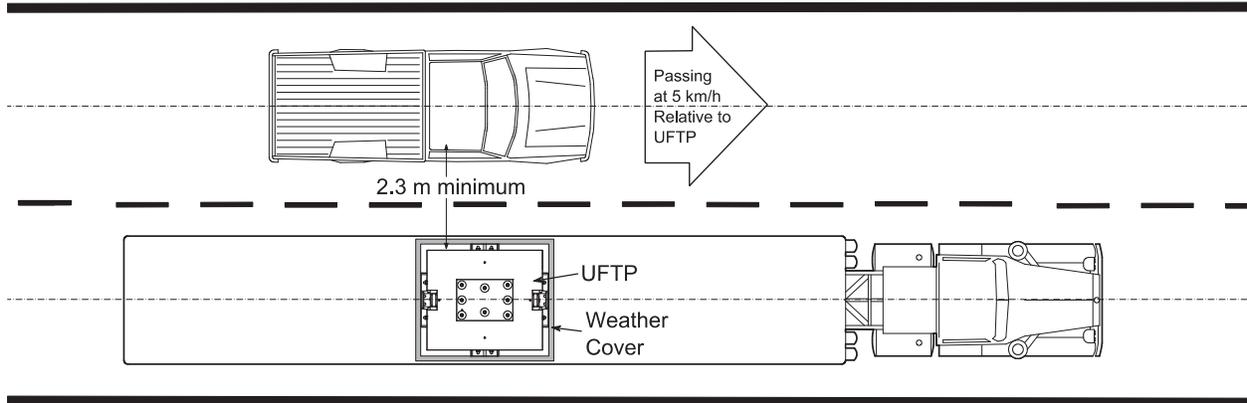


Figure B-14: Vehicle Occupant – Passing UFTP Shipment on Highway

Vehicle Occupant on Highway passing UFTP Shipment Dose Calculation

A vehicle occupant may receive a dose from a UFTP shipment as it is being passed.

Dose received from UFTP shipment while passing at 5 km/h at 2.3 m away

In this case, the UFTP is assumed to be a stationary receptor while the vehicle occupant passes the shipment at a relative speed difference of 5 km/h between the vehicle and the UFTP shipment. Dose received by a stationary receptor from moving source is presented in Appendix D. Using the method described, the dose received by the vehicle occupant at 2.3 m from side of the truck as it passes at 5 km/h is 2.89×10^{-6} mSv.

Annual Dose received by Vehicle Occupant

$$\begin{aligned} \text{Dose} &= \text{dose} \times \text{frequency} \\ &= 2.89 \times 10^{-6} \text{ mSv} \times 62 \text{ shipments} \\ &= 0.00018 \text{ mSv} \end{aligned}$$

Conclusions

The annual dose due to used fuel transportation estimated to be received by an occupant of a vehicle occupant on a highway passing a UFTP shipment is 0.00018 mSv. This dose is orders of magnitude lower than the regulatory dose limit for the public of 1 mSv per year. The annual dose to a vehicle occupant on a highway passing a UFTP shipment is approximately equal to an annual FED of 2 minutes and 41 seconds.

B.15 VEHICLE OCCUPANT IN CONGESTED TRAFFIC ON HIGHWAY – BEHIND UFTP SHIPMENT

Description: An occupant in a vehicle on a highway in congested traffic approaches a UFTP shipment from behind, travels behind the shipment for a period of 30 minutes and then passes the UFTP shipment. See Figure B-15 below.

Speed: 5 km/h. While passing, the relative speed between the moving UFTP shipment and the vehicle occupant is assumed to be 5 km/h. The vehicle occupant is assumed to approach the UFTP shipment.

Distance: 2.3 m, 10 m and 18 m. The vehicle occupant is assumed to be present at 18 m when travelling behind the UFTP shipment for a period of 25 minutes, at 10 m behind the UFTP shipment during stop-and-go traffic for a period of 5 minutes and at 2.3 m when passing the UFTP shipment (see Figure B-15).

Frequency: 6 shipments. The vehicle occupant is assumed to be exposed to 6 shipments per year.

Note: The exposure frequency is presented in Khan, et al., (2015) with the following reasoning: “It is unlikely that the transporter loaded with the UFTP and a specific individual will be in close proximity to each other on a regular basis. This observation reflects varied schedules for the transporter and traffic volume considerations. For these reasons, six exposures are suggested.”

Time, distance and frequency references: Khan, et al., (2015).

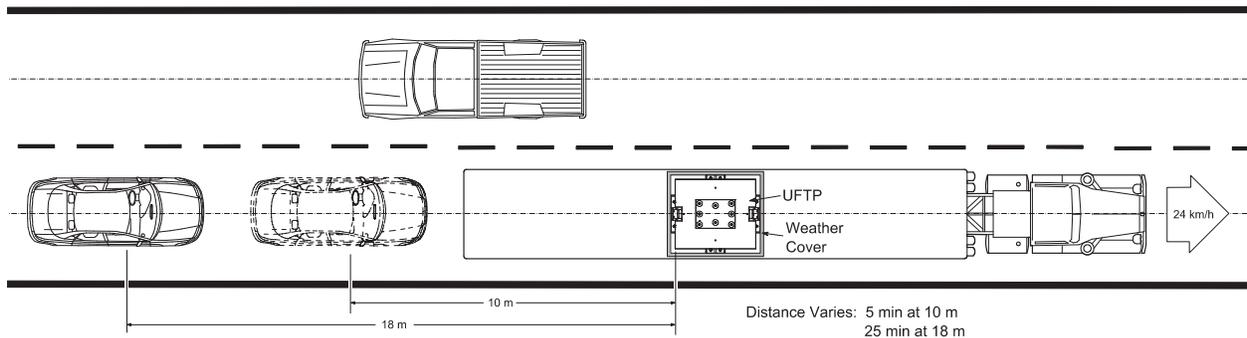


Figure B-15: Vehicle Occupant in Congested Traffic on Highway – Behind UFTP shipment

Vehicle Occupant on Urban Road behind UFTP Shipment Dose Calculation

A vehicle occupant may receive a dose from a UFTP shipment as it is being passed.

Dose received from UFTP shipment while passing at 5 km/h at 2.3 m away

In this case, the UFTP is assumed to be a stationary receptor while the vehicle occupant passes the shipment at a relative speed difference of 5 km/h between the vehicle and the UFTP shipment. Dose received by a stationary receptor from moving source is presented in Appendix D. Using the method described, the dose received by the vehicle occupant at 2.3 m from side of the truck as it passes at 5 km/h is 2.89×10^{-6} mSv.

Dose received while following UFTP at 18 m for 25 minutes

$$\begin{aligned} \text{Dose} &= \text{dose rate at 18 m} \times \text{time} \\ &= 0.000050 \text{ mSv/h} \times 25 \text{ minutes} \\ &= 2.08 \times 10^{-5} \text{ mSv} \end{aligned}$$

Dose received while following UFTP at 10 m for 5 minutes

$$\begin{aligned} \text{Dose} &= \text{dose rate at 10 m} \times \text{time} \\ &= 0.00013 \text{ mSv/h} \times 5 \text{ minutes} \\ &= 1.12 \times 10^{-5} \text{ mSv} \end{aligned}$$

Dose per occurrence

$$\begin{aligned} \text{Dose} &= \text{dose due to passing} + \text{dose due to following at 18 m} + \text{dose due to following at 10 m} \\ &= 2.89 \times 10^{-6} \text{ mSv} + 2.08 \times 10^{-5} \text{ mSv} + 1.12 \times 10^{-5} \text{ mSv} \\ &= 3.49 \times 10^{-5} \text{ mSv} \end{aligned}$$

Annual Dose received by Vehicle Occupant

$$\begin{aligned} \text{Dose} &= \text{dose} \times \text{frequency} \\ &= 3.49 \times 10^{-5} \text{ mSv} \times 6 \text{ shipments} \\ &= 0.00021 \text{ mSv} \end{aligned}$$

Conclusions

The annual dose due to used fuel transportation estimated to be received by an occupant of a vehicle occupant on a highway in congested traffic travelling behind a UFTP shipment is 0.00021 mSv. This dose is orders of magnitude lower than the regulatory dose limit for the public of 1 mSv per year. The annual dose to an occupant of a vehicle occupant on a highway in congested traffic behind a UFTP shipment is approximately equal to an annual FED of 3 minutes and 9 seconds.

B.16 VEHICLE OCCUPANT IN CONGESTED TRAFFIC ON CONTROLLED ACCESS HIGHWAY – BEHIND UFTP SHIPMENT

Description: An occupant in a vehicle on a highway in congested traffic approaches a UFTP shipment from behind, travels behind the shipment for a period of 60 minutes and then passes the UFTP shipment. See Figure B-16 below.

Speed: 5 km/h. While passing, the relative speed between the moving UFTP shipment and the vehicle occupant is assumed to be 5 km/h. The vehicle occupant is assumed to approach the UFTP shipment.

Distance: 2.3 m, 10 m and 24 m. The vehicle occupant is assumed to be present at 24 m when travelling behind the UFTP shipment for a period of 55 minutes, at 10 m behind the UFTP shipment during stop-and-go traffic for a period of 5 minutes and at 2.3 m when passing the UFTP shipment (see Figure B-16).

Frequency: 1 occurrence per year. It is very unlikely that the same vehicle occupant will experience more than one of these events per year.

Time, distance and frequency references: Khan, et al., (2015).

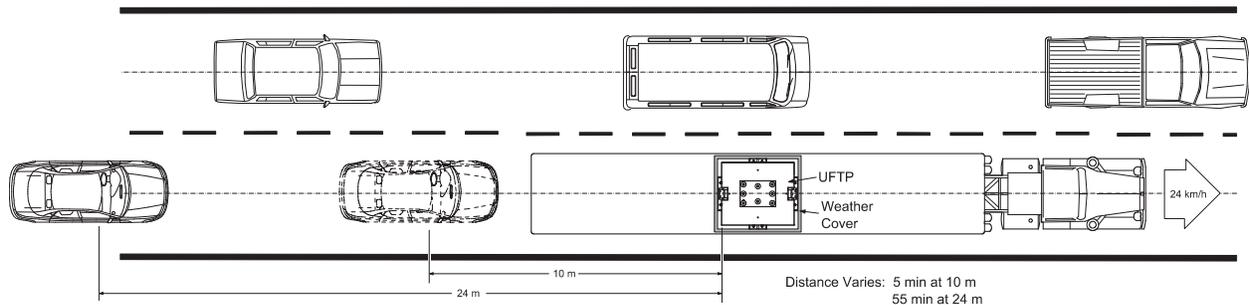


Figure B-16: Vehicle Occupant in Congested Traffic on a Controlled Access Highway – Behind UFTP shipment

Vehicle Occupant on Urban Road behind UFTP Shipment Dose Calculation

A vehicle occupant may receive a dose from a UFTP shipment as it is being passed. As the occurrence frequency of the vehicle occupant is low, the UFTP is assumed to contain peak burnup fuel (higher dose to the vehicle occupant).

Dose received from UFTP shipment while passing at 5 km/h at 2.3 m away

In this case, the UFTP is assumed to be a stationary receptor while the vehicle occupant passes the shipment at a relative speed difference of 5 km/h between the vehicle and the UFTP shipment. Dose received by a stationary receptor from moving source is presented in Appendix D. Using the method described, the dose received by the vehicle occupant at 2.3 m from side of the truck as it passes at 5 km/h is 3.90×10^{-6} mSv.

Dose received while following UFTP at 24 m for 55 minutes

$$\begin{aligned} \text{Dose} &= \text{dose rate at 24 m} \times \text{time} \\ &= 0.000032 \text{ mSv/h} \times 55 \text{ minutes} \\ &= 2.93 \times 10^{-5} \text{ mSv} \end{aligned}$$

Dose received while following UFTP at 10 m for 5 minutes

$$\begin{aligned} \text{Dose} &= \text{dose rate at 10 m} \times \text{time} \\ &= 0.00016 \text{ mSv/h} \times 5 \text{ minutes} \\ &= 1.34 \times 10^{-5} \text{ mSv} \end{aligned}$$

Dose per occurrence

$$\begin{aligned} \text{Dose} &= \text{dose due to passing} + \text{dose due to following at 24 m} + \text{dose due to following at 10 m} \\ &= 3.90 \times 10^{-6} \text{ mSv} + 2.93 \times 10^{-5} \text{ mSv} + 1.34 \times 10^{-5} \text{ mSv} \\ &= 0.000047 \text{ mSv} \end{aligned}$$

Conclusions

The annual dose due to used fuel transportation estimated to be received by an occupant of a vehicle occupant on a controlled access highway in congested traffic travelling behind a UFTP shipment is 0.000047 mSv. This dose is orders of magnitude lower than the regulatory dose limit for the public of 1 mSv per year. The annual dose to an occupant of a vehicle occupant on a controlled access highway in congested traffic travelling behind a UFTP shipment is approximately equal to an annual FED of 42 seconds.

B.17 VEHICLE OCCUPANT IN CONGESTED TRAFFIC ON CONTROLLED ACCESS HIGHWAY – BESIDE UFTP SHIPMENT

Description: An occupant in a vehicle on a highway in congested traffic approaches a UFTP shipment from behind, travels beside the shipment for a period of 60 minutes and then passes the UFTP shipment. See Figure B-17 below.

Speed: 5 km/h. While passing, the relative speed between the moving UFTP shipment and the vehicle occupant is assumed to be 5 km/h. The vehicle occupant is assumed to approach the UFTP shipment.

Distance: 2.3 m and 10 m. The vehicle occupant is assumed to be present at 10 m when travelling beside the UFTP shipment for a period of 55 minutes, at 2.3 m when beside the UFTP during stop-and-go traffic for a period of 5 minutes and at 2.3 m when passing the UFTP shipment (see Figure B-17).

Frequency: 1 occurrence per year. It is very unlikely that the same vehicle occupant will experience more than one of these events per year.

Time, distance and frequency references: Khan, et al., (2015).

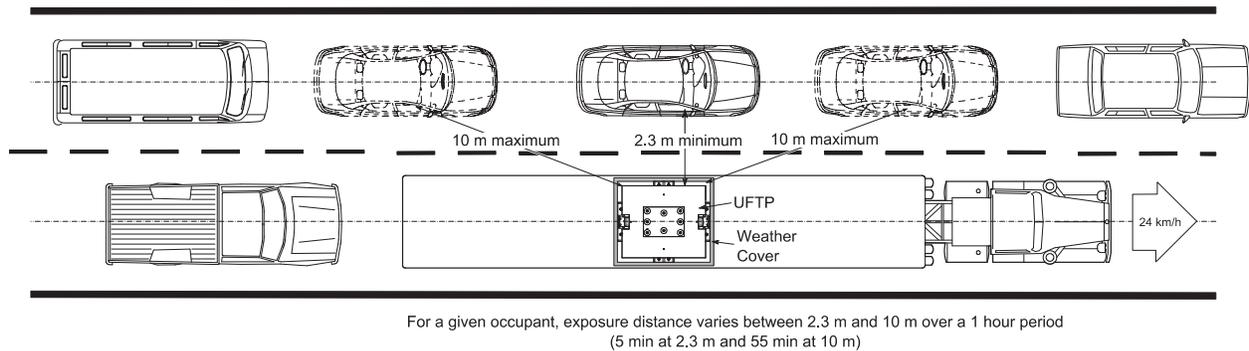


Figure B-17: Vehicle Occupant in Congested Traffic on a Controlled Access Highway – Beside UFTP Shipment

Vehicle Occupant in Congested Traffic on a Controlled Access Highway – Beside UFTP Shipment Dose Calculation

A vehicle occupant may receive a dose from a UFTP shipment as it is being passed. As the occurrence frequency of the vehicle occupant is low, the UFTP is assumed to contain peak burnup fuel (higher dose to the vehicle occupant).

Dose received from UFTP shipment while passing at 5 km/h at 2.3 m away

In this case, the UFTP is assumed to be a stationary receptor while the vehicle occupant passes the shipment at a relative speed difference of 5 km/h between the vehicle and the UFTP shipment. Dose received by a stationary receptor from moving source is presented in Appendix D. Using the method described, the dose received by the vehicle occupant at 2.3 m from side of the truck as it passes at 5 km/h is 3.90×10^{-6} mSv.

Dose received while beside UFTP at 10 m for 55 minutes

$$\begin{aligned} \text{Dose} &= \text{dose rate at 10 m} \times \text{time} \\ &= 0.00016 \text{ mSv/h} \times 55 \text{ minutes} \\ &= 1.48 \times 10^{-4} \text{ mSv} \end{aligned}$$

Dose received while beside UFTP at 2.3 m for 5 minutes

$$\begin{aligned} \text{Dose} &= \text{dose rate at 2.3 m} \times \text{time} \\ &= 0.00270 \text{ mSv/h} \times 5 \text{ minutes} \\ &= 2.25 \times 10^{-4} \text{ mSv} \end{aligned}$$

Dose per occurrence

$$\begin{aligned} \text{Dose} &= \text{dose due to passing} + \text{dose due to following at 24 m} + \text{dose due to following at 10 m} \\ &= 3.90 \times 10^{-6} \text{ mSv} + 1.48 \times 10^{-4} \text{ mSv} + 2.25 \times 10^{-4} \text{ mSv} \\ &= 0.00038 \text{ mSv} \end{aligned}$$

Conclusions

The annual dose due to used fuel transportation estimated to be received by an occupant of a vehicle occupant on a controlled access highway in congested traffic travelling beside a UFTP shipment is 0.00038 mSv. This dose is orders of magnitude lower than the regulatory dose limit for the public of 1 mSv per year. The annual dose to an occupant of a vehicle occupant on a controlled access highway in congested traffic is approximately equal to an annual FED of 5 minutes and 39 seconds.

B.18 INDIVIDUAL AT A REST STOP

Description: An individual is present at a rest stop during the same period the UFTP shipment is stopped. See Figure B-18 below.

Time: 30 minutes. En-route rest stops are typically 30 minutes in length. It is also assumed that the individual approaches and departs the scene at a walking speed of 5 km/h.

Distance: 20 m. The individual is assumed to be present at 20 m from the stationary UFTP during the time the UFTP shipment is parked at the rest stop (see Figure B-18).

Frequency: 2 occurrences per year. It is very unlikely that the same individual will experience more than two of these events per year.

Time, distance and frequency references: Khan, et al., (2015).

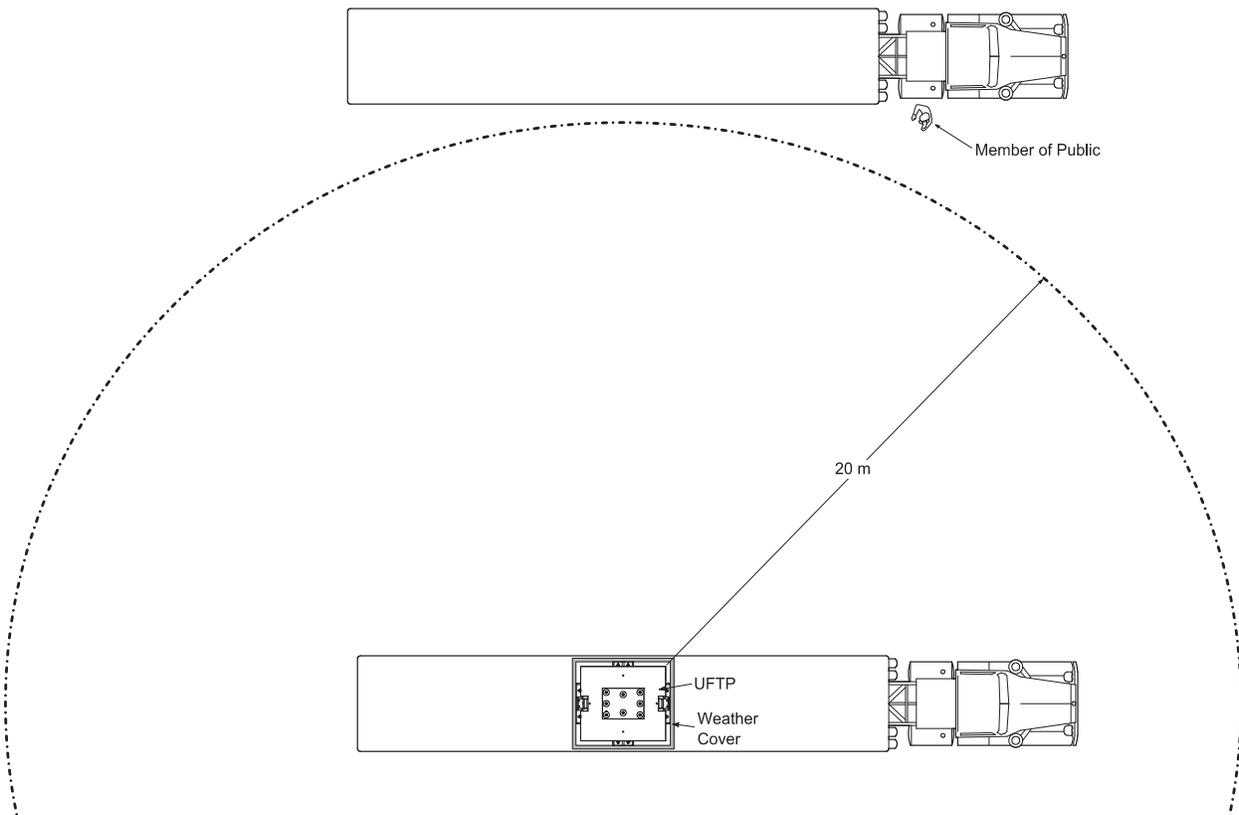


Figure B-18: An Individual at a Rest Stop in the Proximity of a UFTP Shipment.

Individual at Rest Stop Dose Calculation

An individual may receive a dose from a UFTP shipment while parked at a rest stop. As the occurrence frequency of the unplanned stop is low, the UFTP is assumed to contain peak burnup fuel (higher dose to the individual).

Dose received during refuelling at 20 m from UFTP for 30 minutes

$$\begin{aligned} \text{Dose} &= \text{dose rate at 20 m} \times \text{time} \\ &= 0.000048 \text{ mSv/h} \times 30 \text{ minutes} \\ &= 0.000024 \text{ mSv} \end{aligned}$$

Dose received from UFTP shipment during approach and departure at 5 km/h

In this case, the UFTP shipment is assumed to be a stationary with the individual approaching and departing the scene at a walking speed of 5 km/h. Dose received by a moving receptor from stationary source is equivalent to the dose to a stationary receptor and a moving source presented in Appendix D. Using the method described, the dose received by the individual during approach to within 20 m from side of the truck and then departure at 5 km/h is 6.03×10^{-7} mSv.

Dose per occurrence

$$\begin{aligned} \text{Dose} &= \text{dose during rest stop} + \text{dose due to approach and departure} \\ &= 0.000024 \text{ mSv} + 6.03 \times 10^{-7} \text{ mSv} \\ &= 2.46 \times 10^{-5} \text{ mSv} \end{aligned}$$

Annual Dose received by Individual at Rest Stop

$$\begin{aligned} \text{Dose} &= \text{dose} \times \text{frequency} \\ &= 2.46 \times 10^{-5} \text{ mSv} \times 2 \text{ occurrences} \\ &= 0.000049 \text{ mSv} \end{aligned}$$

Conclusions

The annual dose due to used fuel transportation estimated to be received by an individual in the proximity of a UFTP shipment at a rest stop is 0.000049 mSv. This dose is orders of magnitude lower than the regulatory dose limit for the public of 1 mSv per year. The annual dose to an individual in the proximity of a UFTP shipment at a rest stop is approximately equal to an annual FED of 44 seconds.

B.19 COMMERCIAL DRIVER AT REFUELLING STOP

- Description:** A commercial driver is present at a refuelling station while a UFTP shipment is being refuelled. See Figure B-19 below.
- Time:** 30 minutes. Filling of the fuel tanks on a standard tractor requires approximately 20 minutes. An additional 10 minutes is assumed for record keeping activities. It is also assumed that the commercial driver approaches and departs the scene at a walking speed of 5 km/h.
- Distance:** 4 m. The commercial driver is assumed to be present at 4 m from the stationary UFTP during the entire time required to refuel (see Figure B-19).
- Frequency:** 1 occurrence per year. It is very unlikely that the same commercial driver will experience more than one of these events per year.

Time, distance and frequency references: Khan, et al., (2015) and Caravan Logistics.

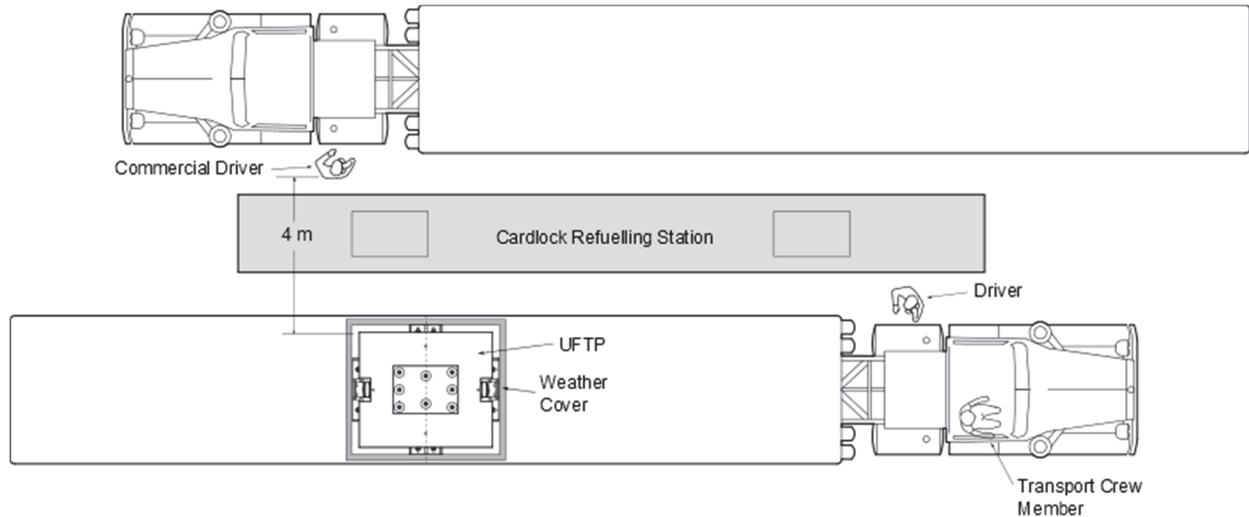


Figure B-19: A Commercial Driver Refuelling a Vehicle as a UFTP Shipment is being Refuelled.

Commercial Driver Dose Calculation

A commercial driver may receive a dose from a UFTP shipment during refuelling near a UFTP shipment. As the occurrence frequency of the unplanned stop is low, the UFTP is assumed to contain peak burnup fuel (higher dose to the individual).

Dose received during refuelling at 4 m from UFTP for 30 minutes

$$\begin{aligned} \text{Dose} &= \text{dose rate at 4 m} \times \text{time} \\ &= 0.0010 \text{ mSv/h} \times 30 \text{ minutes} \\ &= 0.00050 \text{ mSv} \end{aligned}$$

Dose received from UFTP shipment during approach and departure at 5 km/h

In this case, the UFTP shipment is assumed to be a stationary with the commercial driver approaching and departing the scene at a walking speed of 5 km/h. Dose received by a moving receptor from stationary source is equivalent to the dose to a stationary receptor and a moving source presented in Appendix D. Using the method described, the dose received by the commercial driver during approach to within 4 m from side of the truck and then departure at 5 km/h is 2.51×10^{-6} mSv.

Dose per occurrence

$$\begin{aligned} \text{Dose} &= \text{dose during refuelling} + \text{dose due to approach and departure} \\ &= 0.00050 \text{ mSv} + 2.51 \times 10^{-6} \text{ mSv} \\ &= 0.00050 \text{ mSv} \end{aligned}$$

Conclusions

The annual dose due to used fuel transportation estimated to be received by a commercial driver during refuelling is 0.0005 mSv. This dose is orders of magnitude lower than the regulatory dose limit for the public of 1 mSv per year. The annual dose to a commercial driver during refuelling is approximately equal to an annual FED of 7 minutes and 32 seconds.

B.20 INDIVIDUAL AT UNPLANNED STOP

Description: An individual is present along a highway as near and unplanned stop of a UFTP shipment. See Figure B-20 below.

Time: 6 hours. The UFTP shipment is assumed to be stopped for a period of 6 hours. It is assumed that a minor repair to the trailer can be made or a replacement tractor can be obtained during this time period.

Distance: 25 m. The individual is assumed to be present at 25 m from the stationary UFTP shipment (see Figure B-20).

Frequency: 1 occurrence per year. It is very unlikely that the same individual will experience more than one of these events per year.

Time, distance and frequency references: Khan, et al., (2015).

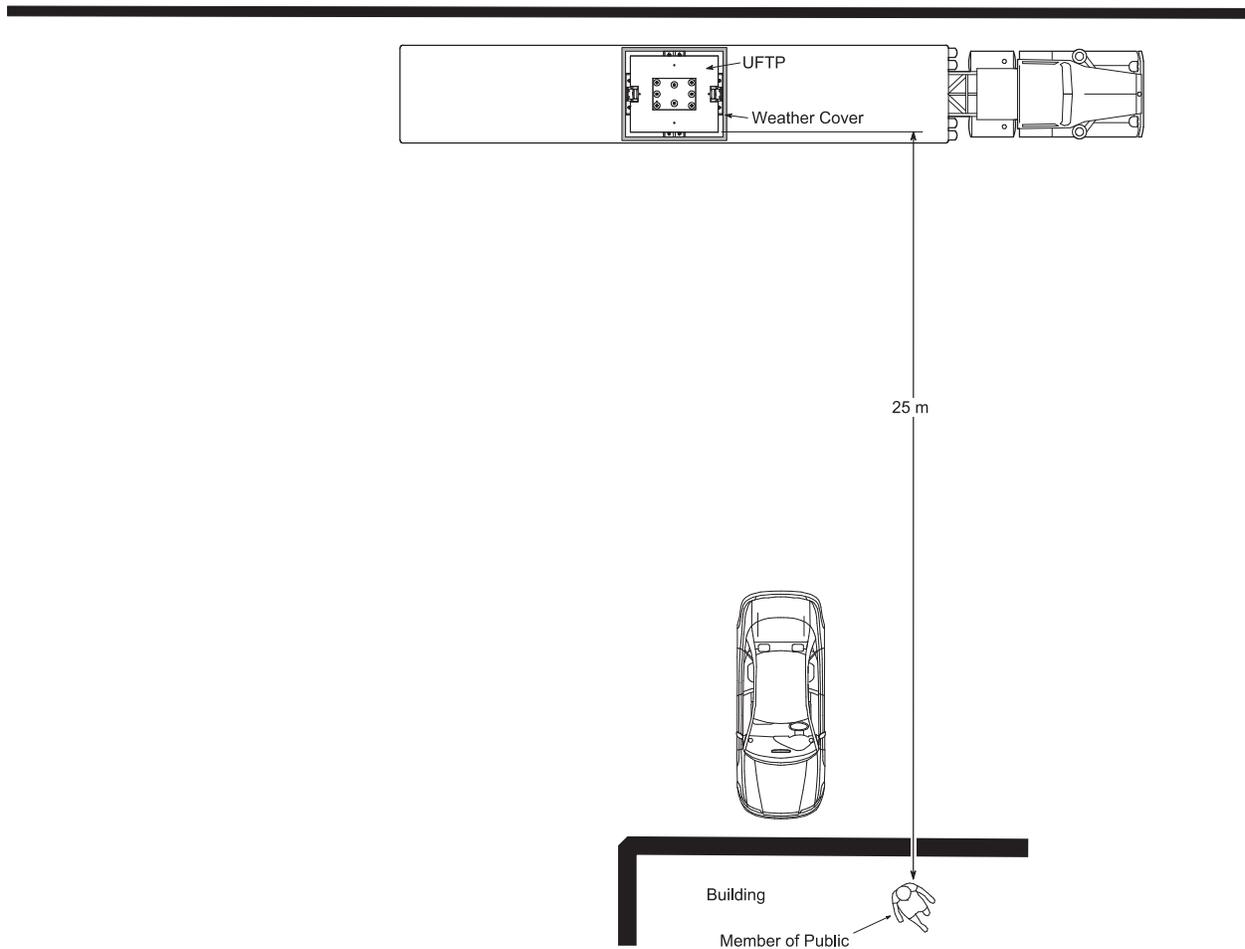


Figure B-20: An Individual along a Highway 25 m from the UFTP Shipment

Individual near Unplanned Stop Dose Calculation

An individual may receive a dose from a UFTP shipment during an unplanned stop. As the occurrence frequency of the unplanned stop is low, the UFTP is assumed to contain peak burnup fuel (higher dose to the individual).

Dose received during unplanned stop at 25 m from UFTP for 6 hours

$$\begin{aligned} \text{Dose} &= \text{dose rate at 25 m} \times \text{time} \\ &= 0.000029 \text{ mSv/h} \times 6 \text{ hours} \\ &= 0.00017 \text{ mSv} \end{aligned}$$

Dose received from UFTP shipment during approach and departure at 5 km/h

In this case, the UFTP shipment is assumed to be a stationary with the individual approaching and departing the scene at a walking speed of 5 km/h. Dose received by a moving receptor from stationary source is equivalent to the dose to a stationary receptor and a moving source presented in Appendix D. Using the method described, the dose received by the individual during approach to within 25 m from side of the truck and then departure at 5 km/h is 4.56×10^{-7} mSv.

Dose per occurrence

$$\begin{aligned} \text{Dose} &= \text{dose during unplanned stop} + \text{dose due to approach and departure} \\ &= 0.00017 \text{ mSv} + 4.56 \times 10^{-7} \text{ mSv} \\ &= 0.00017 \text{ mSv} \end{aligned}$$

Conclusions

The annual dose due to used fuel transportation estimated to be received by an individual during an unplanned stop is 0.00017 mSv. This dose is orders of magnitude lower than the regulatory dose limit for the public of 1 mSv per year. The annual dose to an individual during an unplanned stop is approximately equal to an annual FED of 2 minutes and 37 seconds.

APPENDIX C: TRANSPORT WORKER ACTIVITIES AND DOSE CALCULATIONS**CONTENTS**

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C.1 TRACTOR-TRAILER HOOKUP / UNHOOK

Performed by: Driver

Requirement: Operational procedures

Description: A UFTP trailer is hooked up to the tractor unit prior to departure or unhooked from the tractor unit after arrival. See Figure C-1 below.

Duration: Hooking up or unhooking the trailer from the tractor typically takes 5 minutes broken down as follows:

- 2 min at 4 m to raise / lower landing gear
- 2 min at 7 m to connect / disconnect electrical and pneumatic hookups
- 1 min at 8 m driving in the tractor to connect / disconnect the trailer

Distance: Driver is located 4, 7 and 8 m from the front surface of the UFTP (see Figure C-1).

Frequency: One hookup and one unhook per shipment.

Time references: Ontario Power Generation, Caravan Logistics

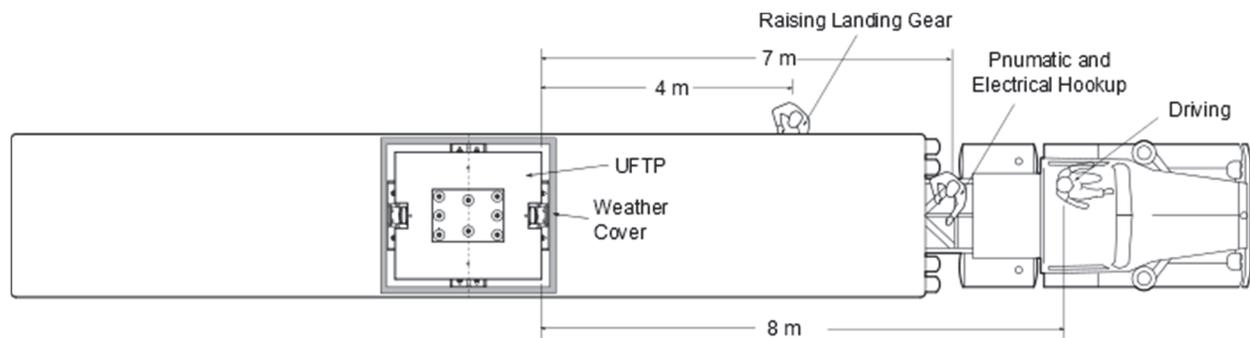


Figure C-1: UFTP Tractor and Trailer being Hooked up or Unhooked

Transport Crew Dose Calculation – Tractor-Trailer Hookup / Unhook:

The transport crew will receive dose from the shipment during tractor-trailer connect/disconnect operations. Shielding provided by the vehicle is not credited.

Dose received during raising and lowering of landing gear

$$\begin{aligned} \text{Dose rate at 4 m} &= 0.0008 \text{ mSv/h (see Figure 6 in main report)} \\ \text{Dose} &= \text{dose rate} \times \text{duration} \\ &= 0.0008 \text{ mSv/h} \times 2 \text{ min} \\ &= 2.7 \times 10^{-5} \text{ mSv} \end{aligned}$$

Dose received during connection / disconnection of electrical and pneumatic lines

$$\begin{aligned} \text{Dose rate at 7 m} &= 0.00025 \text{ mSv/h (see Figure 6 in main report)} \\ \text{Dose} &= \text{dose rate} \times \text{duration} \\ &= 0.00025 \text{ mSv/h} \times 2 \text{ min} \\ &= 8.3 \times 10^{-6} \text{ mSv} \end{aligned}$$

Dose received during connection / disconnection of tractor

$$\begin{aligned} \text{Dose rate at 8 m} &= 0.00020 \text{ mSv/h (see Figure 6 in main report)} \\ \text{Dose} &= \text{dose rate} \times \text{duration} \\ &= 0.00020 \text{ mSv/h} \times 1 \text{ min} \\ &= 3.3 \times 10^{-6} \text{ mSv} \end{aligned}$$

Total dose received during hookup / Unhook

$$\begin{aligned} \text{Dose} &= 2.7 \times 10^{-5} \text{ mSv} + 8.3 \times 10^{-6} \text{ mSv} + 3.3 \times 10^{-6} \text{ mSv} \\ &= 0.000038 \text{ mSv} \end{aligned}$$

The dose received by the transport crew during a tractor-trailer hookup or unhook operation is 0.000038 mSv.

Conclusions

The dose due estimated to be received by the transport crew during each pre- or post-shipment trailer hookup / unhook is 0.000038 mSv. The dose to the transport crew per occurrence is approximately equal to a FED of 35 seconds.

C.2 DOCUMENTATION CHECK

Performed by: Transport Crew

Requirement: In accordance with Transport Canada Transportation of Dangerous Goods Regulations, Section 3, and CNSC Packaging and Transport of Nuclear Substances Regulations Section 26 (4).

Description: Transport crew is in tractor reviewing shipment documentation, and bills of lading. See Figure C-2 below.

Duration: Typically 15 minutes.

Distance: Transport crew is located in the tractor cab approximately 8 m in front of the UFTP as shown in Figure C-2. No credit is given to any additional shielding provided by the tractor-trailer.

Frequency: Each shipment – prior to departure and upon arrival at destination

Time, distance and frequency references: Ontario Power Generation, Caravan Logistics.

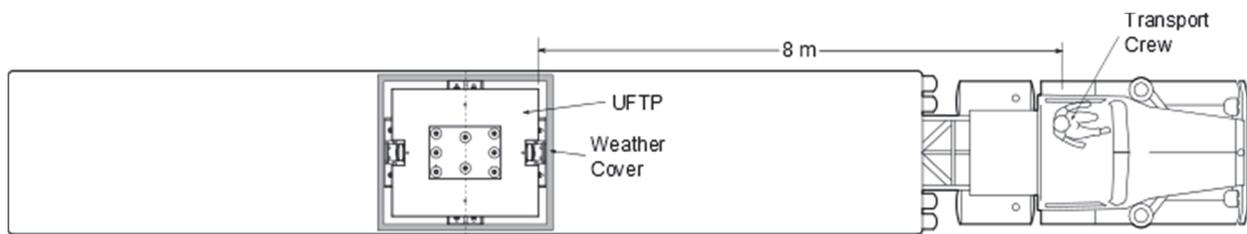


Figure C-2: Documentation Check prior to and post Shipment

Transport Crew Dose Calculation – Documentation Check:

The transport crew may receive dose from the shipment during documentation check operations. Shielding provided by the vehicle is not credited.

Note, conservatively, this operation is assumed to take place in the tractor. However, it can take place at a location at a greater distance

Dose received during documentation check

$$\begin{aligned} \text{Dose rate at 8 m} &= 0.00020 \text{ mSv/h (see Figure 6 in main report)} \\ \text{Dose} &= \text{dose rate} \times \text{duration} \\ &= 0.00020 \text{ mSv/h} \times 15 \text{ min} \\ &= 0.000050 \text{ mSv} \end{aligned}$$

Conclusions

The dose due estimated to be received by the transport crew during each pre- or post-shipment documentation check is 0.000050 mSv. The dose to the transport crew per occurrence is approximately equal to a FED of 45 seconds.

C.3 REST / RELIEF STOP

Performed by: Transport Crew (Driver and Security Escort)

Requirement: Operational protocols in accordance with Ontario Regulation 555/06, Hours of Service and CNSC Regulatory Guide G-208 – Transportation Security Plans for Category I, II or III Nuclear Material, once loaded and in transit, the vehicle should never be left unattended.

Description: One crew member is attending to vehicle while other crew member goes for rest / food / relief. See Figure C-3 below.

Duration: Typically 30 minutes.

Distance: The transport crew is located in the tractor approximately 8 m in front of the UFTP as shown in Figure C-3. No credit is given to any additional shielding provided by the tractor-trailer.

Frequency: One stop for every 400 km travelled. All trips over 200 km in length are assumed to have at least one stop.

Time, distance and frequency references: Ontario Power Generation, Caravan Logistics.

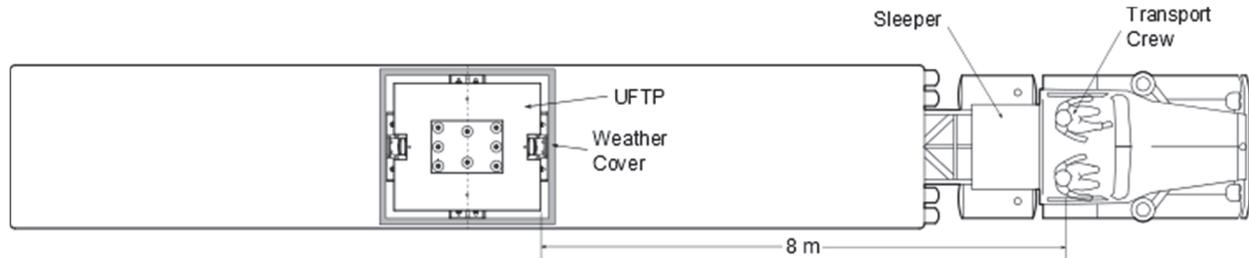


Figure C-3: UFTP Shipment during Transport

Transport Crew Dose Calculation – Rest / Relief Stop:

The transport crew will receive dose from the shipment during a rest stop. Shielding provided by the vehicle is not credited.

Dose received during rest stop

$$\begin{aligned} \text{Dose rate at 8 m} &= 0.00020 \text{ mSv/h (see Figure 6 in main report)} \\ \text{Dose} &= \text{dose rate} \times \text{duration} \\ &= 0.00020 \text{ mSv/h} \times 0.5 \text{ h} \\ &= 0.00010 \text{ mSv} \end{aligned}$$

The dose received by the transport crew during a rest stop is 0.00010 mSv.

Conclusions

The dose due estimated to be received by the transport crew during each rest / relief stop is 0.00010 mSv. The dose to the transport crew per occurrence is approximately equal to a FED of 1 minute and 30 seconds.

C.4 REFUELLING – UFTP TRACTOR-TRAILER

Performed by: Transport Crew

Requirement: Only trips of 1400 km or more require refuelling with loaded UFTP

Description: Driver stands beside vehicle during refuelling. Security escort remains in tractor. See Figure C-4 below.

Duration: One vehicle refuelling stop is typically 20 minutes in length.

Distance: Driver is located 6 m from the UFTP. Security Escort is located 8 m from the UFTP.

Frequency: Frequency is calculated based on trip length (see Table 12 in main report).

Time, distance and frequency references: Caravan Logistics, Ontario Power Generation

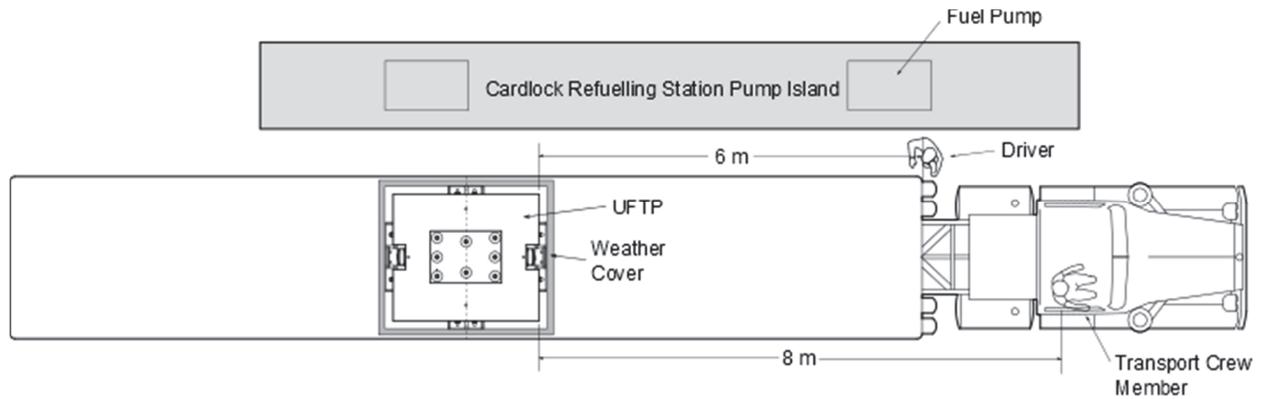


Figure C-4: UFTP Shipment in Cardlock Refuelling Station

Transport Crew Dose Calculation – Refuelling:

The transport crew will receive dose from the shipment during refuelling of the UFTP tractor-trailer. Shielding provided by the vehicle is not credited.

Dose received during refuelling

$$\begin{aligned} \text{Dose rate at 6 m} &= 0.00035 \text{ mSv/h (see Figure 6 in main report)} \\ \text{Dose} &= \text{dose rate} \times \text{duration} \\ &= 0.00035 \text{ mSv/h} \times 0.33 \text{ h} \\ &= 0.00012 \text{ mSv} \end{aligned}$$

Conclusions

The dose due estimated to be received by the transport crew during each rest / relief stop is 0.00012 mSv. The dose to the transport crew per occurrence is approximately equal to a FED of 1 minute and 45 seconds.

Note: Average burnup of 220 MWh/kgU is assumed in this calculation as the transport crew are expected to refuel the tractor between 30 and 40 times per year, whereas peak burnup of 280 MWh/kgU is assumed for the commercial driver (see Section 5.2 and Appendix B.19) who is assumed to be in close proximity to a refuelling UFTP shipment only once per year.

C.5 EN-ROUTE TRANSPORT CREW DOSE CALCULATION

Performed by: Transport Crew (Driver and Security Escort)

Requirement: In accordance with Ontario Regulation 555/06, Hours of Service.

Description: Crew is in UFTP tractor driving en-route to repository. See Figure C-5 below.

Duration: In transit time is dependent on trip length. Transit times for various trip lengths are calculated in Table 9 of main report.

Distance: The transport crew is located in the tractor approximately 8 m in front of the UFTP as shown in Figure C-5. No credit is given to any additional shielding provided by the tractor-trailer.

Frequency: Frequency is calculated based on trip length. See calculations in Table 11 of main report

Time, distance and frequency references: See calculations in Tables 9 and 11 of main report.

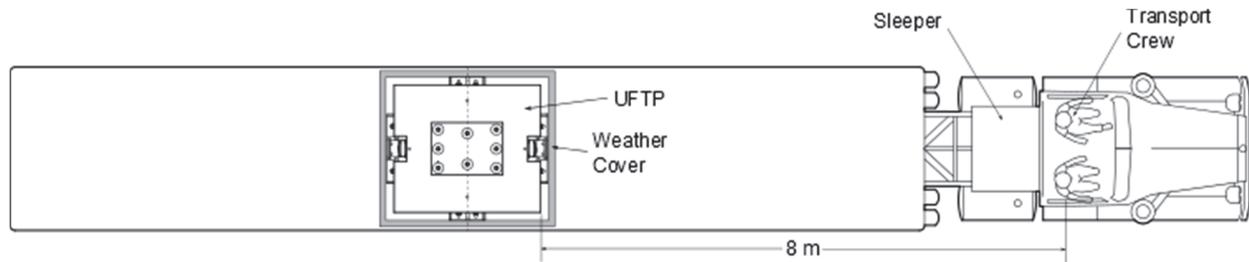


Figure C-5: UFTP Shipment during Transport

Transport crew Dose Calculation:

The transport crew will receive a radiological dose from the shipment during various transportation activities. The dose received during transport is the sum of all the doses received during each activity.

Dose received during Transport

The doses received by the transport crew during pre- and post-shipment activities and while en-route are tabulated in Table C-5-1. Additional shielding provided by trailer deck is not credited in the calculations.

Annual Dose received by Transport Crew

The estimated annual doses received by a transport crew are presented in Table C-5-2.

Conclusions

The annual dose to a transport crew or transport crew member ranges between 0.27 mSv per year and 0.35 mSv per year, which is less than the regulatory public dose limit. The maximum annual dose to a transport crew member is approximately equal to an annual FED of 88 hours and 37 minutes.

Table C-5-1: Transport Crew Dose Summary – Per-shipment Dose

Doses in mSv	Shipment Length			
	50 km	250 km	600 km	1700 km
Pre-shipment Activities				
Trailer Hookup	0.000038	0.000038	0.000038	0.000038
Documentation Check	0.000050	0.000050	0.000050	0.000050
Condition Inspection	0.00058	0.00058	0.00058	0.00058
Pre-shipment Total	0.00066	0.00066	0.00066	0.00066
En-route Activities				
Driving (time: hh:mm)	0.00015 (0:44)	0.00095 (4:45)	0.0020 (9:51)	0.0052 (26:00)
Rest Stops (frequency)	0.00 (0)	0.00010 (1)	0.00010 (1)	0.00040 (4)
Condition Inspections (frequency)	0.00 (0)	0.00 (0)	0.0012 (2)	0.0046 (8)
Refuelling (frequency)	0.00 (0)	0.00 (0)	0.00 (0)	0.00012 (1)
Post-shipment Activities				
Trailer Unhook	0.000038	0.000038	0.000038	0.000038
Documentation Check	0.000050	0.000050	0.000050	0.000050
Post-shipment Total	0.000088	0.000088	0.000088	0.000088
Per-shipment Dose	0.0009	0.0018	0.0040	0.011

Table C-5-2: Transport Crew Dose Summary – Annual Dose

Doses in mSv	Shipment Length			
	50 km	250 km	600 km	1700 km
Annual Shipments	295	164	86	32
Pre-shipment Activities				
Trailer Hookup	0.011	0.006	0.003	0.001
Documentation Check	0.015	0.008	0.004	0.002
Condition Inspection	0.17	0.094	0.050	0.018
Pre-shipment Total	0.20	0.11	0.057	0.021
En-route Activities				
Driving	0.044	0.16	0.17	0.17
Rest Stops	0.00	0.016	0.009	0.013
Condition Inspections	0.00	0.00	0.099	0.15
Refuelling	0.00	0.00	0.00	0.004
En-route Total	0.044	0.17	0.277	0.33
Post-shipment Activities				
Trailer Unhook	0.011	0.006	0.003	0.001
Documentation Check	0.015	0.008	0.004	0.002
Post-shipment Total	0.026	0.014	0.008	0.003
Annual Transport Crew Dose	0.27	0.30	0.34	0.35

C.6 VEHICLE INSPECTIONS

Performed by: Vehicle Inspector / Driver

Requirement: In accordance with the Ontario Highway Traffic Act R.S.O. 1990, Chapter H.8 Section 216.1, a commercial vehicle may be stopped, and the vehicle, equipment, and contents may be examined.

In accordance with CNSC Regulatory Guide G-208 Section 5.2.2.5, prior to shipment qualified personnel should conduct a rigorous security search of the vehicle to ensure that there has been no attempt to sabotage it.

Additionally, in accordance with O. Reg. 199/07, s. 8 (1), a driver shall monitor the condition of each commercial motor vehicle and trailer he or she is driving, drawing, or in charge of to detect the presence of a major or minor defect.

Description: The UFTP tractor-trailer is inspected by an inspector to the requirements of the Commercial Vehicle Safety Alliance (CVSA) Level I, Level II or Level VI inspections or by the driver to the requirements of an en-route vehicle condition inspection. Figure C-6-1 below shows the elements of a systematic circle check of the vehicle which provides the basis for all inspections.

Duration: Time required to inspect the vehicle is dependent on the inspection level.

- Level I Inspection: 1 hour
- Level II Inspection: ½ hour
- Level VI Inspection: 1½ hours
- Condition Inspection: 10 minutes

Distance: Inspector or driver is located less than 1 m from side of the truck while performing the circle check. Level I and Level VI inspections also require inspector to inspect the underside of the vehicle.

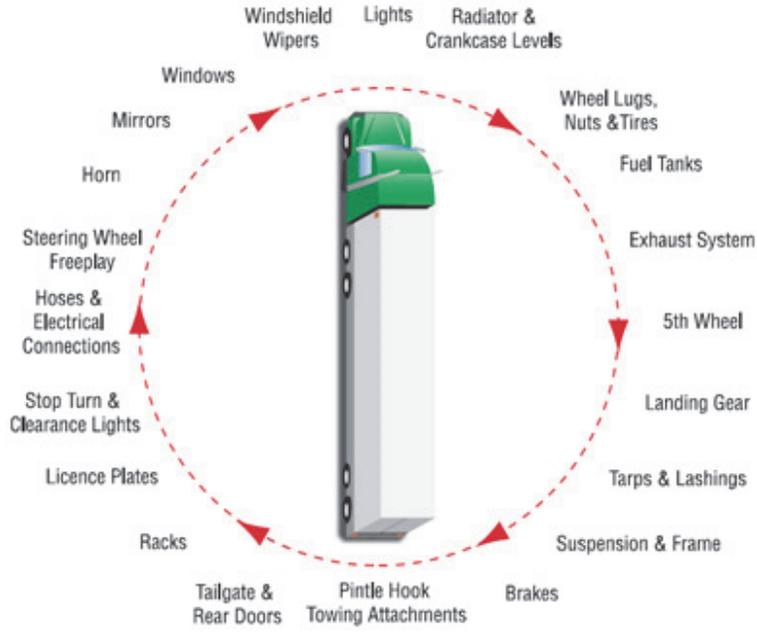
For dose calculations, the circle check around the vehicle is divided into 46 areas within 12 zones (numbered 0 through 11). Each area is 1 m wide and extends outward 1 m from the vehicle. The areas and zones are illustrated in Figure C-6-2. Inspection time is assumed to be distributed equally between the 46 areas. The distance between the UFTP and the area is approximated by the number of the zone (i.e.: an inspector in an area in Zone 2 is located approximately 2 m from the UFTP).

Frequency: CVSA inspection frequency for a given vehicle is unknown. Ontario Ministry of Transportation inspects approximately 110,000 vehicles per year.

For dose calculations, 5% of all UFTP shipments are assumed to be stopped and inspected by the same inspector.

En-route vehicle condition inspections are conducted by the driver prior to departure and once for approximately every 200 km traveled. En-route vehicle condition inspections are not required for trips under 300 km in length.

Time, distance and frequency references: Ontario Ministry of Transportation (MTO),
Ontario Power Generation (OPG),
Caravan Logistics
Commercial Vehicle Safety Alliance



Source: Ontario Ministry of Transportation (MTO)

Figure C-6-1: Commercial Vehicle Circle Check

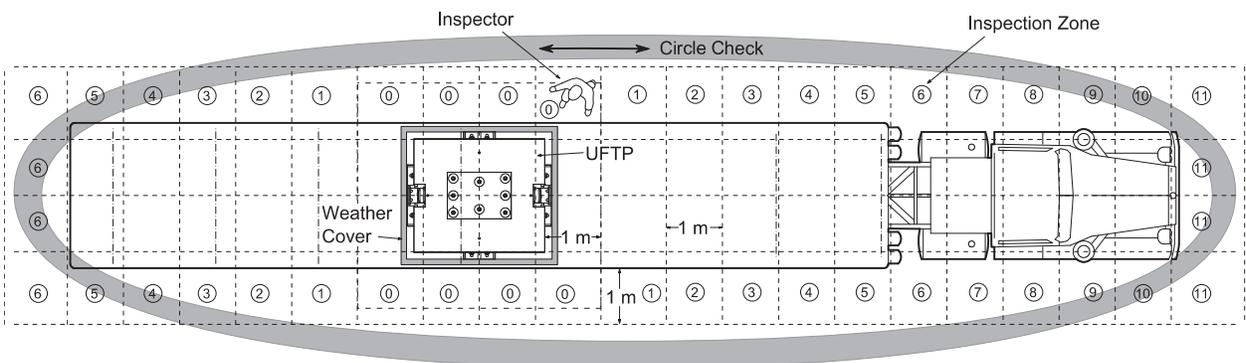


Figure C-6-2: UFTP Vehicle Inspection Areas and Zones

Inspection Dose Calculation:

The inspector or driver will receive a radiological dose from the shipment during the inspection. The dose received during the inspection is the sum of the doses received in each zone.

Dose received during Inspection

The doses received by the inspector or driver during a CVSA Level I, II and VI inspection and vehicle condition assessment by the driver are tabulated in Table C-6-2. Additional shielding provided by trailer deck is not credited in the calculations.

Annual dose received by Inspector

Assuming that the inspector inspects 5% of all UFTP shipments (31 shipments) per year, the estimated annual doses received by an inspector are presented in Table C-6-1.

Table C-6-1: Dose Received during Inspection

Inspection Type	Dose per Inspection [mSv]	Number of Inspections by given Inspector	Annual Dose [mSv]
CVSA Level I	0.0035	31	0.11
CVSA Level II	0.0017	31	0.054
CVSA Level VI	0.0052	31	0.16

Note: Figures rounded to 2 significant digits. Annual dose may not be exact product due to round-off.

Annual dose received by Driver

The vehicle condition assessment is one of numerous activities performed by the driver. Annual dose received by the driver is presented in Appendix C-5

Conclusions:

The annual dose to an inspector carrying out 31 CVSA Level VI inspections of a UFTP shipment is estimated to be 0.16 mSv, which is less than the regulatory public dose limit. The annual dose to a CVSA Level VI inspector is approximately equal to an annual FED of 40 hours and 10 minutes.

Table C-6-2: Dose Received during Inspection

Zone	Average Distance from UFTP	Dose rate [mSv/h] ¹	Frequency in Zone during Circle Check	Condition Assessment		CVSA Level I		CVSA Level II		CVSA Level VI	
				Time [mm:ss]	Dose [mSv]	Time [mm:ss]	Dose [mSv]	Time [mm:ss]	Dose [mSv]	Time [mm:ss]	Dose [mSv]
0	0.4 m	0.014	8	01:44	4.0×10^{-4}	10:26	2.4×10^{-3}	05:13	1.2×10^{-3}	15:39	3.6×10^{-3}
1	1 m	0.0060	4	00:52	8.6×10^{-5}	05:13	5.2×10^{-4}	02:37	2.6×10^{-4}	07:50	7.8×10^{-4}
2	2 m	0.0024	4	00:52	3.5×10^{-5}	05:13	2.1×10^{-4}	02:37	1.1×10^{-4}	07:50	3.2×10^{-4}
3	3 m	0.0012	4	00:52	1.7×10^{-5}	05:13	1.0×10^{-4}	02:37	5.2×10^{-5}	07:50	1.6×10^{-4}
4	4 m	0.00080	4	00:52	1.2×10^{-5}	05:13	7.0×10^{-5}	02:37	3.5×10^{-5}	07:50	1.0×10^{-4}
5	5 m	0.00052	4	00:52	7.5×10^{-6}	05:13	4.5×10^{-5}	02:37	2.3×10^{-5}	07:50	6.8×10^{-5}
6	6 m	0.00035	6	01:18	7.6×10^{-6}	07:50	4.6×10^{-5}	03:55	2.3×10^{-5}	11:44	6.8×10^{-5}
7	7 m	0.00025	2	00:26	1.8×10^{-6}	02:37	1.1×10^{-5}	01:18	5.4×10^{-6}	03:55	1.6×10^{-5}
8	8 m	0.00020	2	00:26	1.4×10^{-6}	02:37	8.7×10^{-6}	01:18	4.3×10^{-6}	03:55	1.3×10^{-5}
9	9 m	0.00016	2	00:26	1.2×10^{-6}	02:37	7.0×10^{-6}	01:18	3.5×10^{-6}	03:55	1.0×10^{-5}
10	10 m	0.00013	2	00:26	9.8×10^{-7}	02:37	5.9×10^{-6}	01:18	2.9×10^{-6}	03:55	8.8×10^{-6}
11	11 m	0.00012	4	00:52	1.7×10^{-6}	05:13	1.0×10^{-5}	02:37	5.2×10^{-6}	07:50	1.6×10^{-5}
Totals			46	10:00	0.00058	60:00	0.0035	30:00	0.0017	90:00	0.0052

1 – See Figure 6 and Table 2 in main report.

Note: Figures rounded to 2 significant digits. Sums of columns may differ from totals due to round-off.

C.7 WEIGHING AT WEIGH STATION

Performed by: Weigh Scale Operator

Requirement: In accordance with the Ontario Highway Traffic Act R.S.O. 1990, Chapter H.8 Section 124, a vehicle may be stopped, weighed and examined.

Description: A UFTP shipment is weighed at a stationary weigh scale. See Figures C-7-1 and C-7-2 below.

Duration: One vehicle weighing stop is typically 2 minutes (0.033 h) in length.

For dose calculations, the dose received by the weigh scale operator is assumed to be the sum of the dose received during the 2 minute weighing and the dose received as the UFTP tractor-trailer exits the inspection station. While exiting the weigh scale, a vehicle speed of 5 km per hour is assumed.

Distance: Weigh scale operator is located 2 m from the tractor. This equates to approximately 9 m from the front surface of the UFTP (see Figure C-7-1) during the weighing and 2 m from the UFTP as the tractor-trailer exits the weigh station.

For weigh scales with small weigh platforms, front and rear axle groupings are weighed independently. Weigh scale operator may be within 2 m of the UFTP during weighing of rear axle grouping. See Figure C-7-2.

Frequency: Frequency of weighing at weigh station is unknown. Ontario Ministry of Transportation inspects approximately 110,000 vehicles per year. The number of commercial vehicles weighed is significantly higher.

For dose calculations, 5% of all UFTP shipments are assumed to be stopped and weighed at a weigh station by the same weigh scale operator.

Time, distance and frequency references: Ontario Ministry of Transportation (MTO)

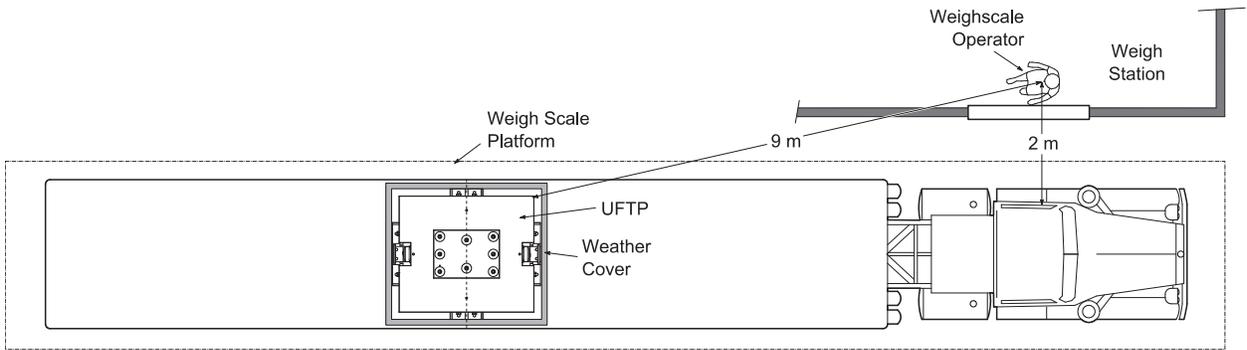


Figure C-7-1: UFTP Shipment in Stationary Weigh Scale (Large Platform)

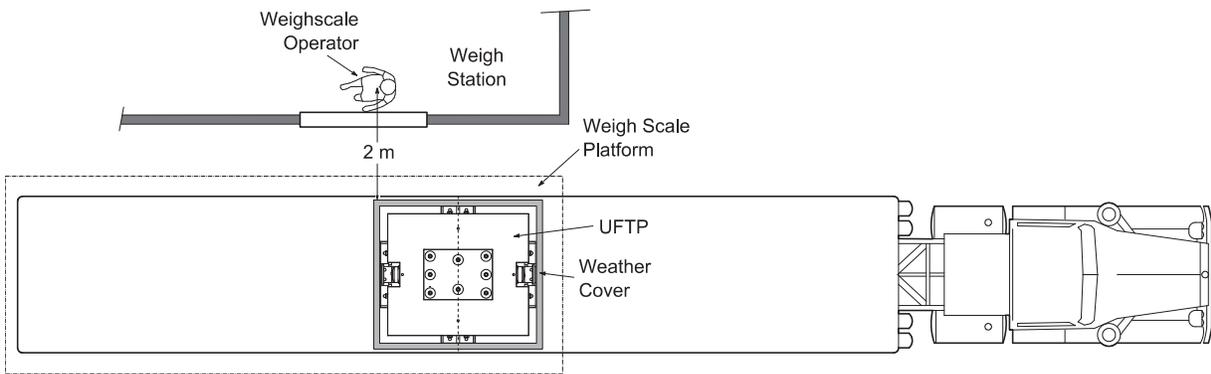


Figure C-7-2: UFTP Shipment in Stationary Weigh Scale (Small Platform – Weighing of Rear Axle Group Shown)

Weigh Scale Operator Dose Calculation:

The weigh scale operator will receive dose from the shipment during the weighing and from the slow moving shipment as the shipment exits the scale. The dose received by the weigh scale operator is the sum of these two doses. Shielding provided by the building is not credited.

Dose received during weighing (large platform and front axle group of small platform)

$$\begin{aligned}
 \text{Dose rate at 9 m} &= 0.00016 \text{ mSv/h (see Figure 6 in main report)} \\
 \text{Dose} &= \text{dose rate} \times \text{duration} \\
 &= 0.00016 \text{ mSv/h} \times 2 \text{ min} \\
 &= 5.33 \times 10^{-6} \text{ mSv}
 \end{aligned}$$

Dose received during weighing (small platform rear axle group)

$$\begin{aligned}
 \text{Dose rate at 2 m} &= 0.00242 \text{ mSv/h (see Figure 6 in main report)} \\
 \text{Dose} &= \text{dose rate} \times \text{duration} \\
 &= 0.00242 \text{ mSv/h} \times 2 \text{ min} \\
 &= 8.07 \times 10^{-5} \text{ mSv}
 \end{aligned}$$

Dose received from passing slow-moving UFTP shipment

Dose received by a stationary receptor from moving source is presented in Appendix D. Using the method described, the dose received by the weigh scale operator at 2 m from side of truck as it passes at 5 km/h is 3.04×10^{-6} mSv.

Total dose received by weigh scale operator during weighing (large platform)

$$\begin{aligned}
 \text{Dose} &= \text{dose during weighing} + \text{dose due to drive-by} \\
 &= 5.33 \times 10^{-6} \text{ mSv} + 3.04 \times 10^{-6} \text{ mSv} \\
 &= 8.4 \times 10^{-6} \text{ mSv}
 \end{aligned}$$

The dose received by the weigh scale operator during the weighing is 8.4×10^{-6} mSv.

Total dose received by weigh scale operator during weighing (small platform)

$$\begin{aligned}
 \text{Dose} &= \text{dose during weighing front axle group} + \text{rear axle group} + \text{dose due to drive-by} \\
 &= 5.33 \times 10^{-6} \text{ mSv} + 8.07 \times 10^{-5} \text{ mSv} + 3.04 \times 10^{-6} \text{ mSv} \\
 &= 8.9 \times 10^{-5} \text{ mSv}
 \end{aligned}$$

The dose received by the weigh scale operator during the weighing is 8.9×10^{-5} mSv.

Annual dose received by weigh scale operator

Assume 5% of shipments (31 shipments) are weighed at stationary weigh scales per year by the same weigh scale operator:

Large Platform

$$\begin{aligned}\text{Dose} &= 8.4 \times 10^{-6} \text{ mSv} \times 31 \text{ shipments} \\ &= 0.00026 \text{ mSv}\end{aligned}$$

Annual dose if all 620 shipments are weighed by same operator: 0.0052 mSv

Small Platform

$$\begin{aligned}\text{Dose} &= 8.9 \times 10^{-5} \text{ mSv} \times 31 \text{ shipments} \\ &= 0.0028 \text{ mSv}\end{aligned}$$

Annual dose if all 620 shipments are weighed by same operator: 0.055 mSv

Conclusions:

The radiological dose due to used fuel transportation estimated to be received by a weigh scale operator is 0.0028 mSv, which is less than the regulatory dose limit for the public. The annual dose to a weigh scale operator is approximately equal to an annual FED of 41 minutes and 27 seconds.

C.8 WEIGHING WITH PORTABLE SCALE

Performed by: Portable Weigh Scale Operator

Requirement: In accordance with the Ontario Highway Traffic Act R.S.O. 1990, Chapter H.8 Section 124, a vehicle may be stopped, weighed and examined.

Description: UFTP tractor-trailer is weighed using a portable weigh scale. See Figure C-8 below.

Duration: Time required to weigh tractor-trailer is typically 15 minutes (0.25 h).

Distance: Weigh scale operator is located less than 1 m from side of the tractor-trailer. Weigh scale operator places scales in front of each of the 7 axles one axle at a time and tractor-trailer moves forward onto scales for weighing. Relative distances between the operator position at each axle and the surface of the UFTP are shown in Figure C-8. Time required to weigh each axle is assumed to be the same.

Frequency: Frequency of weighing with portable scales is unknown. Ontario Ministry of Transportation inspects approximately 110,000 vehicles per year. The number of commercial vehicles weighed at government and commercial weigh stations is significantly higher.

For dose calculations, 5% of all UFTP shipments are assumed to be stopped and weighed with a portable weigh scale by the same weigh scale operator.

Time, distance and frequency references: Ontario Ministry of Transportation (MTO)

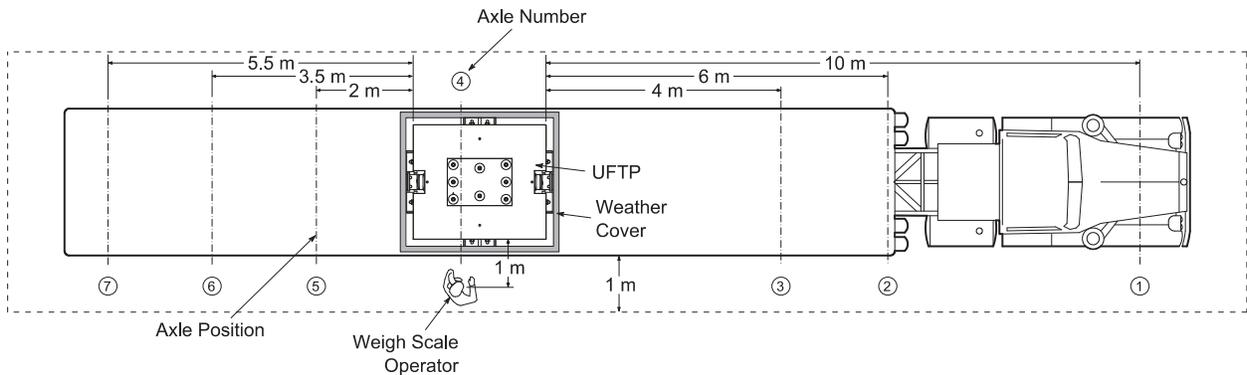


Figure C-8: UFTP Shipment weighed with Portable Weigh Scale

Portable Weigh Scale Operator Dose Calculation:

The portable weigh scale operator will receive dose from the shipment during the weighing of each axle. The dose received by the portable weigh scale operator is the sum of the doses received at each axle.

Dose received during Weighing

The dose to the portable weigh scale operator is calculated in Table C-8. Additional shielding provided by trailer deck is not credited.

Table C-8: Dose Received during Weighing with Portable Scale

Axle	Distance from UFTP [m]	Dose rate [mSv/h]¹	Time [min]	Dose [mSv]
1	10	0.00013	2:09	0.000005
2	6	0.00035	2:09	0.000013
3	4	0.0008	2:09	0.000029
4	1	0.0060	2:09	0.00022
5	2	0.0024	2:09	0.000086
6	3.5	0.0010	2:09	0.000036
7	5.5	0.00042	2:09	0.000015
Totals			15	0.00040

1 – See Figure 6 in main report.

A dose of 0.00040 mSv for one weighing is equivalent to 0.0016 mSv in one hour which represents an average distance of 2.5 m (see Figure 6 in main report) from the UFTP during the entire weighing.

Annual dose received by weigh scale operator

Assume operator weighs 5% of shipments (31 shipments) per year:

$$\begin{aligned} \text{Dose} &= 4.0 \times 10^{-4} \text{ mSv} \times 31 \text{ shipments} \\ &= 0.012 \text{ mSv} \end{aligned}$$

Annual dose if all 620 shipments are weighed by same operator: 0.25 mSv

Conclusions:

The annual dose due to the weighing of the UFTP shipment estimated to be received by a portable weigh scale operator is 0.012 mSv, which is less than the regulatory public dose limit of 1 mSv per year. The annual dose to a portable weigh scale operator is approximately equal to an annual FED of 3 hours and 4 minutes.

C.9 MINOR BREAKDOWN OR TIRE REPAIR

Performed by: Mechanic / Tow Truck Operator

Requirement: ALARA

Description: A malfunction or broken part on the UFTP tractor-trailer is repaired en-route. See Figure C-9 below.

Duration: Changing the inner tire of a dual tire pair typically requires 1 hour. Repair of a maxi-pot brake chamber typically requires ½ hour.

Distance: Mechanic is located 0.4 m from the UFTP (see Figure C-9) for the tire repair and at 1 m for the maxi-pot repair.

Frequency: 1 occurrence per year. It is very unlikely that the same mechanic / tow truck operator will experience more than one of these events per year.

Time, distance and frequency references: Caravan, Marvin Freiburger and Sons.

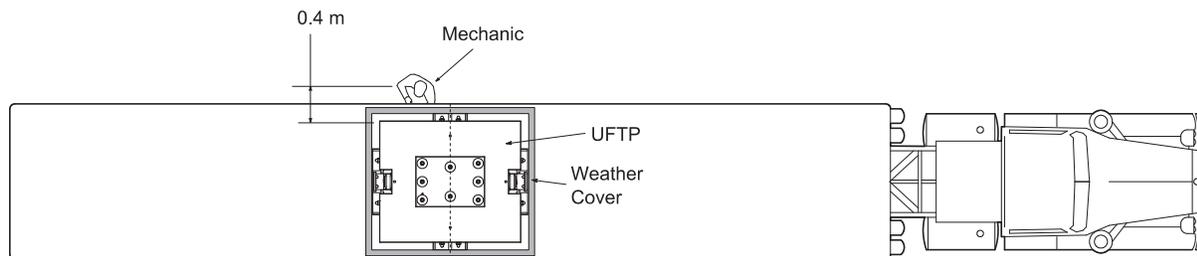


Figure C-9: Performing Minor Repair on UFTP Shipment

Mechanic Dose Calculation:

A mechanic or tow truck driver may receive dose from the shipment during a minor repair or while fixing a tire. A tire or minor breakdown repair is assumed to be a singular occurrence experienced by a given mechanic. Conservatively, dose rates for peak burnup fuel (see Section 3.2.1) are used in the dose calculations.

Dose received during Tire Repair

$$\begin{aligned}\text{Dose rate at 0.4 m} &= 0.017 \text{ mSv/h (see Figure 7 in main report)} \\ \text{Dose} &= \text{dose rate} \times \text{duration} \\ &= 0.017 \text{ mSv/h} \times 1 \text{ h} \\ &= 0.017 \text{ mSv}\end{aligned}$$

Dose received during Breakdown Repair

$$\begin{aligned}\text{Dose rate at 1 m} &= 0.0082 \text{ mSv/h (see Table 2 in main report)} \\ \text{Dose} &= \text{dose rate} \times \text{duration} \\ &= 0.0082 \text{ mSv/h} \times 1/2 \text{ h} \\ &= 0.0041 \text{ mSv}\end{aligned}$$

Conclusions:

The radiological dose due to used fuel transportation estimated to be received by a mechanic or tow truck operator is 0.017 mSv, which is less than the regulatory dose limit for the public of 1 mSv per year. The annual dose to a mechanic repairing a tire located directly underneath the UFTP is approximately equal to an annual FED of 4 hours and 12½ minutes.

APPENDIX D: CALCULATION OF DOSE TO INDIVIDUAL DUE TO PASSING UFTP SHIPMENT

Several scenarios identified in this report include a stationary individual exposed to a UFTP shipment as it slowly passes by (i.e.: a resident along a shipment route). A radiological dose from the shipment may be received by the individual as the UFTP shipment passes by. This appendix describes the method used to account for the dose received by the individual due to the passing shipment.

This appendix provides an estimated exposure of a person standing at a fixed distance (l) normal to the transport-truck path going at a constant speed (v). The assumptions used in deriving the exposure are listed as follows.

1. The UFTP shipment will not change its travelling speed.
2. The person is stationary and facing perpendicular to the UFTP shipment travel path during the exposure period.
3. The person is located sufficiently far away from the UFTP therefore a point-source approximation can be applied, i.e. using the $1/r^2$ approximation to estimate dose rates at distance farther than 5 m.
4. The person is on the same elevation as the UFTP; no credit is given to the risen height of the truck bed.
5. No credit is given to any intervening structure between the person and the UFTP shipment; therefore there is no material attenuation other than geometric attenuation.

INTEGRATED DOSE AT THE RECEPTOR

Assuming the person standing at P is at a fixed normal distance l from the travel path of the transport truck (see Figure D-1), the dose rate at location P, defined as $d(P)$, is inversely If S is defined to be the dose rate at h metres from the UFTP, then $d(r)$ at distance r can be formulated as follows.

$$d(r) = \frac{S \times h^2}{r^2} \quad (D1)$$

or

$$d(r) = \frac{S \times h^2}{(x^2 + l^2)} \quad (D2)$$

proportional to the distance between the UFTP and the receptor, i.e. distance r .

where x is the distance of the UFTP to the plane that is perpendicular to travel-path. Distance x at time t for a truck travelling at constant speed v is defined as

$$x = vt \quad (D3)$$

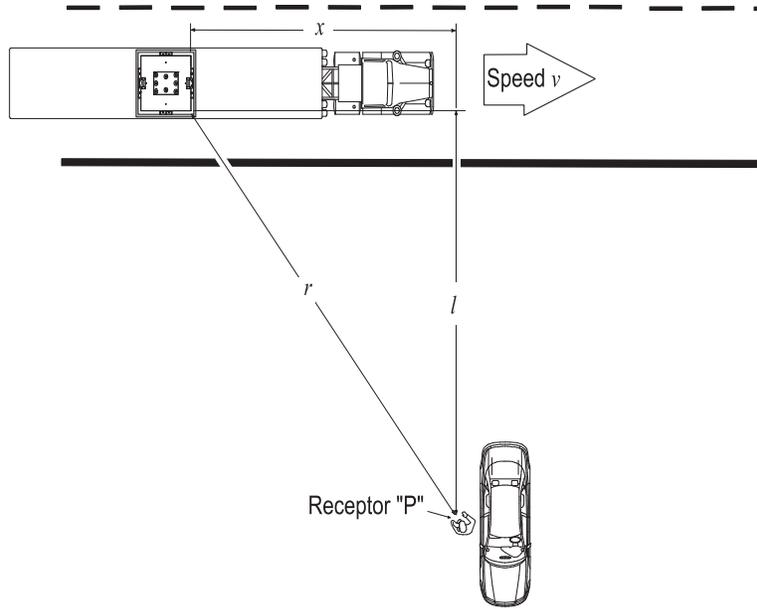


Figure D-1: Schematic of the Receptor Location P to the Travel Path

Therefore the total dose D at the receptor location P due to an approaching transport truck carrying one UFTP can be calculated by integrating equation D2.

$$D = \int_{-\infty}^{\infty} \frac{S \times h^2}{(vt)^2 + l^2} dt \quad (D4)$$

Since:

$$dx = vdt \quad (D5)$$

equation D4 becomes:

$$D = \int_{-\infty}^{\infty} \frac{S \times h^2}{x^2 + l^2} \frac{dx}{v} \quad (D6)$$

Completing the integration, the total dose D for a person standing at location P due to a non-stopping transport truck carrying one UFTP travelling at constant speed v at a non-varying distance l normal to the travel path is calculated by the following equation.

$$D = \frac{\pi S h^2}{3600vl} \quad (D7)$$

The units for v and l are in m/s and m respectively. The units for D and S are in mSv and mSv/h respectively.

DOSE PROFILE AT THE RECEPTOR

Presenting the information in a different format, Table D-1 shows the variation of the dose exposure as a function of truck speed and the separation distance l . Note that all doses are calculated based on the average (220 MWh/kgU burnup) dose rates presented in Table 2 and Figure 6 in the main report with no credit given to any intervening structures between the receptor and the truck.

Table D-1: Integrated Dose at different Truck Speeds and Separating Distances – Average Burnup

Distance l from Receptor to Truck Path	Integrated Dose D at Receptor Location P [mSv]						
	5 km/h	10 km/h	24 km/h	30 km/h	50 km/h	80 km/h	100 km/h
2 m	3.0×10^{-6}	1.5×10^{-6}	6.3×10^{-7}	5.1×10^{-7}	3.0×10^{-7}	1.9×10^{-7}	1.5×10^{-7}
3 m	2.3×10^{-6}	1.2×10^{-6}	4.9×10^{-7}	3.9×10^{-7}	2.3×10^{-7}	1.5×10^{-7}	1.2×10^{-7}
10 m	8.5×10^{-7}	4.2×10^{-7}	1.8×10^{-7}	1.4×10^{-7}	8.5×10^{-8}	5.3×10^{-8}	4.2×10^{-8}
30 m	2.8×10^{-7}	1.4×10^{-7}	5.9×10^{-8}	4.7×10^{-8}	2.8×10^{-8}	1.8×10^{-8}	1.4×10^{-8}

APPENDIX E: RATIONALE FOR LIMITING SCOPE TO ROAD TRANSPORT

Assumptions

- Radiological dose to members of the public and transportation workers received during road transport bounds (exceeds) dose received during rail transport

Data

Member of the Public

- Assessment has shown that the highest doses to members of the public during road transportation are received by:
 - Traffic Control Person;
 - Commercial Driver Refuelling Truck; and
 - Vehicle Occupant on Controlled Access Highway during Congested Traffic
- From Table 17 in the main report, public dose for these activities ranges from 0.00038 mSv/year to 0.00054 mSv/year.

Transport Crew

- Assessment has shown that the highest dose to transportation workers is received by the Transport crew.
- From Appendix C.5 (highest dose to driver is 0.35 mSv for a 1700 km trip):
 - Annual dose due to driving 0.17 mSv
 - Annual dose due to inspections 0.15 mSv
 - Annual dose due to other activities 0.03 mSv

Assessment:

Member of the Public

- During road transport, members of the public share the road with used fuel shipments. This potentially places members of the public in close proximity to UFTP.
- Rail transport typically occurs along corridors of land owned by the railroads, not readily accessible by members of the public.
- A rail shipment is assumed to carry 10 UFTPs. To a resident along a rail line, dose due to one rail shipment will be equivalent to 10 road shipments. The annualized dose to a resident along a rail line will be similar to the annualized dose to a resident along a road.
- Access to rail corridors by members of the public is possible, but access may be enforced by rail authorities.
- Trains transporting used fuel shipments will be loaded and unloaded in secure facilities limiting access to members of the public.
- While in transit, trains will generally be moving, thereby limiting dose to members of the public.

- It is very unlikely that a member of the public will be in close proximity to a rail used fuel shipment resulting in a dose higher than the ones calculated to be received by a Traffic Control Person, Commercial Driver Refuelling Truck or a Vehicle Occupant on Controlled Access Highway during Congested Traffic.

It is concluded that a member of the public in proximity to a road shipment will receive a greater dose than a member of the public in proximity to a rail shipment.

Locomotive Engineer

- Locomotive engineer is responsible for the safe operation of the train from point of origin to destination.
- Train consists of a minimum of five railcars each containing 2 UFTPs, with buffer cars on each end and two locomotives pulling the train (NWMO, 2013).
- Only radiation emitted by the first UFTP on rail car need be considered. Radiation from each UFTP behind the first must pass through its own shielding plus the shielding and contents of all UFTPs in front of it. It has been shown (Batters, et al., 2012) that radiation from UFTPs behind the first is negligible at the front external face of the first UFTP.
- A typical railcar is approximately 15 m long. A typical locomotive (EMD SD40) is approximately 21 m long. Together, the buffer car and a locomotive would be at least 36 m long.
- The locomotive engineer would be located at least the length of the buffer car and the rear locomotive away from the first UFTP. As this distance is greater than 30 m, (without crediting shielding provided locomotive) the dose to the locomotive engineer during transit would be negligible (see Appendix A).
- Dose received by transport crew during road transport and en-route vehicle condition inspections accounts for approximately 90% of a driver's occupational dose. A locomotive engineer would receive negligible dose during transit and is not required to conduct en-route vehicle condition inspections.

It is concluded that the transport crew will receive a higher occupational dose than a locomotive engineer.

Dose Estimate for Intermodal Transfer Worker

- An intermodal transfer worker is responsible for loading or unloading UFTP onto or from a railcar.
- Loading and unloading will typically take place at a specialized designated facility.
- Most of the loading and unloading operations are anticipated to be automated.
- Transfer is assumed to take 5 minutes during which the worker is assumed to be located an average distance of 2 m from the UFTP for 4 minutes and right beside the UFTP for 1 minute.

Dose received at 2 m from UFTP

$$\begin{aligned}
 \text{Dose rate at 2 m} &= 0.0024 \text{ mSv/h (see Figure 6 in main report)} \\
 \text{Dose} &= \text{dose rate} \times \text{duration} \\
 &= 0.0024 \text{ mSv/h} \times 4 \text{ min} \\
 &= 1.60 \times 10^{-4} \text{ mSv}
 \end{aligned}$$

Dose received at contact with UFTP Weather Cover (0.4 m from UFTP surface)

Dose rate at contact = 0.0139 mSv/h (see Figure 6 in main report)

$$\begin{aligned} \text{Dose} &= \text{dose rate} \times \text{duration} \\ &= 0.0139 \text{ mSv/h} \times 1 \text{ min} \\ &= 2.32 \times 10^{-4} \text{ mSv} \end{aligned}$$

Total dose received by intermodal transfer worker per UFTP transfer

$$\begin{aligned} \text{Dose} &= \text{dose at 2 m} + \text{dose at contact} \\ &= 1.60 \times 10^{-4} \text{ mSv} + 2.32 \times 10^{-4} \text{ mSv} \\ &= 3.9 \times 10^{-4} \text{ mSv} \end{aligned}$$

Annual dose received by intermodal transfer worker

Assume worker is present for all 620 transfers during a one year period

$$\begin{aligned} \text{Dose} &= \text{dose per event} \times \text{events per year} \\ &= 3.9 \times 10^{-4} \text{ mSv} \times 620 \\ &= 0.24 \text{ mSv} \end{aligned}$$

The dose received by the intermodal transfer worker during the transfer is 0.24 mSv which is less than the dose received by the transport crew.

Conclusions

Due to the restricted access members of the public have to rail yards and rail transport corridors and the fact that members of the public will share the transport routes along roads, the potential dose received by members of the public during road transport will equal or exceed the potential dose members of the public may receive during rail transport.

The annual dose estimated to be received by a locomotive engineer is negligible. The annual dose to a worker engaged in intermodal operations (loading or unloading UFTP from railcar) is estimated to be 0.24 mSv/y. The dose to the locomotive engineer and intermodal worker have been calculated to be less than the dose received by members of the UFTP transport crew during road transport.

References

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