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Assessing Radiological Dose to Members of the Public and Workers during Used Nuclear Fuel Transportation

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Abstract

Large scale transportation of Canada's inventory of used nuclear fuel is still several decades away. However, the impact of the used fuel transportation program is actively being evaluated. This assessment examines the potential radiological dose that may be received by members of the public and transportation workers resulting from the transportation of used nuclear fuel by road using the Used Fuel Transportation Package (UFTP) illustrated in Figure 1.

As transportation of used nuclear fuel will occur in the public domain, members of the public and transportation workers may be in the proximity of passing UFTP shipments. Thus, the radiological impact of used fuel shipments on residents along transport routes, individuals in vehicles sharing the transport routes, individuals at rest stops, cyclists, UFTP transport crew, transportation inspectors, roadside workers, etc. is examined.

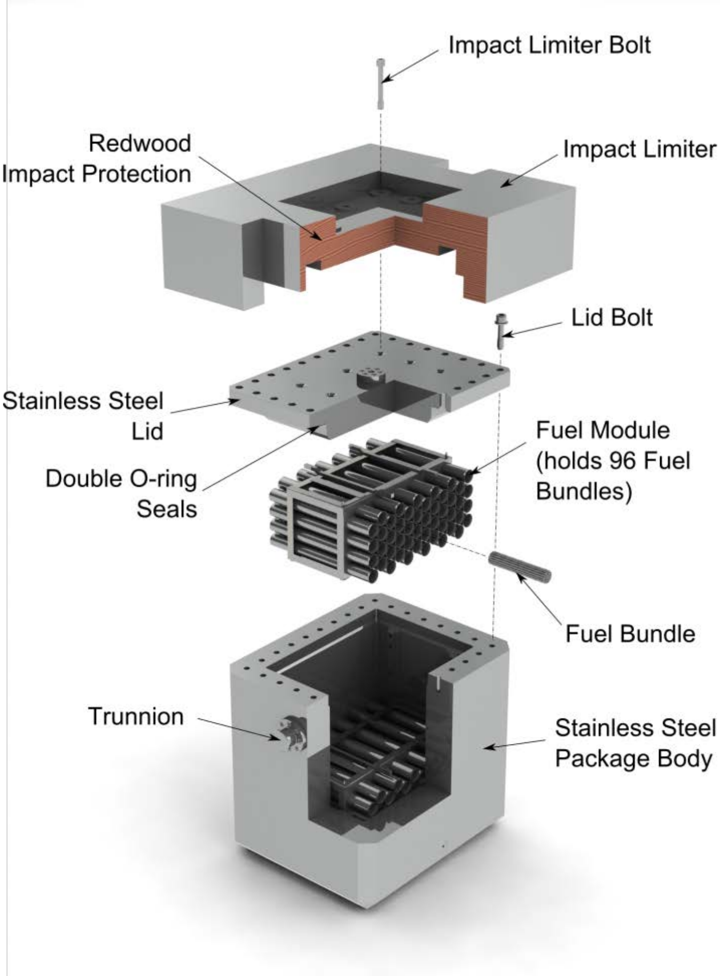

Figure 1 Used Fuel Transportation Package

Using dose rates at various distances from the UFTP, and estimated exposure time, distance and frequency data gathered by researchers from Carleton University, doses to individuals are calculated and annualized. These doses are compared to the regulatory dose limits defined in the Radiation Protection Regulations published by the Canadian Nuclear Safety Commission (CNSC). Activities including package loading, preparation for shipment, and securing onto the transport trailer are typically conducted by workers at a licensed facility and are thus outside the scope of this assessment.

Annual radiological dose to individuals is calculated to range from 1.3 x 10^{-6} mSv for a hitchhiker along the transport route (equivalent to 1 second in an airplane at altitude) to 0.35 mSv for the transport crew of used fuel shipments (equivalent to 90 hours in an airplane at altitude). All doses to members of the public and transportation workers are calculated to be below the annual regulatory public dose limit of 1 mSv per year, therefore no individuals including transportation workers require designation as a Nuclear Energy Worker (NEW). However, dose rates and resulting occupational doses received by workers have been calculated and are not based on measured values. Dose monitoring of occupational activities and NEW designation requirements for workers will be established when the radiation protection program is developed, prior to the operational startup of the used fuel transportation program.

Introduction

In 2012, the Nuclear Waste Management Organization (NWMO) prepared an assessment [1] which calculated dose rates at various distances from the UFTP and estimated radiological dose to members of the public due to the transport of used nuclear fuel in the UFTP. The dose estimates were built around generic, internationally available exposure time, distance and frequency assumptions.

In 2014, the NWMO conducted an assessment of radiological dose to transportation workers engaged in UFTP transport [2]. Work was also initiated to refine exposure time, distance and frequency assumptions and to frame them in a Canadian context. Carleton University [3] was contracted to explore these relationships between individuals and the UFTP.

Using dose rates established in [1] and the time, distance and frequency data collected by Carleton, the dose assessments were updated [4]. Activities placing individuals in the proximity of a UFTP shipment were identified and grouped into the following categories: Resident, Pedestrian, Hitchhiker Roadside worker, Cyclist, Vehicle occupant, Traveler at a Stop, Commercial driver at a refuelling Stop, Transport crew – (the driver and security escort for the UFTP shipment), Commercial vehicle inspector, Mechanic, and Commercial weigh scale operator.

Dose calculations are limited to individuals within a 30 m radius of the package. The basis for this is 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 a NEW.

In the Canadian Nuclear Safety and Control Act, a NEW is 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.”

Public dose due to used fuel transportation

Roads and highways serve as the primary transport infrastructure for Canadians. Used fuel 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 used fuel transportation program, members of the public will be exposed to radiation fields emitted by the UFTP.

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. Recognizing 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 [3] in Ottawa were contracted to use the Darlington, Ontario to Ignace, Ontario 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 to 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 three categories of roads. 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;
2. a member of the public near the UFTP during refuelling; and
3. a member of the public near the UFTP during an unplanned stop.

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.

Typical scenario and dose calculation

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. This analysis examines the dose due to UFTP transport, thus calculated dose becomes a function of the remaining three: exposure time, distance and frequency.

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 individual will receive is the sum of the doses of all activities the individual engages in. The annual dose to the individual is calculated to allow comparison with the allowable limits

Consider the following scenario: an individual in a vehicle on an urban road (such as a stretch of highway passing through a community) approaches a UFTP shipment from behind, travels behind the shipment for a period of time, is stopped behind the shipment at a traffic signal, and upon the traffic signal turning green, passes the shipment and carries on. This scenario is illustrated in Figure 2, below.

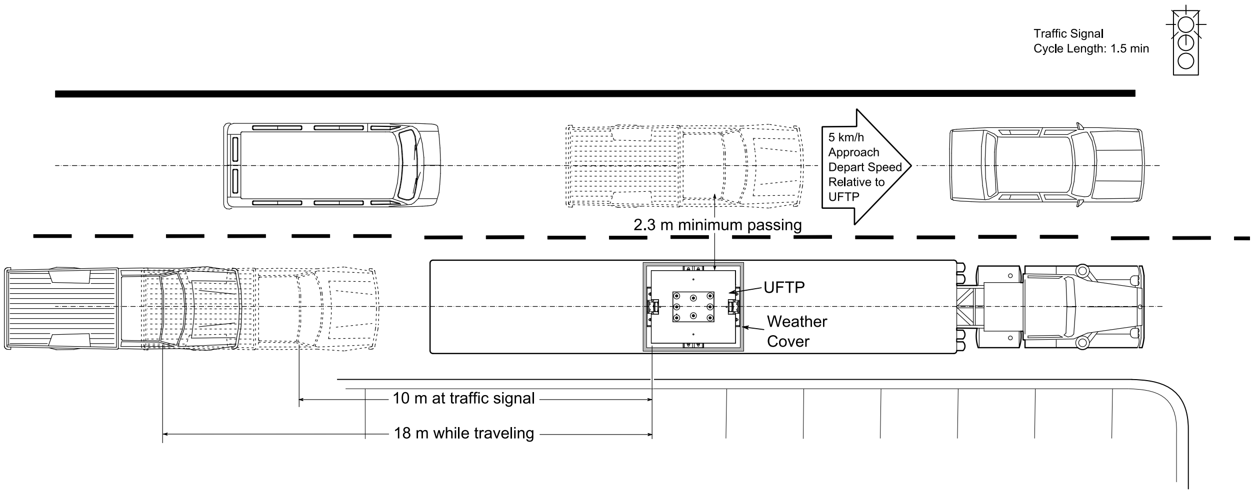

Figure 2 Vehicle Occupant on Urban Road behind Shipment

The dose to the individual in the vehicle is calculated by breaking the scenario into discrete components and summing the doses calculated for each component. The actions of vehicle approach, passing the UFTP shipment and departure are considered as one component. Travel behind the shipment, as a second and stopping behind the shipment as a third. Although the calculations for the second and third components are identical, the time and distance parameters are not the same, thus these components must be considered separately.

The dose received by an individual in a vehicle during approach to, passing of, and departure from the UFTP shipment is equivalent to the dose the received by an individual in a vehicle passing a stationary shipment at a low speed where the low speed is the relative speed difference between the vehicles. This speed is assumed to be 5 km/h. This speed was chosen as being representative of a low passing speed on a roadway. Increasing this speed would result in reduced exposure time and a lower calculated dose, thus, this speed provides conservatism in the calculations. 5 km/h is also a typical walking speed, so this reference speed is used for all calculations of this nature.

The dose received during approach, passing and departure can be calculated using equation (1), below:

$$D = \frac{\pi\, S\, h^2}{1000\, v\, l} \qquad (1)$$

where D is the dose (mSv) received by the individual; S is the dose rate (mSv/h) at h metres from the UFTP; v is the speed (km/h) of the individual; and l is the minimum distance (m) between the individual and the UFTP. For a minimum separation distance of 2.3 m between the individual and the UFTP, the dose to the individual passing the UFTP at a relative speed of 5 km/h is calculated to be 2.89×10^{-6} mSv. The dose received by an individual travelling behind, or being stopped behind a UFTP shipment is the product of the dose rate at the distance the individual is from the UFTP and the time spent at that distance. For simplicity, the individual in the vehicle is assumed to be travelling behind the UFTP at a fixed distance. In an urban setting, this distance was measured by Carleton [3] to be 18 m while travelling and 10 m while stopped at a signal.

In this scenario, the individual is assumed to travel behind the shipment for a period of 2.5 minutes and be stopped behind the UFTP at a traffic signal for a period of 1.5 minutes resulting in doses of 2.08×10^{-6} mSv and 3.36×10^{-6} mSv respectively. The total dose per occurrence is the sum of the three doses, or 8.34×10^{-6} mSv.

The methodology described above is applied to calculate doses to individuals in all identified categories. In total, 28 separate scenarios placing members of the public and workers in the vicinity of a UFTP shipment were examined. Each of these scenarios is examined in detail in [4] with a summary of results illustrated in Figure 3.

Occupational dose due to used fuel transportation

Occupational 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.).

For each occupational activity, data 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 with a Canadian context. This data was analyzed and used to calculate radiological dose for each activity and subsequently for each worker. Occupational doses for each scenario is examined in detail in [4] with a summary of results provided in Figure 3.

Radiological dose received by the transport crew for a given shipment is largely a function of shipment duration. The dose received by a transport crew was found to range 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. 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 a NEW (the regulatory dose limit of 100 mSv averaged over five years for a Nuclear Energy Worker).

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 a 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). 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.

Dose rates and resulting occupational doses received by the transport workers are calculated and 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.

Providing context using the concept of 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.

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 [5]. This is lower than the worldwide average of approximately 2.4 mSv per year [5]. In Canada at ground elevation (most of Canada's population lives close to sea level) approximately 0.32 mSv or 18% 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 in Calgary at an elevation of 1048 m will typically receive more cosmic dose (approx. 0.47 mSv/y) than a person living in Victoria at sea level (approx. 0.29 mSv/y) [5].

Using this concept, 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 [6]. Thus, during a 2½ hour airplane flight from Toronto to Winnipeg, the individual would receive a dose of approximately 0.01 mSv, or a dose approximately equivalent to a full-mouth or panoramic dental x-ray [7]. In other words, the dose received from a dental x-ray is approximately equal to a flight-time equivalent dose (FED) of 2½ hours. The average annual natural background radiation in Canada is approximately 450 hours of FED.

As the FED concept provides a good benchmark for contextualizing radiological dose, doses calculated in this assessment are presented in both milliSieverts (mSv) and in FED in units of time (hours, minutes, or seconds).

Results

All doses to members of the public and transportation workers (illustrated in Figure 3) 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.

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. The annual occupational dose to transport workers was also assessed to be below the regulator dose limit of 1 mSv per year. Since this occupational dose remains below the regulatory public dose limit, the assessment concludes that transportation workers would not need to be designated as

NEWs. However, dose rates and resulting occupational doses received by workers have been calculated and are not based on measured values. Dose monitoring of occupational activities for workers and NEW designation requirements will be established when the radiation protection program is developed, prior to the operational start-up of the used fuel transportation program.

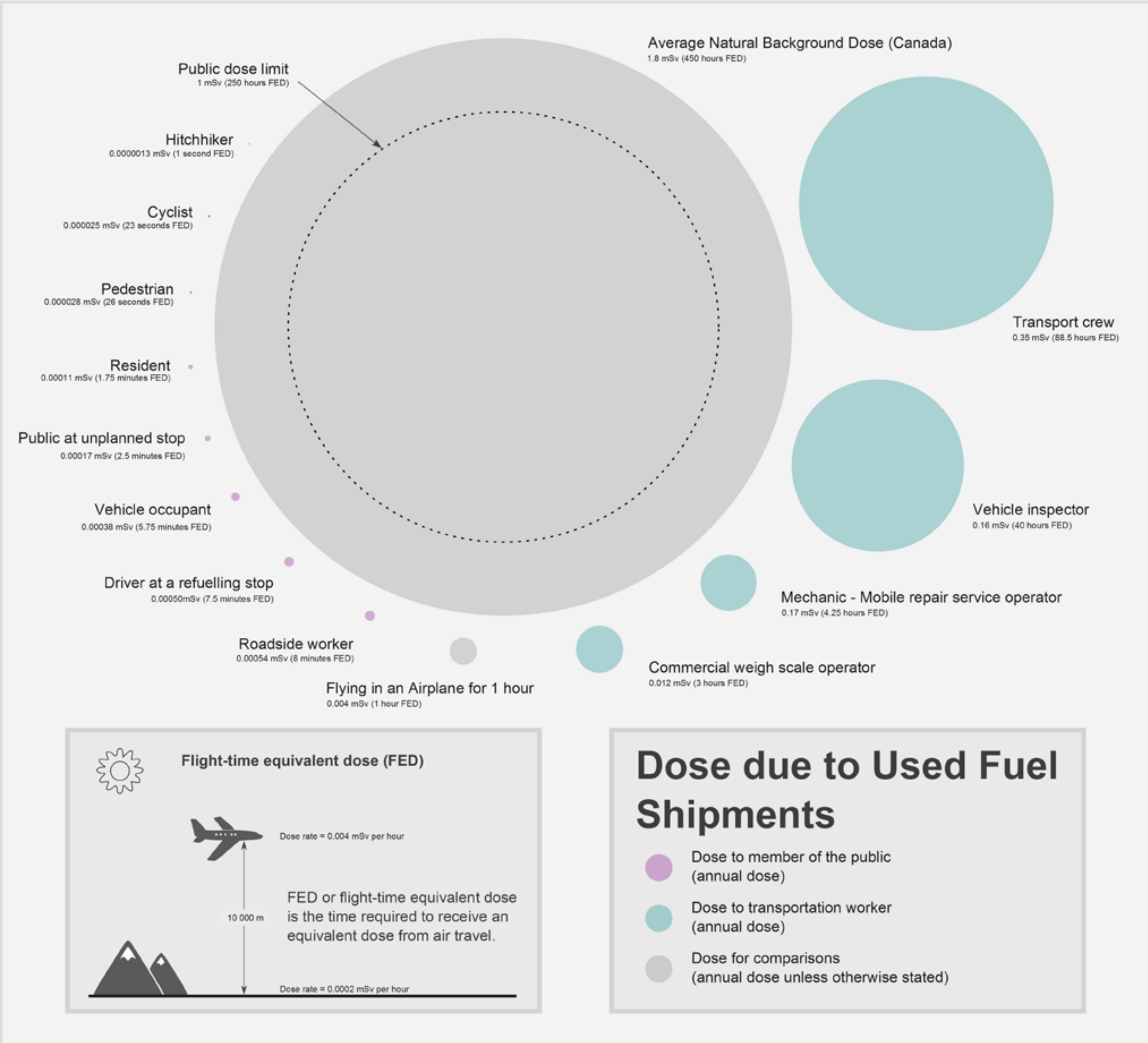

Figure 3 Radiological Dose due Used Fuel Transportation Package Shipments

Conclusions

Annual radiological dose is calculated to range from 1.3 x 10^{-6} mSv for a hitchhiker along the transport route (equivalent to 1 second in an airplane at altitude) to 0.35 mSv for the transport crew of the used fuel shipment (equivalent to 90 hours in an airplane at altitude). All doses to members of the public and transportation workers are calculated to be below the annual regulatory public dose limit of 1 mSv per year, therefore no individuals including transportation workers require designation as a Nuclear Energy Worker as defined in Canadian law.

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