Transportation of Nuclear Fuel

by D.R. Prowse
This publication is a revised edition of a report previously published as Chapter 4 of AECL-5800.
Transportation of Nuclear Fuel

by D.R. Prowse

Dr. Prowse is a chemical engineer who was, until recently, the coordinator of safety analysis studies at the Whiteshell Nuclear Research Establishment of AECL at Pinawa, Manitoba. From 1971 to October 1978 he was involved in safety analysis of nuclear reactor facilities, advanced reactor coolant development and energy utilization studies with AECL.
Shipment of used fuel from nuclear reactors to a central fuel management facility is discussed with particular emphasis on the assessment of the risk to the public due to these shipments. The methods of transporting used fuel in large shipping containers is reviewed. In terms of an accident scenario, it is demonstrated that the primary risk of transport of used fuel is due to injury and death in common road accidents. The radiological nature of the used fuel cargo is, for all practical purposes, an insignificant factor in the total risk to the public.

Le transport du combustible épuisé provenant de réacteurs nucléaires jusqu'à une installation centrale de gestion de combustible est examiné en insistant particulièrement sur l'évaluation du risque pour le grand public qui est dû à ce transport. Les méthodes de transport du combustible épuisé dans de grands châteaux de transport sont examinées. Sous l'angle d'un scénario d'accident, il est démontré que le risque principal couru lors du transport du combustible épuisé n'est constitué que par des blessures et la mort d'accidents routiers courants. La nature radiologique de la cargaison de combustible épuisé est, pour toutes fins pratiques, un facteur négligeable par rapport au risque total pour le grand public.
INTRODUCTION

This report is mainly concerned with the transportation of used fuel from Canadian nuclear reactors. Fresh fuel as fed to reactors is, for all practical purposes, non-radioactive and is not a particularly hazardous material, even under accident conditions. It is used fuel which is highly radioactive and which, therefore, deserves more detailed consideration.

This discussion will touch on three principal aspects of the situation. First, the general characteristics of used fuel that are of interest to transportation studies will be described. Second, the methods of transporting this fuel will be reviewed. Finally, an accident scenario and the probable risks of such an accident will be presented. Since not all aspects of transportation of used fuel can be covered within the space available, references to more detailed studies are provided.

It is worthwhile to review the reason why transportation of used fuel will be necessary. At present, used fuel is stored at the various nuclear reactor sites. However, these sites are not considered to be the best sites for final management of the fuel. Rather, the current plan in Canada is for a single fuel management centre which would contain all facilities for final management of the fuel, including a deep underground repository for permanent disposal of radioactive waste. Therefore, used fuel will have to be transported at some time in the future.

CHARACTERISTICS OF USED FUEL

The basic unit of used fuel from CANDU* reactors is the fuel bundle, which is constructed of sealed tubes of zirconium alloy filled with pellets of uranium dioxide. During irradiation in a reactor, a wide variety of radionuclides are formed in the uranium dioxide matrix. Some of these radionuclides emit intense gamma radiation or neutrons which can penetrate the zirconium sheath and present a direct external hazard to exposed personnel. Therefore, adequate shielding of the fuel bundle must be provided. Other radionuclides emit alpha or beta particles which, being less penetrating than gamma radiation, are absorbed in either the uranium dioxide pellets or the zirconium sheath. Such radionuclides do not present a direct external radiation hazard, but if released or dispersed into the biosphere, and if subsequently ingested or inhaled, could present an internal radiation hazard. The radioactive emissions generate heat within the fuel bundle and its immediate surroundings.

After irradiation in a reactor, fuel bundles are stored in water-filled bays. The current plan is to store the fuel bundles for five to ten years before transportation to a central fuel management centre. During this storage period, both the radiation fields and the associated decay heat decrease significantly. The decrease in gamma and neutron fields is illustrated in Figure 1.

*CANada Deuterium Uranium, the Canadian-designed heavy water moderated nuclear reactor.
virence due to mechanical fracture of the used fuel bundle resulting from impact.

2. The likelihood that radionuclides could be released and dispersed due to prolonged exposure in a fire.

Uranium dioxide is an unusually rugged material. It is a ceramic, and is not easily crushed by mechanical action. It is not greatly affected by irradiation and, after irradiation, its strength and crush characteristics are comparable to those of naturally occurring sandstone or limestone. Nevertheless, thermal stresses during irradiation in the reactor cause the fuel pellets to crack into many smaller segments. If subsequently separated from the zirconium sheathing, an initially intact pellet would have the appearance of gravel.

The irradiated uranium dioxide pellets are contained within zirconium alloy sheaths. During a severe accident, these sheaths are assumed to rupture, resulting in a release of a fraction of those gaseous fission products (primarily krypton and xenon radionuclides) which had accumulated in the free gas space in the fuel elements. These gases would normally be retained within the shipping container, but even if they were released in an accident, there would be no significant hazard to either the general public or people in the immediate vicinity of the accident.

Because of their mechanical crush characteristics, impact forces during a severe accident could result in local crushing of some fuel segments into, at most, a coarse powder. Even if such a mixture were ejected from the shipping container during the course of the accident, this powder-fuel mixture would be difficult to suspend or disperse in air. Therefore, there is only a low probability that any significant fraction of the uranium dioxide fragments could be converted into an easily dispersible or directly respirable aerosol.

If fuel fragments are subjected for prolonged periods to high temperatures, then some gaseous and non-volatile fission products may be released at the scene of an accident. The designation "non-volatile" is used since at normal pressure and temperatures, these fission products are non-volatile solids. The non-volatile fission products which are of importance include cesium, ruthenium and strontium.

To attain a significant release of both gaseous and non-volatile fission products, the pellet fragments must be subjected to prolonged exposure at high temperatures. Experimental evidence indicates that even after being heated in air at 800°C for 90 minutes, only small and generally insignificant amounts of these fission products are volatilized. In air, such volatilization is accompanied by further oxidation of the uranium dioxide and disintegration of the pellet into a coarse powder. If heated in air at 800°C for 90 minutes, a significant release of activity will occur. However, even under these conditions, only a small fraction of the non-volatile fission products, most notably ruthenium (Ru) and cesium (Cs), are released.

To summarize, used fuel is a rugged material whose primary hazard is due to its associated gamma fields. Radionuclides in spent fuel which could have significant health hazards are not easily dispersed solely by mechanical forces during an accident. Fission products which have significant hazard to health may be volatilized from fuel pellets but only after prolonged exposure to unusually high temperatures. Even those radionuclides that are released from the fuel bundle would normally be retained within the shipping container, as will be considered in the next section.

METHODS OF TRANSPORTING USED FUEL

In assessing transportation methods, one needs to know how much spent fuel must be transported. The quantities to be transported cannot be estimated unequivocally since the total used fuel available for transportation will depend on the installed nuclear capacity in Canada and the corresponding inventory of used fuel accumulated at the reactor sites. Nevertheless, projections of installed capacity have been made (Table 1) and these will form the basis of the following discussion.

A standard 600 MW(e) CANDU reactor annually discharges about 80 tonnes of used fuel, which is equivalent to 4000 fuel bundles per year. If stacked as cordwood, the resulting pile of fuel bundles would be approximately 1 metre wide and 1 metre high by 18 metres long.

To date, there have been no large scale shipments of used fuel from commercial reactor sites in Canada. Consequently, all used fuel discharged from these reactors is stored on-site in water-filled bays. At the end of 1977, about 2100 tonnes of used fuel were stored at reactor sites.

Used fuel will be shipped in containers which have two vital functions:

1. To provide shielding from the gamma rays from the used fuel.

Table 1: Used Fuel Projections for Canada

<table>
<thead>
<tr>
<th>Year</th>
<th>Installed nuclear generating capacity (MW(e))</th>
<th>Used fuel discharge rate (Tonnes U/year)</th>
<th>Total amount of used fuel accumulated (Tonnes U)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1977</td>
<td>3500</td>
<td>450</td>
<td>2090</td>
</tr>
<tr>
<td>1980</td>
<td>6100</td>
<td>800</td>
<td>3960</td>
</tr>
<tr>
<td>1985</td>
<td>12 000</td>
<td>1550</td>
<td>9250</td>
</tr>
<tr>
<td>1990</td>
<td>21 000</td>
<td>2570</td>
<td>18 850</td>
</tr>
<tr>
<td>1995</td>
<td>36 000</td>
<td>4680</td>
<td>35 830</td>
</tr>
<tr>
<td>2000</td>
<td>60 000</td>
<td>7830</td>
<td>64 920</td>
</tr>
</tbody>
</table>
2. To provide a high level of containment for the used fuel in the event of an accident.

A cutaway view of a typical container for transport of used fuel by rail is shown in Figure 2. It is approximately 3 metres long and 2 metres in diameter. Its walls are approximately 25 cm thick and consist of an outer shell of 9 cm of steel and an inner liner of 16.5 cm of lead. This thickness of shielding can reduce the gamma fields from inside the flask by a factor of ten million. Therefore, when filled with 5-year cooled CANDU used fuel, the dose rate at the flask surface is less than 1 milli-rem per hour.

The total weight of the container is approximately 50 tonnes and it is capable of transporting about 3.5 tonnes of spent fuel. Several other features which are noteworthy are the cooling fins and the protective shield which is employed to provide additional impact protection for the lid.

The container shown has been licensed for shipment of used fuel in Canada and has also been used to ship used fuel from Canada to Europe for experimental purposes. Figures 3 to 5 illustrate its use during one of those shipments.

Because of the shielding requirements, shipping containers have a low ratio of used fuel payload to total shipping weight. A container designed to be shipped by truck would probably weigh 35 tonnes but would be capable of transporting only 2 to 3 tonnes of used fuel.
If designed for rail shipment, then a container with a total weight of 100 tonnes may be capable of transporting up to 10 tonnes of used fuel.

Over the past 25 years, there have been about 400 000 shipments of radioactive material, primarily radioactive isotopes for medical diagnostic purposes within Canada. Of these, about 500 have been of used fuel. At present, about 50 000 radioactive shipments are being made per year, of which 20 are of used fuel. Most of the used fuel shipments, involving only fuel with a low level of irradiation, have been from the Chalk River Nuclear Laboratories to a plant outside Ottawa which processes the fuel to recover radionuclides for medical applications.

An estimate of the future rate of shipment of used fuel from commercial nuclear reactor sites is presented in Table 2. If large scale shipment begins in 1985, an initial rate of 200 container shipments per year by rail would be required. Such an estimate assumes that discharged fuel will be stored at reactor sites for a minimum of five years before shipment and that the accumulated inventory of used fuel will be reduced over a 10-year period. This initial rate is projected to increase to about 500 container shipments per year by rail by the year 2000.

The net conclusion that can be drawn from these statistics is that used fuel shipments will constitute a minor fraction of the total shipment of all goods in the present and foreseeable future.
Table 2  Future Used Fuel Container Shipments in Canada

<table>
<thead>
<tr>
<th>Year</th>
<th>Shipments/Year</th>
</tr>
</thead>
<tbody>
<tr>
<td>up to 1985</td>
<td>15 - 20</td>
</tr>
<tr>
<td>1985</td>
<td>200 (rail)</td>
</tr>
<tr>
<td>2000</td>
<td>500 (rail)</td>
</tr>
<tr>
<td>Total (up to 2000)</td>
<td>3600 (rail)</td>
</tr>
</tbody>
</table>

LICENSING REQUIREMENTS

Shipments of used fuel are subject to the rules and regulations of the Atomic Energy Control Board\(^6\), which generally follow those recommended by the International Atomic Energy Agency.

To obtain a licence for shipping used fuel, it must be demonstrated that the shipping container could withstand a series of qualification tests\(^6\), each potentially more destructive than any accident situation. This demonstration is usually performed using a series of scaled models of the shipping container. The most common model size is one-half full scale, although, for smaller shipping containers (less than 10 tonnes), full scale models have been employed. The qualification tests require that the container be subjected to:

1. A free-fall from a height of nine metres (9 m) onto an essentially unyielding surface in such a manner as to inflict maximum damage to the container and its contents. (A free-fall of 9 m results in an impact velocity of about 50 km per hour).
2. A free-fall of 1.3 m upon a hardened steel pin.
3. A thermal test at a temperature of 800°C for 30 minutes. This is accomplished by either complete immersion in a hydrocarbon fire, or by insertion in a large furnace.

At the end of each of these individual tests, the container must be tested for integrity of shielding and for leak tightness. Failure of the container to maintain its shielding or leak tightness represents non-compliance with the licensing requirement.

Although a container is tested for impact resistance at 50 km per hour, the structural capability of existing containers is much greater than indicated by this test. However, since containers are not normally tested at higher impact velocities, their capability can only be estimated. For example, it has been estimated that the shipping container illustrated in Figure 2 could withstand direct impact on an unyielding surface at velocities up to 110 km per hour without structural failure.

Impact on an unyielding surface is a rigorous test of the containment capability of a shipping container but represents accident conditions which would be expected to occur only under the most unusual circumstances. In practice, the unyielding surface is simulated by a thick, hardened steel plate on a concrete block whose total weight is up to ten times that of the shipping container. Actual surfaces yield more readily than the test surface and therefore may be expected to cause less damage than an unyielding surface.

Recently\(^7\), an attempt has been made to analyse the differences between impact on real target surfaces and impact on an unyielding test surface. The results of such an analysis, which was made for thick-walled steel shipping containers in their range of elastic deformation, are given in Table 3. The tabulated values are the ratio of the maximum deceleration force for impact with the selected surface to that for impact at the same velocity with an unyielding test surface. Since damage and deformation of a flask are due to deceleration forces during impact, the ratios provide a useful measure of the potential reduction in damage to a container when impacting on surfaces other than the unyielding test surface.

These estimates of the effect of target hardness have been qualitatively confirmed in a test sequence performed at Sandia Laboratories in 1975\(^8\). In this test sequence, two obsolete shipping containers of identical design were drop-tested onto two different target materials. In the first test, a container was dropped 610 metres from a helicopter onto prairie hardpan. The container, which impacted at a velocity of 396 kilometres per hour, penetrated 2.4 metres into the hard prairie. In the next test, the second container was subjected to a regulatory drop test of 9 metres onto an unyielding test surface. Both flasks survived the test sequences essentially undamaged. However, the flask which was dropped onto prairie hardpan sustained less damage than the flask subjected to the regulatory drop test.

Sandia Laboratories have also recently completed\(^9\) a series of tests which were selected to simulate very severe accident environments. The accident scenarios were:

1. Crashes of a tractor-trailer rig carrying a container

Table 3  Impact Surface Characteristics for Thick-Walled Steel Shipping Containers

<table>
<thead>
<tr>
<th>Surface type</th>
<th>Example</th>
<th>Deceleration force ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unyielding</td>
<td>Steel-Covered Abutments</td>
<td>1.0</td>
</tr>
<tr>
<td>Hard Rock</td>
<td>Granite</td>
<td>0.45</td>
</tr>
<tr>
<td>Soft Rock</td>
<td>Sandstone</td>
<td>0.40</td>
</tr>
<tr>
<td>Hard Soil</td>
<td>Clay Hardpan</td>
<td>0.30</td>
</tr>
<tr>
<td>Soft Soil</td>
<td>Sand</td>
<td>0.15</td>
</tr>
</tbody>
</table>
into a massive concrete barrier at 100 and 130 kilometres per hour.

2. High speed (130 kilometres per hour) impact of a locomotive into a truck-mounted container at a simulated grade crossing.

The crash sequence of the tractor-trailer rig at 130 kilometres per hour is shown in Figures 6 to 9. In Figure 6, the intact tractor-trailer rig is shown being accelerated up to test velocity by an attached rocket motor assembly. In Figure 7, the tractor-trailer rig is shown just after impact of the tractor with the massive concrete test target. Figure 8 illustrates the progressive destruction of the tractor-trailer rig during impact and just before impact of the flask on the concrete target. Because of the progressive destruction of the trailer, the flask velocity at impact was reduced from 130 kilometres per hour to about 100 kilometres per hour. Subsequent inspection revealed that the front of the flask had bulged slightly and, as predicted prior to the test, was permanently deformed (Fig. 9). However, in this test, as in the other tests listed above, the essential integrity of the container was retained.

These test sequences and discussion show that used fuel containers are extremely rugged and are capable of surviving very severe accidents. Nevertheless, the possible consequences of a container failure are examined in the next section.

Crash Test Sequence

Figure 6

Figure 7

Figure 8

Figure 9
ACCIDENT SCENARIO AND RISK TO PUBLIC

There are several features of shipments of used fuel which are predictable and self-evident. First, there will be accidents associated with some of these shipments. Second, in some accidents, radioactivity will be released. Such releases will constitute a risk to the public in excess of that normally associated with similar conventional transportation accidents. In this section, an estimate of risks due to these accidents will be presented.

To assess risks, it is assumed for purposes of illustration that a used fuel shipment is being made using a 25-tonne shipping container on a truck. The preparation for such a shipment would include:

1. Informing police along the shipment route that such a shipment is being made.
2. Labelling the shipment with appropriate warning signs.
3. Equipping the truck with a two-way radio and, where possible, making direct contact between the shipment and monitoring stations.
4. Ensuring that emergency response teams are available and on continuous standby both at the reactor shipment site and at the reception site.

During the trip, the truck carrying the container is assumed to be involved in an accident. In the vast majority of such accidents (Table 4) the container is calculated to retain its structural integrity, so that no radioactivity would be released and the accident would be just another highway accident with its associated problems. Such accidents would, however, activate the emergency response teams who would assume responsibility for co-ordinating activities at the scene of the accident.

To date, the safety record of used fuel shipments has been exemplary and conforms to the accident probabilities given in Table 4. In Canada, there have been about 500 shipments of used fuel, one of which involved a minor accident. In this accident, a tractor-trailer combination left the highway and overturned. The shipping container remained attached to the trailer and did not suffer any substantial structural damage. No radioactivity was released at the scene of the accident.

In the United States, there have been over 4000 used fuel shipments, one of which involved an accident that could be classified as moderate to severe. In this accident, a truck carrying a shipping container overturned at a curve on a highway. The truck driver was killed, but the container was not damaged and no radioactivity was released.

Although to date, there have been no recorded instances of radioactive release associated with used fuel shipment accidents, there exists the possibility that in a small number of accidents, involving high impact speeds and subsequent fires of duration of up to an hour, the structural integrity of the shipping flask could be breached and some radioactivity, primarily as fission product gases, could be released at the accident scene. Such accidents, referred to as moderate in Table 4, present low risk to the public and no difficulty would be experienced in removing any hazardous contamination from the scene of the accident.

In a rare number of accidents, a significant release of radionuclides could occur. The most probable sequence of events leading to such a release would be a collision at speeds greater than 110 kilometres per hour followed by an unusually severe and prolonged hydrocarbon fire of several hours. The fire would have to completely envelop the damaged shipping flask.

The probability of occurrence of such an accident is difficult to estimate realistically. One recent study has conservatively estimated that such an accident could occur once in every 250 000 used fuel shipments. However, another study concluded that such an accident could realistically occur only once in 10 000 000 shipments. The variance in these estimates remains unresolved.

For this unusually severe accident, up to 200 curies of non-volatile fission products, primarily cesium radionuclides, could be volatilized and dispersed into the environment surrounding the scene of the accident. The effects of such a dispersal depend on numerous factors, including prevailing meteorological conditions and the population density at and around the scene of the accident.

Under unusually adverse meteorological conditions, a member of the public who remained 100 metres from the container for several hours, could inhale sufficient volatilized radionuclides to obtain a radiation dose of up to 10 rem. This dose does not exceed the current emergency dose limit of 25 rem recommended by

Table 4 Accident Characterization

<table>
<thead>
<tr>
<th>Characterization of accident</th>
<th>Probability of accident</th>
<th>Estimate of radionuclides released</th>
</tr>
</thead>
<tbody>
<tr>
<td>Minor</td>
<td>1 in 1000 shipments</td>
<td>None</td>
</tr>
<tr>
<td>Moderate</td>
<td>1 in 10 000 shipments</td>
<td>Some fission product gases (Kr-85)</td>
</tr>
<tr>
<td>Severe</td>
<td>1 in 250 000 shipments to 1 in 10 000 000 shipments</td>
<td>Some fission product gases (Kr-85) and non-volatile fission products (Cs, Ru, etc.)</td>
</tr>
</tbody>
</table>
the International Commission on Radiological Protection (ICRP)\textsuperscript{14}. Further, to obtain such a dose, the individual concerned would have to remain immersed in the smoke plume from the fire. With normal rescue and protective measures, or at greater distances from the container, maximum radiation doses would be significantly lower.

If an individual received a dose of 10 rem, this would imply an increase of about 1 per cent in the probability of contracting cancer\textsuperscript{15} during the remainder of his or her lifetime. This slightly increased probability would be the unfortunate consequence of a very rare and severe accident.

Irrespective of the severity of an accident, the sequence of events following the accident would probably unfold as follows:

1. A passing motorist or local resident would inform police of the accident.
2. The police would arrive at the accident scene, and recognize both the severity of the accident and its type. They would cordon off the accident area and contact the emergency response team nearest to the accident. Traffic would be rerouted to the extent deemed necessary.
3. The nearest response team would be dispatched to the accident while the remaining response team coordinated and directed police activities via radio.
4. When the emergency response team arrived at the accident, it would assess the damage and the probable hazard, and assume responsibility for coordinating action at the accident scene.

Subsequent action would depend on the severity of the accident. Procedures have been formulated to handle every incident ranging from no release of radioactivity up to radioactive contamination of the accident location.

The response scenario just outlined is a hypothetical but rational picture of the events following a very severe accident. Risk to the public due to radiological release from such an accident is not zero, but is low even in the unlikely event of a release of radioactivity.

In addition to the immediate radiological hazard to individuals at the scene of an unusually severe accident, some local contamination could occur. Because of post-accident monitoring procedures and subsequent evacuation of local inhabitants, if necessary, this contamination would not likely pose any health hazard. However, the contamination would have to be cleaned up and the local environment returned to essentially pre-accident conditions. Decontamination procedures have been developed to perform such a task.

An estimate of the cost of decontamination of an accident area involves many assumptions and, of necessity, represents only an approximation. More accurate analysis requires specific information about land use near the accident site, the nature of the accident, the quantity and type of fission products released, etc. However, the cost of decontamination would probably be roughly proportional to the population density surrounding the accident site. In the event of an unusually severe accident in a rural area, decontamination costs could be as high as one million dollars\textsuperscript{13}. A similar accident in a heavily populated urban area could have a cost which is roughly ten times this. These estimated costs are high, but the chance of such an accident is extremely low. The required insurance cost per shipment to defray such improbable accident costs would be very modest.

To this point, considerable emphasis has been placed on an assessment of the radiological hazards associated with an unusually severe accident. Such accidents are spectacular. However, when the probability and consequences of such accidents are compared to the more common risks of shipment of used fuel, then the risk due to these accidents is placed in its proper perspective. Such a comparison is presented in Table 5.

Before discussing the comparison of Table 5 in more detail, the basis for the tabulated estimates will be outlined. Fatalities due to conventional road hazards, such as collisions with other vehicles or with stationary objects, have been previously estimated as 4 \times 10^{-5} fatalities per carrier-kilometre\textsuperscript{10,13}. Radiological doses delivered to the public during the course of a normal used fuel shipment have been previously estimated as ranging from 0.05 man-rem/shipment\textsuperscript{13} to 0.10 man-rem/shipment\textsuperscript{16}. For this analysis, an estimate of 0.05 man-rem/shipment was employed. When this estimate is combined with the estimate of 1.5 \times 10^{-4} latent cancer

<table>
<thead>
<tr>
<th>Table 5</th>
<th>Comparison of Hazards due to Used Fuel Shipment by Truck (1000 kilometres per shipment)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Number of shipments per fatality</td>
</tr>
<tr>
<td>Conventional Road Hazard Accidents</td>
<td>25 000</td>
</tr>
<tr>
<td>Radiological Hazard Externally</td>
<td>133 000</td>
</tr>
<tr>
<td>Radiation Dose Delivered During Normal Shipment (\sim0.05 man-rem/shipment)</td>
<td>133 000</td>
</tr>
<tr>
<td>Radiation Dose Due to Accidents Minor Accident (\sim1 man-rem/accident)</td>
<td>7 000 000</td>
</tr>
<tr>
<td>Moderate Accident (\sim10 man-rem/accident)</td>
<td>7 000 000</td>
</tr>
<tr>
<td>Severe Accident (up to 500 man-rem/accident)</td>
<td>3 500 000</td>
</tr>
</tbody>
</table>
fatalities per man-rem\textsuperscript{(16)}, then the estimate in Table 5 of 133 000 shipments per radiological fatality is obtained.

Radiation doses due to minor and moderate transportation accidents have been conservatively estimated as 1.0 and 10.0 man-rem per accident, respectively. These doses have been over-estimated, perhaps as much as by a factor of ten, so as to reflect current uncertainty with respect to used fuel shipment accidents. A very severe accident under un\textsuperscript{av}ourable circumstances, e.g., high population density and slow response, could result in a dose in the range of hundreds of man-rem to the public\textsuperscript{(13)}.

As may be noted from inspection of Table 5, the greatest hazard of death to the general public is due to conventional traffic accidents. The radiological nature of the cargo being shipped is, for all practical purposes, an insignificant factor in assessing the total hazard of such shipments.
REFERENCES


(5) Atomic Energy Control Regulations, Section 23, SOR'74-334, Queen's Printer for Canada, Ottawa (June 4, 1974).

(6) Regulations for the Transportation of Dangerous Commodities by Rail, 10th Amendment, Canadian Transport Commission, Hull, Quebec (August 30, 1974).


