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TRANSPORTATION RISK ASSESSMENTS, WHAT CAN WE LEARN FROM 30 YEARS OF PREDICTIONS?

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ABSTRACT

Transportation risk assessments have been routinely performed for the last 30 years. The common purpose of performing such assessments is to show that the impacts of the future shipments will be small and manageable. This paper reviews the assessment methods that have been used and identifies those advancements that have made predicting future impacts more accurate and realistic. The literature review was not limited to the transport of nuclear materials. The literature review showed that many of the limitations in the early assessments have been eliminated through better analysis tools and the availability of better data. The review also identified which assessment tools are the best predictors of transport impacts.

When looking at the magnitude of radiological exposures to the general public during normal transport of spent fuel, it was found that it was most important to model the exposures to those people who were most likely to come in close proximity to the spent fuel cask during transport. The models used to evaluate the risk of severe accidents were also evaluated to identify the sources of uncertainty and those parameters that most influence the overall severe accident risk. Since the reported accident risk has been typically several orders of magnitude lower than other impacts, the focus of shipment campaigns should be on ensuring that the predicted low accident risks are realized in practice.

This paper clearly shows the value of looking introspectively at the way transport risk assessments are performed. Such efforts identify the uncertainty in current predictions and where efforts should be focused so transport risks can be reduced.

INTRODUCTION

In accordance with the National Environmental Policy Act (NEPA) requirements, major decisions must be accompanied by an appropriate Environmental Assessment. Estimates of transportation impacts have been a part of each assessment. These repeated assessments provide the opportunity to show how controlling parameters have been identified and refined modeling has either reduced the uncertainty in modeling these parameters or ways have been found to reduce their impacts. After scoping studies in the early 1980's, the first environmental assessment were performed in 1986 as part of the process of selecting a proposed repository site. This was followed in 1999 and 2001 by a draft and final environmental impact statement (EIS) that showed that the development and operation of a repository at the Yucca Mountain site had acceptable environmental impacts. This EIS supported a decision to use the mostly rail scenario as the preferred mode for transporting material to the Yucca Mountain Site. The just-published Department of Energy (DOE) NEPA documents update the earlier Final EIS and estimate the impacts of using dedicated rail and the use of the Caliente and Mina rail corridors to ship spent fuel and high-level radioactive wastes and other materials to the Yucca Mountain site. One thing is clear - every assessment has shown that the transportation impacts are small and manageable. These assessments also provide an opportunity to document what we have learned and what further improvements could be realized.

RISK ASSESSMENT METHODOLOGY

The first transportation risk assessment performed in the mid-1970’s mirrored the beyond-design-basis nuclear power reactor accident analyses (Ref.1). Fault trees, used to identify sequence of failures, were reduced to a series of accident sequences and for each sequence the probability of occurrence was estimated. For the controlling accident sequences, the behavior of the spent fuel and cask were modeled to estimate the quantity of material released. Plume models then evaluated the impact of dispersion of these materials into the environment. The same analysis method is used today. The modeling capability and the data available to estimate impacts have improved significantly.

The next advance was the development of tools to model collective doses to the crew and the general population that occur during transport. Regulations limit the external exposure rates but since the value is not zero, some exposure to the general population and the crew will occur during transport. Collective dose estimates were first estimated for the transportation EIS published in 1977 (Ref. 2). To model both the accident risk and the collective doses, the code RADTRAN was developed. In addition to the collective doses, the transportation EIS also considered the possibility that one individual could be exposed to multiple shipments. From this point on, the collective doses to the workers and the general public and to the maximally exposed individuals have been modeled.

In the 1980’s, assessments began to include the estimates of the number of injuries and fatalities from traffic accidents attributable to waste transport.. These non-radiological fatalities were found to add significantly to the overall impact assessment and have also become a standard component in the overall transport impact assessment methodology. About the same time some assessments began to consider pollution health effects resulting from the exhaust and fugitive dust generated as a result of transport. While these impacts have never dominated, current assessments also estimate these impacts.

Before looking in detail at each of models used to estimate accident risk, collective dose, and traffic fatalities, it is insightful to look at the relative importance of these impact categories over time. Table 1 shows a comparison of high-level radioactive waste and spent fuel impacts beginning in 1983. In the first assessment, (Ref. 3) would be expected to be different. The waste volumes are higher, 72,000 metric tons (MT) instead of 70,000 MT used in all the others. In addition the first assessment sent half the spent fuel to the repository site and half to a reprocessing facility. A 25/75 percent truck/rail split was also assumed for the spent fuel. None of the subsequent assessments, (i.e.- the Yucca Mountain EA (Ref 4), the draft and final Environmental Impact Statement (FEIS) (Ref, 5) and the DSEIS (Ref. 6)), considered reprocessing and all but the draft SEIS consider mostly rail cases. For the DSEIS, truck shipments are used for reactor sites that can not handle a rail cask. Some of the parameters have remained quite constant, others have changed significantly.

Starting with the system parameters, such as the number of casks and the total shipment kilometers, both the truck and shipments are quite consistent. For the first two assessments, the truck spent fuel cask held only 2 PWR and 5 BWR fuel assemblies. DOE realized that the cask design was far from optimized and a new cask was designed and licensed that could transport 4 pressurized water reactor (PWR) or 9 boiling water reactor (BWR) spent fuel assemblies. All the remaining assessments shown in Table 1 reflect the use of the new shipment cask. With fewer total shipments, there are fewer shipment kilometers, and as a result, lower impacts. For the DSEIS, all truck shipments were from sites that could not handle a rail cask. If there had been 50,000 truck shipments, simple calculations based on the ratio to other truck shipment numbers, show there would have been 200 million shipment kilometers, very much in agreement with the previous three assessments.

Table 1. Five Assessments of Spent Fuel and High-Level Waste Shipment Impacts

Parameter	IAEA-CN-43/243 (1983)	Yucca Mt EA (1986)	Yucca Mt DEIS (1999)	Yucca Mt FEIS (2001)	Yucca Mt DSEIS (2007)
Truck transport assumption	25 %	100 %	Mostly truck	Mostly truck	Truck only sites
Total shipments	20,617	70,553	49,914	52,986	2,650
Total kilometers (millions)	42	284	193	188	10.6
Collective dose (LCFs)[1]	2 (10)	11 (33)	22	8	0.7 (13)
Accident risk (LCFs)	0.01 est.	-	0.07	0.0002	0.00005
Pollution health effects	< 0.1	-	0.3	0.9	0.1
Traffic fatalities	2 est.	36	4	5	1
Total truck fatalities	4	47	28	13	2
Rail transport assumption	75 %	100	Mostly rail	Mostly rail	Dedicated train
Total shipments	10,061	9,927	10,911	9,646	2,833
Total kilometers (millions)	30	50	39	40	11
Collective dose (LCFs)	20 (100)	0.32 (1)	1	2	3
Accident risk (LCFs)	0.01 est.	-	0.02	0.0004	0.003
Pollution health effects	< 0.2	-	0.3	0.6	1
Traffic fatalities	10 est.	3	2.7	2.5	2
Total rail impacts	20	3.3	4	5	6

[1] LCF refers to ‘latent cancer fatalities”

The rail system parameters are also quite consistent across the five assessments. The number of shipments in the DSEIS is smaller because of the dedicated train assumption, three spent fuel casks per train from commercial sites and 5 from defense sites. The number of rail cask shipments is very consistent with the other assessments, 9,495 casks. The cask shipment kilometers is also quite consistent, 35 million cask kilometers for transport to the repository on the Caliente rail corridor and 37 million cask kilometers for transport to the repository on the Mina corridor. Thus, given the capacity of the repository, the system parameters are reasonably constant and are not a major source of uncertainty. This result will remain the same as long as only one repository site is considered and the reactors providing waste to that repository are well distributed across the United States.

Before comparing the different estimates of collective doses, the latent cancer fatalities (LCFs) must be adjusted to a common dose-to-latent-cancer-fatality conversion factors, the factor used in the DSEIS. The adjusted numbers are shown in parenthesis. In the 1983 assessment, the dose conversion factor was 1.2 x 10^{-4} LCFs per person-rem. For the next assessment the conversion factor was 2 x 10^{-4} and the next two used 4 x 10^{-4} for workers and 5 x 10^{-4} for the general public. In the draft SEIS, the conversion factor was 6 x 10^{-4}. For the truck shipments in the DSEIS, the number shown in parenthesis is the number of LCFs that would be expected if 50,000 truck shipments had made. Excluding the truck impacts from the first assessment, there is a factor of three difference in the collective doses estimates. The differences will be explained later in the paper.

For both truck and rail, the accident risk numbers have decreased with time. This reflects the improvements in modeling the cask behavior in the accident environment. In the first assessments, the cask modeling was largely based on engineering judgment. In the last twenty years, NRC has funded two studies, the first commonly called the Modal Study (Ref. 7) and the second by Spring et al, (Ref. 8).. For the DEIS, the Modal Study results were used and for the last two assessments the Sprung analysis was used. Pollution health effects, have remained small for all assessments. Traffic fatalities have decreased significantly.

The following sections of this paper will look at the components of the transportation impacts in greater detail and thereby document improvements that have occurred and identify where additional improvements might be realized. The sections will examine shipment kilometers, accident risk modeling, collective dose impacts, and accident and fatality rates. The final section will examine uncertainties and worthwhile advances.

Shipment Kilometers

Both the quality of the data and the assessment tools have advanced significantly in the last 30 years. In the initial analyses, the fraction of travel in the various population zones and their associated densities were estimated for United States Geological Survey maps and summaries of US census data. With the advent of the HIGHWAY (Ref. 9) and INTERLINE (Ref. 10) routing codes, all this changed. For the first time a route could be selected and the population density and distance traveled through the three zones could be calculated for each route. The successor code, TRAGIS (Ref.11) advances the technology even further by considering the actual shape of the routes between two points and the resident population within some distance, typically 800 meters, on each side of the curved routes.

Table 2. Route Characteristics for Truck Transport from Turkey Point to Yucca Mountain

Parameter	Trans EIS (1977)	Yucca Mt EA (1986)	Yucca Mt DEIS (1999)	Yucca Mt FEIS (2001)	Yucca Mt DSEIS (2007)
Total distance (km)	1000	4184	4840	5186	5064
Rural fraction (%)	90	82	80.3	80.6	77.2
Suburban fraction (%)	5	17	17.0	16.6	19.7
Urban fraction (%)	5	1.0	2.7	2.8	3.1
Rural density (people/km^2)	6	6	7.2	7.6	9.8
Suburban density (people/km^2)	719	719	348	359	343
Urban density (people/km^2)	3861	3861	2284	2254	2390
Total exposed population	-	693,539	613,456	673,077	750.319

How different are the routes? Table 2 shows the results of routing calculations made over the last twenty years, for shipments of spent fuel from the same site, Turkey Point in Florida, to the Yucca Mountain repository. Over that time period, the calculations are based on three different census databases, (1980, 1990, and 2000) and the level of detail used in the calculations has advanced dramatically. The advances in technology are really hidden by the constancy of the results.

Accident Risk Modeling

In the 1977 analysis (Ref 2) the results were summarized in plots of exposure versus the probability of greater exposure, often called risk spectrum curves. With the publishing of the transportation EIS, all accident risk estimates have been presented as a single overall risk number obtained by multiplying the consequences of all the accidents times their likelihood and then summing the resultant products. This has become the standard way of presenting accident risk impacts.

Each subsequent analyses have taken advantage of a more thorough understanding of the transport accident environment and the behavior of the packaging in these accident environments. The two major advances occurred with the publishing of the Modal Study, (Ref 7) and the Sprung analysis (Ref. 8). The first one provided the first detailed structural analysis of a cask in accidents more severe than regulatory tests. The second reanalyzed the transport accident environment data used in the Modal Study and then evaluated several designs of rail and truck casks. The reanalysis added a detailed modeling of the radionuclide release from the spent fuel, within the cask cavity and then through the breach in the cask. Figure 1 shows a comparison of the release fraction versus probability curves for particulates. It can be seen that modeling of the behavior of the released material in the cask reduces the calculated amount of material released to the environment by several orders of magnitude.

In Table 1, the accident risk is shown as a single number. The release distribution shown in Figure 1 can also be reduced to a single number. The release risk for particulates in the Modal Study, obtained by multiplying the probability of a given release times its release fraction and then summing the results is 5.5×10^{-9} for the Modal Study and 2.7×10^{-11} using the Sprung model. The Sprung model has a release risk that is more than a factor of 200 lower. This explains why the accident risk numbers shown in Table 1 for the FEIS and DSEIS are lower than the repository DEIS which used the Modal Study results. The engineering estimates used in the earlier studies were even more conservative.

There are three other components of the accident risk calculation that have not been discussed. The first is the likelihood of an accident severe enough to cause a release. This will be discussed in the “Accident and Fatality Rate” section. The second is plume modeling, and the third is exposure to the population from the released plume. RADTRAN has been used for estimating the population exposure to the released material. The plume modeling as remained constant from RADTRAN to RADTRAN 5 (Ref. 12). The exposed population used in the accident modeling as been the population estimated from the routing tools. The routing models just consider the population out to 800 meters (about ½ a mile) on either side of the route. Using that population distribution is equivalent to saying that the distribution extends out to 80 kilometers (the extent of the plume model), which is an overestimation for urban areas. While better estimates of the exposed population could be developed, good risk management principles would suggest making improvements to other areas rather than trying to more accurately model the accident risk.

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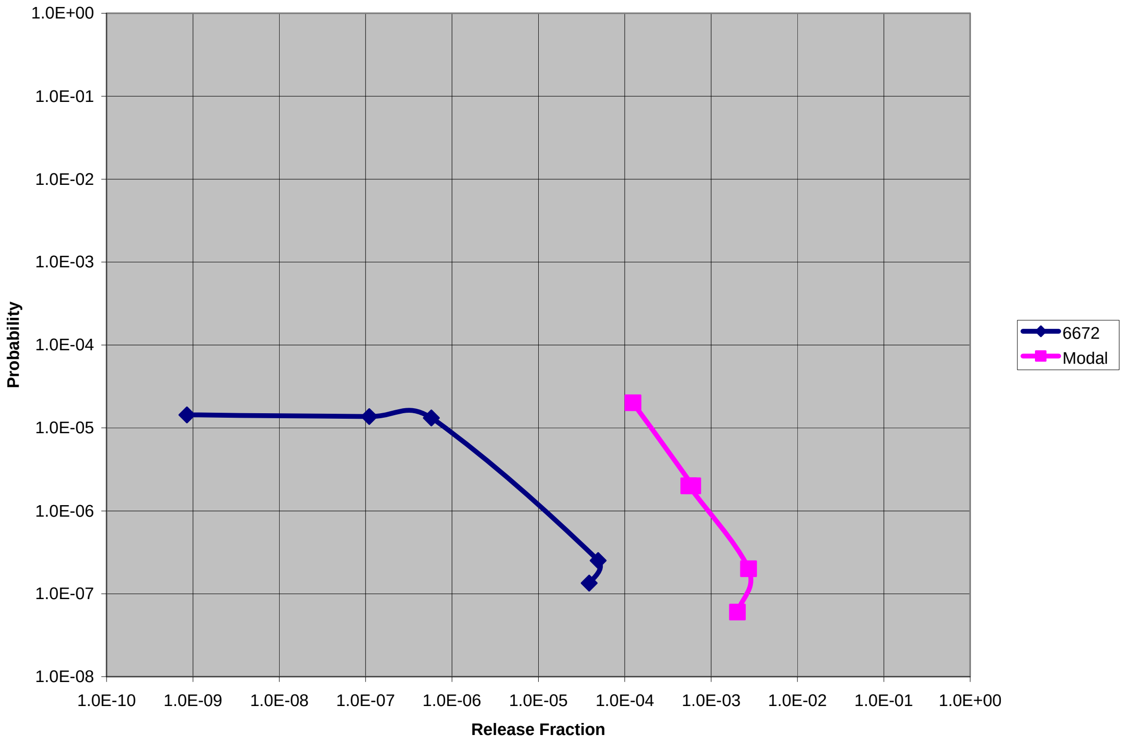

Figure 1. Release Fractions for Particulates by Severity Category

Collective Dose Impacts

In parallel to the transport accident modeling, it was recognized early on that since the packaging can not completely eliminate the radiation given off by the material being shipped, the exposures received by the transport crew and the general population along the route must be considered. Three types of exposure are estimated, to the population residing within 800 meters of the route, the people sharing the route, and during stops. The models used to estimate the exposure to people residing near the route and sharing the route have not changed since they were first developed

The stops models have changed significantly over time. Every assessment of exposures during stops has considered three parameters: the number of stops, the duration of stops and the distribution of the exposed population around the cask during these stops. To simplify the analysis, the first two parameters, the frequency of stops and the duration of stops have been combined into a single parameter, the hours stopped per kilometer. In the initial assessments the value of this parameter was very high, 0.086 hours per kilometer for rail and 0.011 hours per kilometer for truck. The population distribution was modeled as 50 individuals at 20 meters for truck and 100 people at 20 meters for rail. The use of these values is the reason why the collective dose impacts were so high in the 1983 assessment shown in Table 1. Using good risk management principles, projects were initiated to validate these estimates. The result was a report by Ostmeyer (Ref. 13) that provided the justification to significantly reduce the collective doses that occur during classification and regular rail stops. The report reduced the hours per kilometer for rail stops to 0.036, a factor of 2 reduction. The population around the stop was the population density obtained from the routing codes, a further reduction in exposure. For the classification stops, the number of classifications per trip was also specified:

$$N_c = 2 + 0.0018 \cdot D$$

Where: D is the total kilometers traveled, and
N_c is the number of classification stops

The duration of classification stop was specified to be 60 hours for cars in regular rail service and 2 hours for cars in dedicated train service. The population density around the classification yard was specified to be 719 non-involved railroad workers per square kilometer, equivalent to the default suburban population density. The model used a shielding factor of 0.1, meaning that the freight cars in the classification yard shielded the yard workers from 90 percent of the radiation emitted from the cask. The Ostmeyer model also specified the exposure to the crew transporting the radioactive material during classification stops. Three types of activities were considered: inspections, rail car repairs, and sorting activities. The first two were considered to be the same for both dedicated and regular train service and the latter just for regular train service. The Ostmeyer model was hard wired into RADTRAN III and all subsequent versions of the code. Incorporating the Ostmeyer model into the collective dose assessment resulted in a significant reduction in impacts. This was the case until the FEIS where the additional exposure to escorts was considered. The exposure to the workers, crew and escorts still dominates the collective dose from rail transport of radioactive materials.

For the FEIS, additional studies were performed for truck stops. The net effect of those studies is to reduce the stop time from 0.011 hours per kilometer to 0.0014, almost an order of magnitude. The 0.0014 value was obtained by combining two types of truck stops, a 10 minute vehicle inspection stop every 161 kilometers (100 miles) and a 20 minute rest and refueling stop every 845 kilometers (525 miles). For truck transport, the crew dose has been the dominant contributor to the collective dose. The regulatory limit for these individuals is 2 millirem per hour (mrem/hr) and this value has always been used to estimate these exposures.

While the collective dose to previously modeled individuals has gotten smaller, additional groups such as escorts have been added, essentially canceling the previous gains that have been realized for rail transport. All the collective dose assessments have assumed that the radiation emitted from the cask is at the regulatory limit, which is clearly conservative. In addition, for the DEIS, FEIS and draft SEIS, escalation factors have been used to estimate the population that might be exposed during the time waste was being shipped to the repository. These escalation factors have increased the collective dose estimates by factors of more than two with no corresponding credit for the waste aging which would lower the exposure rate from the cask. Since large scale shipments of spent fuel and high-level radioactive waste have not occurred in the United States, there is clearly a lot of uncertainty in the exposures that will actually occur when the material is actually moved. Given the uncertainty, the goal has been to make sure that the collective doses are conservatively modeled.

Accident and Fatality Rates

Over the last 30 years there have been several studies that have estimated accident and fatality rates for train and rail. Table 3 summarizes the accident and fatality rates for truck and Table 4 for rail. A study of California truck accident and fatality rates (Ref 14) and two Argonne studies (Ref 15 and 16) have been used in environmental assessments.

Direct comparison among the assessments can not be made because they have not used a common definition of what constitutes an accident. The reporting threshold for the Sandia analysis was all property damage accidents and all accidents in which an injury or fatality occurs. The report states that only 40 percent of the property damage accidents, 80 percent of the injury accidents and 90 percent of the fatal accidents are reported. The assumption is that the results shown have been corrected for the underreporting. The reporting threshold for the Argonne studies was a serious crash, which means a vehicle had to be towed away, there was an injury requiring immediate treatment at a medical facility, or there was a fatality. The serious crash definition is more restrictive so the accident rate would be expected to be lower for the later assessments shown in Table 3.. The California study seems to show more effect of road type but this may simply be showing the effect of fender benders, accidents that would not threaten the integrity of a cask. In 2003, it was shown that the data that was the basis for the second Argonne report under reported for both accidents and fatalities (Ref, 17). To account for the underreporting, the values shown in the fourth column of Table 3 should be multiplied by a factor of 1.6. The adjustments are shown in parentheses. As will be shown later, the fatality rate for heavy combination trucks decreased by a factor of two between 1980 and 1995, so when that factor is incorporated in the rates shown in Table 3, the fatality results are much more consistent.

Table 3. Comparison of Combination Truck Accident and Fatality Rates

Category	SAND82-7066 (1980 - 81)	ANL/ESD/TM-68 (1986 – 88)	ANL/ESD/TM-150 (1994 - 96)
Region	Rural / Urban	Rural / Urban	Rural and Urban
Accident rate	(accidents/10 million vehicle kilometers)		
Interstate	4.35 / 9,63	2.03 / 3.58	3.15 (5.04)
Primary	10.87 / 23.92	3.94 / 3.94	3.66 (5.90)
Secondary	25.79 / 43.19	3.48 / 3.38	6.54 (10.5)
Fatality rate	(fatalities/ 100 million vehicle kilometers)		
Interstate	1.03 / 0.87	1.91 / 2.37	0.88 (1.40)
Primary	0.99 / 0.78	5.82 / 5.82	2.32 (3.72)
Secondary	1.65 / 0.96	4.62 / 4.62	1.96 (3.13)

The summary of the rail accident and fatality rate estimates is shown in Table 4. The first study (Ref 18) is the only one that considers both regular and dedicated train fatality rates. Except to state that the rate for regular trains is on a per train basis with one car per train and for dedicated trains on a per train basis with 10 cars per train, it is not known how the values shown were developed. The Argonne accident rate estimate is on a per railcar basis and since on average, four cars derail in an accident, the number of railcar accidents estimated in the FEIS was based on the an accident rate that was four times the rate shown in the second Argonne report. The adjustments to the values shown for the second Argonne report, shown in parenthesis, make the agreement between the two Argonne reports much closer. The DSEIS estimate is based on an 8 car dedicated train using the following equation:

$$A_r = 7.5 + 0.17 \cdot N_c \, .$$

Where N_c is the number of cars in the train consist and
A_r is the composite accident rate per 10 million rail car km.

This formulation explicitly takes into consideration the train length, a parameter that would seemingly be important for short dedicated trains. This is a significant advancement in modeling train accident rates.

Table 4. Comparison of Rail Accident and Fatality Rates

Category	SAND85-2515	ANL/ESD/TM-68 (1986 – 88)	ANL/ESD/TM-150 (1994 - 96)	DSEIS
Regular rail				
Accidents (10mkm)		26.6	4.9 (19.6)	
Fatalities (100m-railcar-km)	2.82	0.07	7.8	
Dedicated rail				
Accidents (10mkm)				8.9
Fatalities (100m-train-km)	198			9.6[1]

[1] for an 8 car dedicated train

The estimates of fatality rates show a larger uncertainty. The Federal Railroad Administration (FRA) annually publishes data on fatalities, the number of train miles, and the number of rail car miles. Thus both the numerator and denominator needed to calculate the rate at the national level are readily available. There appears to be no standard way of using the data. To give an example, the fatality rate reported in the first Argonne report is very low. The low number is partially explained by the footnote to the table. The footnote states that only those fatalities that are similar to the fatalities associated with truck fatal accidents were included. This probably means that grade crossing and trespasser fatalities, which account for about 95 percent of the annual fatalities associated with rail transport were not considered. The fatalities are presented per train-km in the Sandia document and by car-km in the DSEIS. The number shown in Table 4 is for an 8 car dedicated train. Even using a train consist of 10 cars would leave the Sandia estimate more than an order of magnitude higher but if the average length of a train consist (about 60 cars) were used, the estimate shown in the Sandia analysis and in the DSEIS for dedicated trains would be much more consistent.

Approximately 95 percent of the rail fatalities are the result of acts by other individuals at grade crossings and as a result of trespassing. Eliminating these fatalities, which was probably done in the first Argonne assessment, would reduce the fatal accident rate by a factor of 20. Clearly a common way to estimate rail fatalities is needed.

Uncertainties and Worthwhile Advances

This paper has presented the results of several sequential assessments of the impacts of transporting spent fuel and high-level radioactive wastes to the proposed repository site at Yucca Mountain. By systematically looking at the parameters used to estimate transportation impacts it has been possible to show how the technology has advanced. The development of a truck cask that can handle 4 PWR and 9 BWR assemblies is a significant advance. The two NRC funded studies, modeling of the behavior of a cask containing spent fuel is also a significant advance. The analysis of accident risk impacts has evolved to the point where it can be shown that they are no longer a significant contributor to the overall impacts associated with transporting spent fuel and high-level radioactive waste to the Yucca Mountain site.

Similar advances have been made in modeling the collective doses occurring during transport. The population residing around the transport route can be accurately estimated using TRAGIS. It is believed that more operational data for shipments that closely model the shipments of spent nuclear fuel and high-level radioactive waste would provide a better basis for the values being used in the models, and therefore would reduce the uncertainty in the current results. The last two assessments, the FEIS and DSEIS, have looked at population escalation and show how these factors multiply the impacts by factors of more than two depending on how far out the projections are made. By adding this factor, a new and perhaps more uncertain parameter has been added to the equation. An estimate of the uncertainty associated with this parameter is certainly warranted. All impact estimates have used the regulatory limits for cask exposure rates. The conservatism here, if modeled, probably balances part of the effect of population escalation factors used to estimate future impacts.

The biggest uncertainty remaining seems to be accident and fatality rates for trains. Given the small contribution of accident risk to the overall transportation impacts, more accurate modeling of accident rates will have only a small impact on the overall impacts. More accurately modeling fatalities could have a significant impact. For both rail and truck there is only a small underreporting rate for fatalities. For heavy combination trucks, data on the national level is readily available as shown in Table 5, extracted from the Large Truck Crash Study (Ref 19) funded by the Federal Motor Carrier Safety Administration (FMCSA).

It can be seen from Table 5 that as the vehicle distance traveled more than doubled the fatal accident rate went down by almost a factor of three. In comparing the data in Tables 3 and 5, the results from the two Argonne studies are quite consistent with the data in Table 5. Since the results in Table 5 are for the type of vehicle that would transport spent nuclear fuel the repository, any assessment of truck fatalities should be consistent with these data.

Table 5. Large Combination Truck Fatality Rates

Year	Millions of Motor Vehicle km	Fatality/100M km
1975	75,195	4.59
1980	110,527	4.05
1985	125,630	3.70
1990	151,827	2.78
1995	185,800	2.00
2000	217,294	1.73
2003	222,608	1.69

Focusing on fatality data, in the two Argonne studies,(Ref 15 and 16), listed in Table 3, the fatality rates were actually specified for each state. This creates an additional uncertainty in the modeling because there is uncertainty in the denominator of the rate equation and for some states where there are not many fatal accidents. In a study of hazardous truck transport in the Cleveland –Youngstown Ohio area (Ref. 21), the analysts showed that the accident rates were likely to have a Poisson distribution which means that the standard deviation is equal to the mean accident rate. The authors then developed an unbiased way of adjusting the accident rate on those segments with only few accidents so as to correct for the wide variations in rates that occur when there are only a few accidents or fatalities. If State level data are to be used in future assessments, then adjustments such as those made in this report should be part of any future accident rate projections. The more the data is disaggregated into smaller groupings, the more years of data are needed. At least 5 years of accident data is probably needed to eliminate the yearly variations that naturally occur.

Like FMCSA, the FRA maintains a database of train accidents and fatalities. They also publish an annual report that summarizes the results for that year. In a report by Anderson and Barkin (Ref 20), it was shown that the derailment rate on Class 4 and 5 track was about 50 and 30 percent of the overall derailment rate respectively. Should track class be included in the analysis or be considered a known conservatism in the modeling? Is there a similar impact for fatalities?

CONCLUSIONS

Over the last 30 years, many improvements in the modeling of transportation impacts have been made. The current assessments present a far more accurate assessment of the overall transport impacts. The two areas where residual uncertainties appear large would be addressed by obtaining more operational data on shipments and perhaps integrating the data into TRAGIS so the routing would be better coupled with the impacts. Good data on fatality rates are available for heavy combination trucks on a national level but more analyses are needed if state level data is to be used. A common method of handling rail fatality data is needed. The current projections of impacts are small and quite manageable. Any of the suggested improvements would simply serve to provide a better basis for the projected impacts and further reduce the uncertainty in these projections.

ACKNOWLEDGMENTS

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