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Risks Of Transportation Along Various Routes To The Nevada Test Site, Revision 1

Ruth. F. Weiner

Prepared by
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ABSTRACT

Residents of Southern Nevada have expressed interest in the risks posed by transportation of radioactive materials to the Nevada Test Site (NTS) for disposal. Residents of the urban sections of Clark County and rural areas of Nye County, in particular, are concerned because the trucks carrying this material pass through fairly densely populated areas on both primary and secondary highways. This study estimates collective doses to the population from shipments to the NTS from DOE-approved sites along these routes. The study also estimates doses to various individual receptors, both for routine, incident-free transportation and for transportation accidents. The routes analyzed were selected in consultation with the Community Advisory Board for Nevada Test Site Programs and encompass the possible truck routes through the state of Nevada from appropriate ports of entry to the NTS. The program and code RADTRAN was used to estimate transportation risks. Vehicles used met all DOE and DOT shipping requirements.

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1.0 SUMMARY

Residents of Southern Nevada have expressed interest in the risks posed by transportation of radioactive materials to the Nevada Test Site (NTS) for disposal. Residents of the urban sections of Clark County and rural areas of Nye County, in particular, are concerned because the trucks carrying this material pass through fairly densely populated areas on both primary and secondary highways. This study estimates collective doses to the population from shipments to the NTS from DOE-approved sites along these routes. The study also estimates doses to various individual receptors, both for routine, incident-free transportation and for transportation accidents. The routes analyzed were selected in consultation with the Community Advisory Board for Nevada Test Site Programs and encompass the possible truck routes through the state of Nevada from appropriate ports of entry to the NTS. The program and code RADTRAN was used to estimate transportation risks. Vehicles used met all DOE and DOT shipping requirements.

Doses from both routine, incident-free transportation and from transportation accidents were estimated. The parameters on which these estimates are based include the measured external dose rate from the shipments, dimensions of the truck and cargo, vehicle speed, relevant population densities, traffic count, and lengths of the route segments analyzed. Parameters used in estimating accident doses include average Nevada accident frequencies, the conditional probabilities of various kinds of accidents, and the radionuclide inventories of the various shipments considered.

Previous studies of transportation to the NTS assumed that the external dose rate from undamaged radioactive cargo was always the maximum allowed by regulation: 14 mrem/hour at one meter from a cargo package about 3 to 4 meters long. In this study, the greatest external dose rate was 10 mrem/hour, and the average, 1.12 mrem/hour. In this study, the largest dose per shipment to a member of the public along the route would be a little less than one millionth of a millirem (10^{-6} mrem) and the average, about one ten-millionth of a millirem (10^{-7} mrem). If the regulatory maximum external dose rate had been used for all shipments, the average dose to a member of the public per shipment would have been an order of magnitude larger and the same as the largest dose: about 1.5×10^{-6} mrem.

The average background dose in Nevada is 400 millirem (mrem) per year from non-DOE activities, and is an external dose. The doses of ionizing radiation from the shipments considered are orders of magnitude smaller than this. Collective (population) doses to residents along the routes and to occupants of vehicles sharing the route are of the order of one person-mrem or less – usually less. The average individual dose to a resident along the route, which may be instructively compared to background, varies from about five billionths (5×10^{-9}) of a millirem to about 5/100,000 of a millirem. The largest dose to a member of the public along the route is a little less than one millionth of a millirem.

Doses for several scenarios in which a routine shipment was about a meter (39 inches) from a member of the public are all less than annual background. The largest doses are at the rest area, since the receptor in this scenario is exposed for the longest time, but even in this case the largest dose from any shipment is 61 mrem – about 1/6 of annual background.

An accident in which there is no release is equivalent to having the vehicle stop for a period of time and expose members of the public. Collective doses from such an accident are all small compared to background. These collective doses depend more on the size of the exposed population than on any other parameter. The maximum individual dose from a no-release accident is compared to one of the special scenarios: the individual stuck in a traffic jam next to the cargo. The difference in doses is primarily the difference in distance from the cargo and the exposure time.

The collective (population) effects from a release accident are reported as “dose risks” that include the probability of release in a particular accident as well as the dose from the release. Given the uncertainties in the concept of collective dose combined with uncertainties of effects at very small individual doses, the collective consequences are not reported. Maximum individual dose, however, is reported, as well as maximum individual dose risk. The maximum individual dose is no more than a few millirem.

Traffic accidents and fatalities may be compared appropriately to health effects; in this case, latent cancer fatalities (LCF). Risk from traffic accidents and radiological risk from the shipments are both very small. LCF is a risk calculated by multiplying dose in rem by 0.0006; a health effect from a dose as small as the doses calculated in this study has never been observed or verified. Risk from traffic accidents and radiological risk from the shipments are both very small. The largest LCF risk from the transportation studied is along the southern route and is 1.7/10,000 (1.7×10^{-4}). The risk of being in a traffic accident on this route is ten times larger (1.1×10^{-3}) than the LCF risk and the risk of a fatal traffic accident is about 1/40 of the LCF risk. By comparison, the LCF risk from 8-hour exposure to background radiation on this route is 2700 times larger than the largest LCF risk from a shipment. LCF risks for all shipments and routes are shown in Table 24.

2.0 INTRODUCTION

Residents of Southern Nevada have expressed interest in the risks posed by transportation of radioactive materials to the Nevada Test Site for disposal. Residents of the urban sections of Clark County and rural areas of Nye County, in particular, are concerned because the trucks carrying this material pass through fairly densely populated areas on both primary and secondary highways. Excellent studies by the Desert Research Institute (Miller, et al, 2005; 2007) measured the external radiation doses from these trucks and provided a benchmark for estimating the doses sustained by the population along the transportation routes. The studies did not, however, assess the doses to the population in the event of an accident involving these trucks. The present study estimates doses to the population along these routes and to various individual receptors, both for routine, incident-free transportation and for transportation accidents.

3.0 STUDY METHODS

3.1 RADTRAN

The program and code RADTRAN was used to estimate transportation risks (Neuhauser, et al, 2000; Weiner et al, 2006). RADTRAN estimates doses from routine, incident-free transportation by modeling the radioactive cargo as a sphere moving at the speed of the vehicle; the external dose rate at one meter from the cargo (the transport index, or TI) is modeled as a virtual radiation source at the center of this sphere. Input data were supplied by DOE/NVOO unless otherwise noted. Doses from transportation accidents that do not involve releases of ionizing radiation also use this model. Accidents in which radioactive material is assumed to be released are modeled by Gaussian dispersion and deposition of released material. Details of these models may be found in Neuhauser et al (2000) and Weiner et al (2006). RADTRAN 5.6 with the input file generator RADCAT 2.3 was used for this study. RADTRAN input data are shown in Tables 1, 2 and 3. All transportation was by truck. Table 1 Shows the parameters related to population, crew, accidents, vehicle speeds, etc.

Table 1. Parameters used in calculating incident-free doses.

Parameter	Parameter Value	Comments and Reference
Package		
Package type	Type A	
Package dimension	See Table 2	INEL04SMC002. 0001; NFSI1000000002, 3
External Dose rate (TI)	See Table 2	INEL04SMC002. 0001; NFSI1000000002, 3
Fraction of emitted radiation that is gamma	1.00 (0.99998)	Calculated from inventory and ICRP38 (1983)
Fraction of emitted radiation that is neutrons	2×10^{-5}	
Crew		
Number of crew	2	
Distance from source to crew	3.1 m	
Dose to truck crew during travel	2 mrem/hr	This is the regulatory maximum.
Truck Speeds		Insurance Institute for Highway Safety, as cited by the U.S. Bureau of Transportation Statistics, State Transportation Statistics 2005, Table 2-9 (www.bts.gov)
Rural	113 km/hr[a]	
Suburban	113 km/hr	
Urban	105 km/hr; Clark Co: 97 km/hr	
Number of people per vehicle sharing route	2	
Minimum and maximum distances to exposed resident population along the route	30 to 800 m	
Population densities (persons per km^2)		
Rural	See Table 5	
Suburban	See Table 5	
Urban	See Table 5	
Shielding: % of energy transmitted to the receptor		
Rural	100%	These values have been used traditionally in RADTRAN to indicate the fraction of energy from external radiation penetrates a dwelling.
Suburban	87%	
Urban	1.8%	
One-way traffic count (vehicles per hour) on Nevada highways		
Clark Co. Rural	3640	From The Transportation Health and Safety Calculation Package, DOE, 2002. The traffic counts for counties other than Clark Co are the average for the state (excluding Clark Co.) because there were not enough data for each of the other counties.
Clark Co. Suburban	1230	
Clark Co. Urban	3160	
Other Nevada Rural	148	
Other Nevada Suburban	311	
Other Nevada Urban	2010	

[a] 1 km = 0.6217 mi.

Table 2 shows the parameters related to the cargo section of the vehicle. . This external dose rate was applied to all shipments in many previous environmental assessments (e.g. DOE, 2002). The doses associated with this shipment are be compared to doses from shipments with different external dose rates in the "Results" section of this analysis. The 1996 FEIS for the Nevada Test Site (DOE, 1996, p. 3-22) used an external dose rate of 0.05 mrem/hr at 1 m.

Table 2. Cargo parameters used in calculating incident-free doses.

		Vehicle (Cargo) Dimensions (m)		
Shipment ID	**Material**	**Length**	**Crew View[a]**	**TI (mrem/hr)**
INL08001	Unknown	8.41	3.66	0.001
INL08002	Unknown	6.06	3.14	0.50
INL08003	Unknown	6.06	3.14	0.01
NFL08041	Caustic	8.41	3.66	0.01
NFL08042	Caustic	8.41	3.66	1.00
NFL08043	Raffinate	8.41	3.66	0.01
POL08131	scrap metal	8.41	3.66	0.01
POL08132	scrap metal	8.41	3.66	0.10
POL08133	scrap metal	8.41	3.66	0.01
POL08134	scrap metal	8.41	3.66	0.01
PORTLP0001002	wet solid ,HEPA filters	6.10	3.14	0.10
NFS100000000302	stabilized caustic	6.10	3.56	2.80
NFS100000000201	stabilized raffinate	6.10	3.56	10.00

[a]The "crew view" is the longest dimension of the surface of the transported package facing the crew cab.

Table 3 shows the radionuclide inventories for each package shipped. Shipments INL08001 and INL08002 each included 12 packages. All TI values are less than the regulatory maximum, which is 14 mrem/hr for these packages (10 mrem/hr at two meters is the regulation in 10 CFR Part 71).

Table 3. Inventory in curies for each package shipped.

Shipment ID	NP237	PA234M	PU238	PU239	TC99	TH231	TH234	U232
INL08001	5.65E-10	8.57E-05	8.57E-11	1.28E-10	4.89E-08	1.08E-06	8.57E-05	1.50E-07
INL08002/INL08003	1.20E-06	1.07E-01	6.60E-06	8.54E-07	1.75E-04	1.07E-01	1.07E-01	1.84E-04
INL08002/INL08003	1.76E-06	1.57E-01	9.69E-06	1.25E-06	2.56E-04	1.92E-03	1.57E-01	2.70E-04
INL08002/INL08003	1.20E-06	1.07E-01	6.60E-06	8.54E-07	1.75E-04	1.30E-03	1.07E-01	1.84E-04
INL08002/INL08003	1.76E-06	1.57E-01	9.69E-06	1.25E-06	2.56E-04	1.92E-03	1.57E-01	2.70E-04
INL08002/INL08003	1.20E-06	1.07E-01	6.60E-06	8.54E-07	1.75E-04	1.30E-03	1.07E-01	1.84E-04
INL08002/INL08003	1.76E-06	1.57E-01	9.69E-06	1.25E-06	2.56E-04	1.92E-03	1.57E-01	2.70E-04
INL08002/INL08003	1.20E-06	1.07E-01	6.60E-06	8.54E-07	1.75E-04	1.30E-03	1.07E-01	1.84E-04
INL08002/INL08003	1.76E-06	1.57E-01	9.69E-06	1.25E-06	2.56E-04	1.92E-03	1.57E-01	2.70E-04
INL08002/INL08003	1.20E-06	1.07E-01	6.60E-06	8.54E-07	1.75E-04	1.30E-03	1.07E-01	1.84E-04
INL08002/INL08003	1.76E-06	1.57E-01	9.69E-06	1.25E-06	2.56E-04	1.92E-03	1.57E-01	2.70E-04
NFL08041								
NFL08042								
NFL08043	6.57E-04		4.86E-06		3.11E-03			
POL08131					1.49E-03			
POL08132					1.15E-03			
POL08133					1.67E-03			
POL08134					1.88E-03			
PORTLP0001002					2.19E-04			
NFS100000000302								
NFS100000000201	6.80E-06		7.20E-06					

Table 3 -- continued. Inventory in curies for each package shipped.

Shipment ID	U234	U235	U236	U238	AM241	PA231	RA226
INL08001	1.54E-05	1.08E-06	5.00E-07	8.57E-05	8.86E-10		
INL08002/INL08003	5.26E-02	1.30E-03	1.34E-05	1.07E-01	2.70E-11		
INL08002/INL08003	7.74E-02	1.92E-03	1.97E-03	1.57E-01	9.14E-06		
INL08002/INL08003	5.26E-02	1.30E-03	1.34E-03	1.07E-01	6.23E-06		
INL08002/INL08003	7.74E-02	1.92E-03	1.97E-03	1.57E-01	9.14E-06		
INL08002/INL08003	5.26E-02	1.30E-03	1.34E-03	1.07E-01	6.23E-06		
INL08002/INL08003	7.74E-02	1.92E-03	1.97E-03	1.57E-01	9.14E-06		
INL08002/INL08003	5.26E-02	1.30E-03	1.34E-03	1.07E-01	6.23E-06		
INL08002/INL08003	7.74E-02	1.92E-03	1.97E-03	1.57E-01	9.14E-06		
INL08002/INL08003	5.26E-02	1.30E-03	1.34E-03	1.07E-01	6.23E-06		
INL08002/INL08003	7.74E-02	1.92E-03	1.97E-03	1.57E-01	9.14E-06		
INL08002/INL08003	5.26E-02	1.30E-03	1.34E-03	1.07E-01	6.23E-06		
INL08002/INL08003	7.74E-02	1.92E-03	1.97E-03	1.57E-01	9.14E-06		
NFL08041	3.62E-02	7.41E-04	8.81E-03	2.22E-05			
NFL08042	2.81E-02	5.73E-04	6.81E-03	1.72E-05			
NFL08043	1.15E-02			2.62E-03		2.38E-03	2.86E-03
POL08131	1.93E-04	6.67E-06		4.04E-05			
POL08132	2.48E-04	8.58E-06		5.19E-05			
POL08133	5.57E-04	1.93E-05		1.17E-04			
POL08134	3.13E-04	1.08E-05		6.64E-05			
PORTLP0001002	2.56E-04	1.48E-05		2.28E-04			
NFS100000000302	7.97E-02	1.64E-03	1.94E-02	5.50E-05			
NFS100000000201	5.40E-03		1.25E-03		9.80E-06	1.13E-03	1.33E-03

3.2 Routes

RADTRAN calculates population doses from routine, incident-free transportation to residents along the routes, usually (as in this case) within a half mile of the route. The routing program WebTRAGIS (Johnson and MIchelhaugh, 2000) was used to plot the routes to the Nevada test Site (NTS) and supply some population data. The population data for the State Route 160 (SR 160) corridor was supplied by Clark County, NV. Figure 1 shows the region of Nevada included in this analysis.

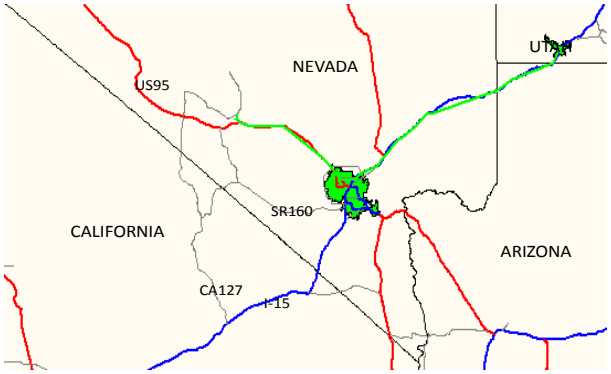

Figure 1. Nevada region studied.

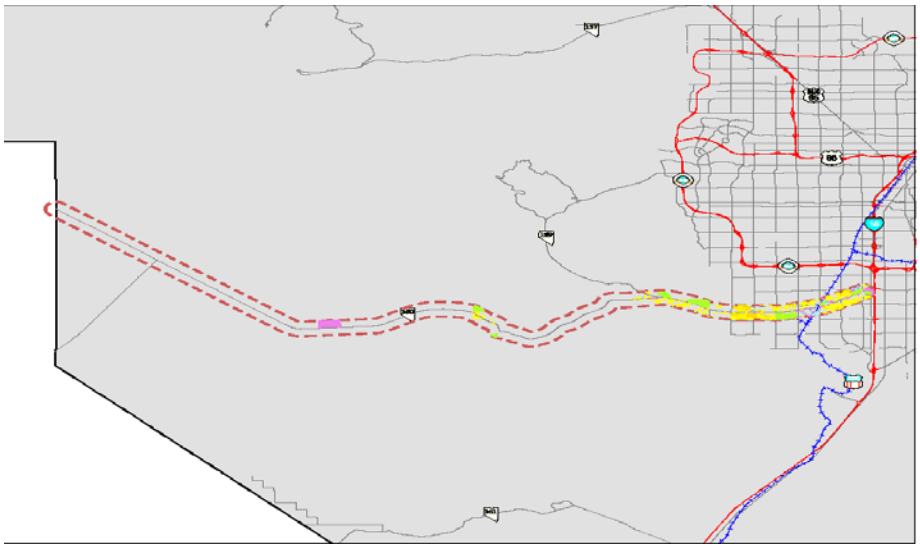

Figure 2. SR160 in Clark County. The dotted line indicates an 800 m. zone.

WebTRAGIS identifies rural, suburban, and urban route segments by population density. Table 4 shows the population bins as defined by WebTRAGIS. The classification of bins as rural, suburban, or urban is somewhat arbitrary. Its consistent use, however, allows comparison with other analyses and provides a certain consistency to RADTRAN analyses. The rural designation allows estimate of the fraction of agricultural land along a route segment; suburban and urban designations do not. The urban designation allows inclusion of non-resident receptors (people who visit a city but don't live there) as well as allowing for the fraction of outside air that does not enter urban buildings. Each designation has an associated shielding factor (see Table 1).

Table 4. Population density bins from WebTRAGIS (converted from persons/mi^2)

	Rural				Suburban				Urban		
Persons/km^2	0	0-59	59-155	155-360	360-843	843-2124	2124-4815	4815-8605	8605-150445	15045-25862	>25862

Correction factors developed by the U.S. Census Bureau (www.census.gov) were used to correct WebTRAGIS densities from the 2000 census. Nevada County population densities supplied by the Nevada state demographer (NV Department of Taxation, 2007) were used to correct the population densities to 2007. Table 5 shows these correction factors

Table 5: Corrected population densities

	Persons/km^2 from Web TRAGIS	Census Bureau Correction[a]	NV Correction Factor	Corrected Persons/km^2
Southern Rte, Clark Co. rural	7.9	9.87	1.0144	10.01
Southern Rte, Clark Co. suburban	333.1	416.04	1.0144	422.03
Southern Rte, Clark Co. urban	2936.7	3794.22	1.0414	3951.30
Southern Rte, Nye Co. rural	5.4	6.74	1.0155	6.85
Southern Rte, Nye Co. suburban	249.3	311.38	1.0617	330.59
Southern Rte, Nye Co. urban	2359	3047.83	1.0712	3264.83
Northern Rte, Elko Co. rural	2.5	3.12	1.0304	3.22
Northern Rte, Elko Co. suburban	89.8	112.16	1.0304	115.57
Northern Rte, White Pine Co. rural	3.2	4.00	1.0282	4.11
Northern Rte, White Pine Co. suburban	454.9	568.17	1.0282	584.19
Northern Rte, White Pine Co. urban	1764.7	2279.99	1.0293	2346.80
Northern Rte, Nye Co. rural	0.7	0.87	1.0155	0.89
CA127 Amargosa Rte, Nye Co. rural	2	2.50	1.0155	2.54
CA127 Pahrump Rte, Nye Co. rural	3.02	3.77	1.0155	3.83
CA127 Pahrump Rte, Nye Co. suburban	286.6	357.96	1.0617	380.05
SR160 Rte, Clark Co. rural	7.6	9.49	1.0144	9.63
SR160 Rte, Clark Co. suburban	262.9	328.36	1.0144	333.09
SR160 Rte, Clark Co. urban	2061.8	2663.85	1.0414	2774.13
SR93 Southern Rte, Clark Co. rural	6.6	8.53	1.0414	8.88
SR93, Southern Rte, Clark Co. suburban	408	527.14	1.0414	548.96
SR93, Southern Rte, Clark Co. urban	2649	3422.51	1.0414	3564.20
Southern Rte from Henderson, Clark Co. rural	29.2	37.73	1.0414	39.29
Southern Rte from Henderson, Clark Co, suburban	495.1	639.67	1.0414	666.15
Southern Rte from Henderson, Clark Co. urban	2939.9	3798.35	1.0414	3955.60

[a]The Census Bureau correction factors for Nevada are rural and suburban = 1.249; urban = 1.292

Table 6 shows the route segments and population densities input into RADTRAN. Tables 5 and 6 show a few route segments that are designated “suburban” but would be “rural” by the WebTRAGIS designations of Table 4: suburban Nye County on the southern route, suburban Elko County on the northern route, and suburban Clark County on the SR160 route. These segments were designated “suburban” because Nevada Department of Taxation (2007) shows them as towns, not rural areas. The only difference is that the shielding factor for suburban route segments is 87% instead of 100%. The only segment where the “suburban” designation might be questioned is the suburban Elko County segment, but since this is only a half mile long, the difference from the rural designation would be negligible.

Table 6. Route-specific parameter input into RADTRAN

Route Segment	Segment Length (km)	Persons/km^2
Southern Route: Clark County rural	130	10.01
Southern Route: Clark County suburban	22.5	422.03
Southern Route: Clark County urban	7.0	3951.30
Southern Route: Nye County rural	136	6.85
Southern Route: Nye County suburban	16	330.59
Southern Route: Nye County urban	0.2	3264.83
Northern route: Elko County rural	94.8	3.22
Northern route: Elko County suburban	0.5	115.57
Northern route: White Pine County rural	130	4.11
Northern route: White Pine County suburban	5.7	584.19
Northern route: White Pine County urban	0.5	2346.80
Northern route: Nye County rural	223	0.89
CA127 via Amargosa rural	24.4	2.54
CA 127 via Pahrump rural	66.9	3.83
CA 127 via Pahrump suburban	13.4	380.05
SR160 Clark Co. rural	76	9.63
SR160 Clark Co. suburban	9.5	333.09
SR160 Clark Co. urban	0.4	2774.13
SR 93 Clark Co. rural	93.4	6.6
SR 93 Clark Co. suburban	6.9	408
SR 93 Clark Co. urban	2.6	2649
Henderson to LV Clark Co. rural	2.9	29.2
Henderson to LV Clark Co suburban	7.6	495.1
Henderson to LV Clark Co. urbanl	14.7	2939.9

3.3 Specific Scenarios

Several specific exposure scenarios were analyzed; they are summarized in Table 7. Each scenario is analyzed as a separate stop, so that the analysis can be applied to any route.

Table 7. Potential exposure scenarios for individuals.

Scenario	Scenario Description	Distance from Source	Exposure time
1	Truck travels slowly past an individual on the sidewalk	1.0 m	15 sec.
2	Individual parked next to a LLW truck at a stoplight	1.0 m	1 min.
3	Individual next to a refueling LLW truck	1.0 m	0.5 hour
4	Individual next to a window looking out on a curb where a LLW truck is parked	1.0 m	1 hour
5	Individual parked next to a LLW truck overnight	1.0 m	8 hours

Table 7 describes conservative scenarios. Scenarios 3 and 4 are particularly conservative. A person refueling his or her car is not going to be as close as one meter to the truck cargo for half an hour; the average truck refueling time is 20 minutes (Griego, et al, 1996) and the average car refueling time is less (Scenario 3). Essentially all sidewalks in the U.S. are more than a meter wide, and being inside a building puts the receptor even further from the truck (Scenario 4). Trucks of this size typically travel about 800 km (about 500 miles) before stopping for refueling (DOE, 2002), so that the only routes in Nevada (in this study) on which there might be a refueling stop or overnight rest stop would be the northern (254 km; 158 mi) and southern (312 km, 194 mi) routes.

3.4 Accident Inputs

The trucks in this study could be involved in two types of accidents: accidents in which there is no release of radioactive material and accidents in which there is such a release. Release of radioactive materials from a vehicle in an accident depends on the severity of that accident. Since the number of accidents releasing radioactive material is too small to be statistically significant, such accidents are described in terms of risk. The risk triplet (Kaplan and Garrick, 1981) is:

- What can happen (the scenario)
- How likely is it (the probability)
- What if it does happen (the consequence)

For computational purposes, risk is calculated as the product of probability and consequence for a particular scenario. For radioactive materials transportation, the scenario is an accident of a particular severity, the probability is the product of the probability of an accident happening at all and the conditional probability of an accident of particular severity, and the consequence is the release of radioactive material associated with that accident. The universe of accidents includes all of the accidents that could happen, including the most probable accident in which there is no release.

Two studies (Fischer, et al, 1987 and Sprung et al, 2000) have thoroughly investigated the types and severities of accidents that Type B[1] casks and packages could have. Unfortunately, no similar studies have been done for Type A transportation packages. NUREG 0170 (USNRC, 1977), using engineering judgment, constructed a table of conditional probabilities and associated release fractions for Type A packages (Table 8). The release fractions were based on the regulatory definition of Type A packaging in 10 CFR Part 71 Appendix A: that 100% of

[1] Type B packagings and casks are designed to withstand a series of accidents (described in 10 CFR Part 71 Subpart E) as well as the rigors of normal, accident-free transportation. Type A packagings are not designed to withstand accidents.

the contents of a Type A package could be released in an accident with no harm to health or environment.

Table 8. **Conditional probabilities and release fractions from tables 5-3 and 5-8 of USNRC (1977)**

Conditional probability	Fraction of contents released
.55	0
.36	.01
.07	.1
.016	1
2.8×10^{-4}	1
1.1×10^{-4}	1
8.5×10^{-5}	1
1.5×10^{-5}	1

The releases in Table 8 are excessively conservative when applied to the shipments under consideration, and when one assumes that everything released can be dispersed downwind (only dispersed material will deliver a dose to a member of the public). The conditional probabilities are also unrealistically conservative. A more realistic, but still conservative, set of conditional probabilities and release fractions was constructed for this study using engineering judgment and is shown in Table 9. Scrap metal in shipments POL08131, POL08132, POL08133, POL08134 is not dispersible. Releases from all other shipments are assumed to be completely dispersible; 5% of the released dispersible material is assumed to be respirable (maximum particle diameter 10 micrometers).

Table 9. **Conditional probabilities and release fractions – this study**

Conditional probability	Fraction of contents released
0.9	0
0.05	0.05
0.03	0.1
0.02	0.2

Risk is the product of probability and consequence. The total risk from an accident is the sum of all conditional probability-consequence products. The total risk for Table 8 is 0.028, while the total risk for Table 9 is 0.0095, or 34% of the total Table 8 risk. Other RADTRAN input parameters for calculating accident risks are shown in Table 10.

Table 10. Parameters used in calculating accident doses and dose risks.

Parameter	Parameter Value	Comments and Reference
Package		
Package type	Type A	
Radionuclide inventory for each shipment	See Table 3	
Physical chemical group	Particulate	Determines dispersibility
Deposition velocity	0.01 m/sec	
Traffic accident rate	3.6×10^{-6}/vehicle-km	Nevada data, State Transportation Statistics, U.S. Bureau of Transportation Statistics, 2005, Table 2-1 (www.bts.gov)
Traffic fatality rate	1.27×10^{-8}/vehicle-km	
Population densities (persons per km^2)		
Rural	See Table 5	Population density is assumed to be constant under the entire plume
Suburban	See Table 5	
Urban	See Table 5; includes non-residents	
Atmospheric dispersion		
Aerosolized fraction	1.0	
Respirable fraction	0.05	
Average dispersibility	National average weather	
Worst-case dispersibility	Pasquill Stability E	
No-release accident		
Exposure time	8 hours	
Distance to population	30 m. to 800 m.	Like incident-free distance
Population densities	See Table 5	
Shielding	See Table 1	

4.0 RESULTS

4.1 Routine, Incident-free Transportation

Radiation doses from routine transportation are external doses, and are directly proportional to the external dose rate from the shipment (the TI) and the length of time any receptor is exposed. Dose from a moving vehicle is therefore inversely proportional to the speed of the vehicle. Collective (population) dose also depends on the number of people exposed.[2]

For each of the routes considered the following per-shipment doses are presented:

- Collective dose to the population along the route from a moving shipment ("off-link dose")
- Collective dose to occupants of vehicles that share the route ("on-link dose")
- Collective dose to the two truck crew.
- Average dose along the route
- Maximum doses to certain receptors: these are independent of the route.

Only one graph is shown for each route, since the relative doses are the same for a route. All doses are in millirem (mrem) or person-mrem: one mrem = 0.01 mSv. For comparison, background in Nevada is about 400 mrem/year.

Five routes were analyzed:

- Southern Route: entering NV from St. George UT on SR160 and I-15.
- Northern Route: entering at Winnemucca, S on US6 through Tonapah
- From CA 127 through Amargosa Springs
- From CA 127 through Pahrump
- SR160 from Las Vegas
- SR93 from Laughlin (Henderson to Las Vegas analyzed separately)

4.1.1 Southern Route: NV-160 (start point at entry to Nevada)

Table 11a. Collective doses to residents along the southern route (person-mrem)

SHIPMENT	CLARK-RURAL	CLARK-SUBURBAN	CLARK-URBAN	NYE-RURAL	NYE-SUBURBAN	NYE-URBAN
INL08001	4.16E-06	2.64E-05	1.72E-06	2.98E-06	1.47E-05	4.05E-08
INL08002_3	7.32E-04	4.65E-03	3.01E-04	5.24E-04	2.59E-03	7.12E-06
NFL08041_2	4.16E-05	2.64E-04	1.72E-05	2.98E-05	1.47E-04	4.05E-07
NFL08043	4.16E-03	2.64E-02	1.72E-03	2.98E-03	1.47E-02	4.05E-05
POLO8131_3_4	4.16E-05	2.64E-04	1.72E-05	2.98E-05	1.47E-04	4.05E-07
POLO8132	4.16E-04	2.64E-03	1.72E-04	2.98E-04	1.47E-03	4.05E-06
PORTLP1002	4.16E-04	2.64E-03	1.72E-04	2.98E-04	1.47E-03	4.05E-06
NFS100000302	8.60E-03	5.46E-02	3.53E-03	6.16E-03	3.05E-02	8.34E-05
NFS100000201	3.07E-02	1.95E-01	1.26E-02	2.20E-02	1.09E-01	2.98E-04
REGULATORY TI	4.42E-02	2.81E-01	1.81E-02	3.17E-02	1.57E-01	4.29E-04

[2] The USNRC has recently cautioned that collective dose is meaningful only in comparing different exposure situations, and not as an absolute value.

Table 11b. Collective doses to occupants of vehicles sharing the southern route (person-mrem)

SHIPMENT	CLARK-RURAL	CLARK-SUBURBAN	CLARK-URBAN	NYE-RURAL	NYE-SUBURBAN	NYE-URBAN
INL08001	6.11E-04	3.58E-05	3.32E-05	2.60E-05	6.43E-06	6.02E-07
INL08002_3	1.07E-01	6.29E-03	5.83E-03	4.57E-01	1.13E-03	1.06E-04
NFL08041_2	6.11E-03	3.58E-04	3.32E-04	2.60E-02	6.43E-05	6.02E-06
NFL08043	6.11E-01	3.58E-02	3.32E-02	2.60E+00	6.43E-03	6.02E-04
POLO8131_3_4	6.11E-03	3.58E-04	3.32E-04	2.60E-02	6.43E-05	6.02E-06
POLO8132	6.11E-02	3.58E-03	3.32E-03	2.60E-01	6.43E-04	6.02E-05
PORTLP1002	6.11E-02	3.58E-03	3.32E-03	2.60E-01	6.43E-04	6.02E-05
NFS100000302	1.26E+00	7.39E-02	6.83E-02	5.38E+00	1.33E-02	1.24E-03
NFS100000201	4.50E+00	2.64E-01	2.44E-01	1.92E+01	4.74E-02	4.44E-03

Table 11c. Collective dose to two truck crew (person-mrem): southern route

SHIPMENT	CLARK-RURAL	CLARK-SUBURBAN	CLARK-URBAN	NYE-RURAL	NYE-SUBURBAN	NYE-URBAN
INL08001	2.06E-03	3.57E-04	1.20E-04	2.16E-03	2.54E-04	3.42E-06
INL08002_3	4.08E-01	7.07E-02	2.37E-02	4.27E-01	5.03E-02	6.76E-04
NFL08041_2	2.06E-02	3.57E-03	1.20E-03	2.16E-02	2.54E-03	3.42E-05
NFL08043	2.06E+00	3.57E-01	1.20E-01	2.16E+00	2.54E-01	3.42E-03
POLO8131_3_4	2.06E-02	3.57E-03	1.20E-03	2.16E-02	2.54E-03	3.42E-05
POLO8132	2.06E-01	3.57E-02	1.20E-02	2.16E-01	2.54E-02	3.42E-04
PORTLP1002	2.06E-01	3.57E-02	1.20E-02	2.16E-01	2.54E-02	3.42E-04
NFS100000302	4.18E+00	7.24E-01	3.22E-01	5.82E+00	6.86E-01	9.24E-03
NFS100000201	1.49E+01	2.58E+00	1.15E+00	2.08E+01	2.45E+00	3.30E-02

Table 11d. Average dose to a resident along the southern route (mrem)

SHIPMENT	CLARK-RURAL	CLARK-SUBURBAN	CLARK-URBAN	NYE-RURAL	NYE-SUBURBAN	NYE-URBAN
INL08001	3.20E-09	2.78E-09	6.22E-11	3.20E-09	2.78E-09	6.20E-11
INL08002_3	5.63E-07	4.90E-07	1.09E-08	5.63E-07	4.90E-07	1.09E-08
NFL08041_2	3.20E-08	2.78E-08	6.22E-10	3.20E-08	2.78E-08	6.20E-10
NFL08043	3.20E-06	2.78E-06	6.22E-08	3.20E-06	2.78E-06	6.20E-08
POLO8131_3_4	3.20E-08	2.78E-08	6.22E-10	3.20E-08	2.78E-08	6.20E-10
POLO8132	3.20E-07	2.78E-07	6.22E-09	3.20E-07	2.78E-07	6.20E-09
PORTLP1002	3.20E-07	2.78E-07	6.22E-09	3.20E-07	2.78E-07	6.20E-09
NFS100000302	6.61E-06	5.75E-06	1.28E-07	6.62E-06	5.77E-06	1.28E-07
NFS100000201	2.36E-05	2.05E-05	4.56E-07	2.36E-05	2.06E-05	4.56E-07

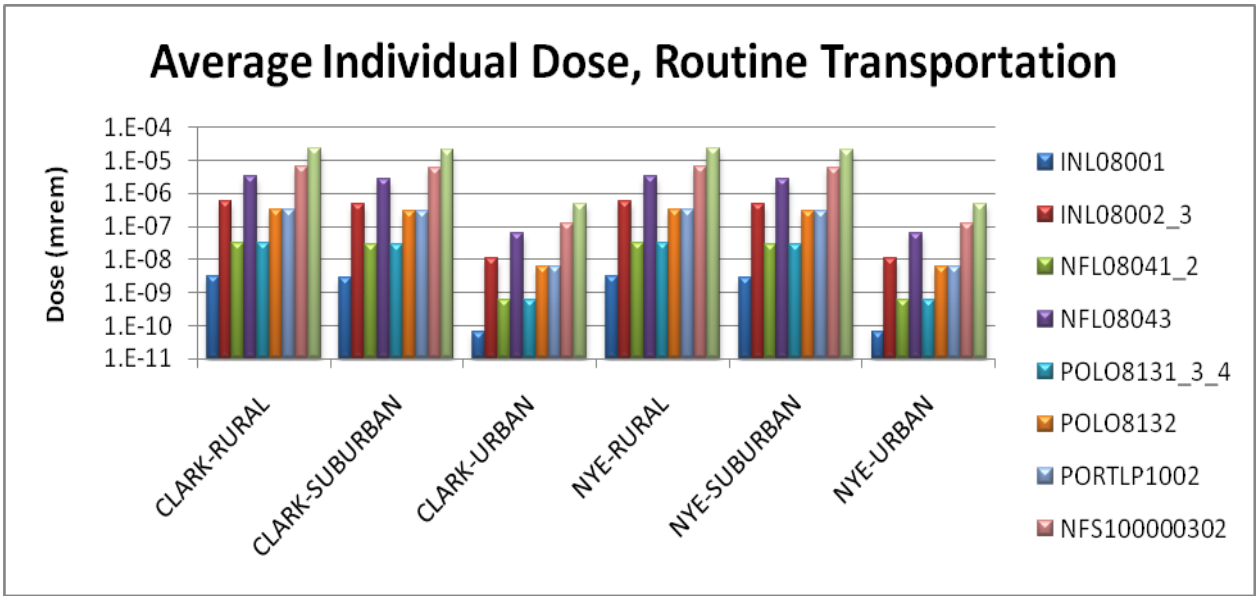

Figure 3. Average individual dose, southern route

4.1.2 Northern Route: I-80, US-93, US-6, US-95 (start point at entry to Nevada)

Table 12a. Collective doses to residents along the northern route (person-mrem)

SHIPMENT	ELKO RURAL	ELKO SUBURBAN	WHITE PINE RURAL	WHITE PINE SUBURBAN	WHITE PINE URBAN	NYE RURAL
INL08001	9.77E-07	1.61E-07	1.71E-06	9.28E-06	7.28E-08	6.34E-07
INL08002_3	1.72E-04	2.83E-05	3.00E-04	1.63E-03	1.28E-05	1.11E-04
NFL08041_2	9.77E-06	1.61E-06	1.71E-05	9.28E-05	7.28E-07	6.34E-06
NFL08043	9.77E-04	1.61E-04	1.71E-03	9.28E-03	7.28E-05	6.34E-04
POLO8131_3_4	9.77E-06	1.61E-06	1.71E-05	9.28E-05	7.28E-07	6.34E-06
POLO8132	9.77E-05	1.61E-05	1.71E-04	9.28E-04	7.28E-06	6.34E-05
PORTLP1002	9.77E-05	1.61E-05	1.71E-04	9.28E-04	7.28E-06	6.34E-05
NFS100000302	2.02E-03	3.33E-04	3.53E-03	1.91E-02	1.50E-04	1.31E-03
NFS100000201	7.20E-03	1.19E-03	1.26E-02	6.83E-02	5.36E-04	4.67E-03
REGULATORY TI	1.04E-02	1.71E-03	1.81E-02	1.69E-02	1.11E-03	3.14E-01

Table 12b. Collective doses to occupants of vehicles sharing the northern route (person-mrem)

SHIPMENT	ELKO RURAL	ELKO SUBURBAN	WHITE PINE RURAL	WHITE PINE SUBURBAN	WHITE PINE URBAN	NYE RURAL
INL08001	1.81E-05	2.01E-07	2.48E-05	2.29E-06	1.51E-06	4.26E-05
INL08002_3	3.19E-03	3.53E-05	4.36E-03	4.03E-04	2.65E-04	7.48E-03
NFL08041_2	1.81E-04	2.01E-06	2.48E-04	2.29E-05	1.51E-05	4.26E-04
NFL08043	1.81E-02	2.01E-04	2.48E-02	2.29E-03	1.51E-03	4.26E-02
POLO8131_3_4	1.81E-04	2.01E-06	2.48E-04	2.29E-05	1.51E-05	4.26E-04
POLO8132	1.81E-03	2.01E-05	2.48E-03	2.29E-04	1.51E-04	4.26E-03
PORTLP1002	1.81E-03	2.01E-05	2.48E-03	2.29E-04	1.51E-04	4.26E-03
NFS100000302	3.75E-02	4.14E-04	5.12E-02	4.73E-03	3.11E-03	8.79E-02
NFS100000201	1.34E-01	1.48E-03	1.83E-01	1.69E-02	1.11E-02	3.14E-01

Table 12c. Collective dose to two truck crew (person-mrem): northern route

SHIPMENT	ELKO RURAL	ELKO SUBURBAN	WHITE PINE RURAL	WHITE PINE SUBURBAN	WHITE PINE URBAN	NYE RURAL
INL08001	1.51E-03	7.94E-06	2.06E-03	9.05E-05	8.54E-06	3.53E-03
INL08002_3	2.98E-01	1.57E-03	4.08E-01	1.79E-02	1.69E-03	6.99E-01
NFL08041_2	1.51E-02	7.94E-05	2.06E-02	9.05E-04	8.54E-05	3.53E-02
NFL08043	1.51E+00	7.94E-03	2.06E+00	9.05E-02	8.54E-03	3.53E+00
POLO8131_3_4	1.51E-02	7.94E-05	2.06E-02	9.05E-04	8.54E-05	3.53E-02
POLO8132	1.51E-01	7.94E-04	2.06E-01	9.05E-03	8.54E-04	3.53E-01
PORTLP1002	1.51E-01	7.94E-04	2.06E-01	9.05E-03	8.54E-04	3.53E-01
NFS100000302	4.06E+00	2.14E-02	5.57E+00	2.44E-01	2.31E-02	7.16E+00
NFS100000201	1.45E+01	7.66E-02	1.99E+01	8.73E-01	8.24E-02	2.55E+01

Table 12d. Average dose to a resident along the northern route (mrem)

SHIPMENT	ELKO RURAL	ELKO SUBURBAN	WHITE PINE RURAL	WHITE PINE SUBURBAN	WHITE PINE URBAN	NYE RURAL
INL08001	3.20E-09	1.04E-09	3.21E-09	2.79E-09	6.20E-11	3.20E-09
INL08002_3	5.63E-07	1.82E-07	5.62E-07	4.89E-07	1.09E-08	5.60E-07
NFL08041_2	3.20E-08	1.04E-08	3.21E-08	2.79E-08	6.20E-10	3.20E-08
NFL08043	3.20E-06	1.04E-06	3.21E-06	2.79E-06	6.20E-08	3.20E-06
POLO8131_3_4	3.20E-08	1.04E-08	3.21E-08	2.79E-08	6.20E-10	3.20E-08
POLO8132	3.20E-07	1.04E-07	3.21E-07	2.79E-07	6.20E-09	3.20E-07
PORTLP1002	3.20E-07	1.04E-07	3.21E-07	2.79E-07	6.20E-09	3.20E-07
NFS100000302	6.60E-06	2.14E-06	6.61E-06	5.74E-06	1.28E-07	6.60E-06
NFS100000201	2.36E-05	7.65E-06	2.36E-05	2.05E-05	4.57E-07	2.36E-05

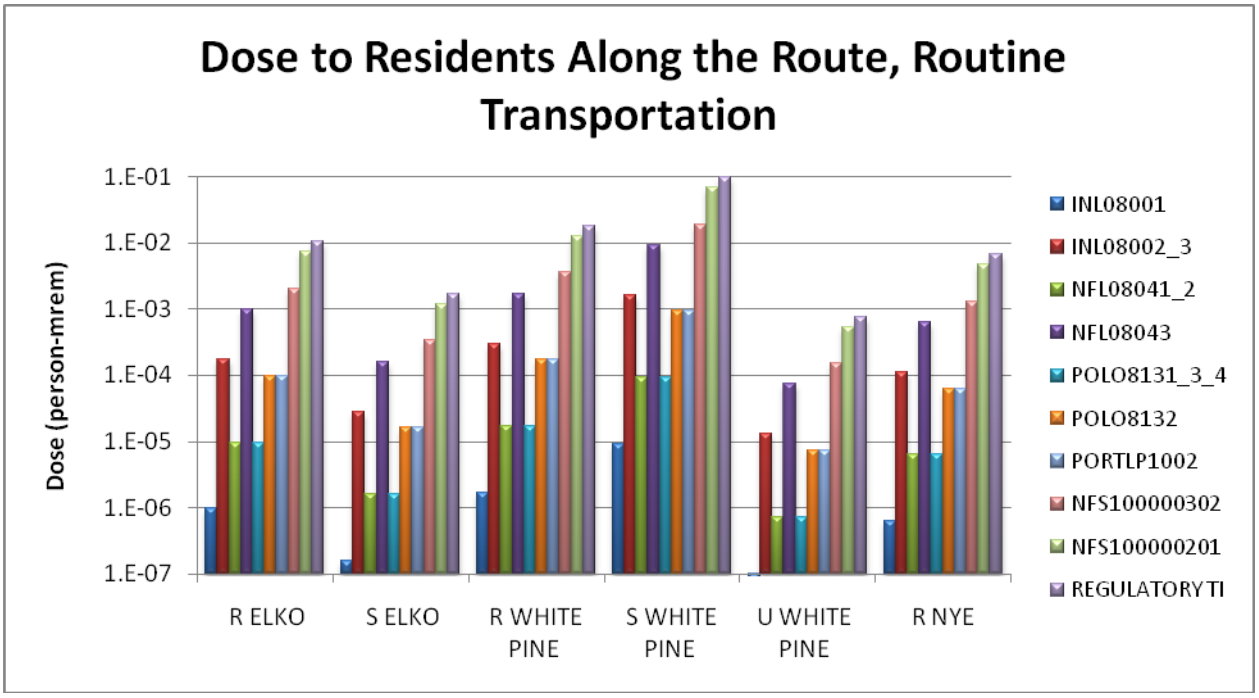

Figure 4. Dose to residents along the route, northern route.

4.1.3 CA-127 through Armargosa Valley (start point at entry to Nevada), CA-127 through Pahrump (start point at entry to Nevada), and SR160 route from Las Vegas.

Table 13a. Collective dose to persons along the CA127 and SR160 routes (person-mrem)

	CA127			SR160 R		
	AMARGOSA RURAL (NYE)	PAHRUMP RURAL (NYE)	PAHRUMP SUBURBAN (NYE)	SR160 RURAL	SR160 SUBURBAN	SR160 URBAN
INL08001	1.98E-07	8.20E-07	1.42E-05	3.01E-06	1.16E-05	3.66E-06
INL08002_3	3.49E-05	1.44E-04	2.49E-03	5.29E-04	2.04E-03	6.43E-04
NFL08041_2	1.98E-06	8.20E-06	1.42E-04	3.01E-05	1.16E-04	3.66E-05
NFL08043	1.98E-04	8.20E-04	1.42E-02	3.01E-03	1.16E-02	3.66E-03
POLO8131_3_4	1.98E-06	8.20E-06	1.42E-04	3.01E-05	1.16E-04	3.66E-05
POLO8132	1.98E-05	8.20E-05	1.42E-03	3.01E-04	1.16E-03	3.66E-04
PORTLP1002	1.98E-05	8.20E-05	1.42E-03	3.01E-04	1.16E-03	3.66E-04
NFS100000302	4.09E-04	1.69E-03	2.91E-02	6.22E-03	2.39E-02	7.56E-03
NFS100000201	1.46E-03	6.04E-03	1.04E-01	2.22E-02	8.53E-02	2.70E-02
REGULATORY TI	2.10E-03	8.70E-03	1.50E-01	3.20E-02	1.23E-01	3.89E-02

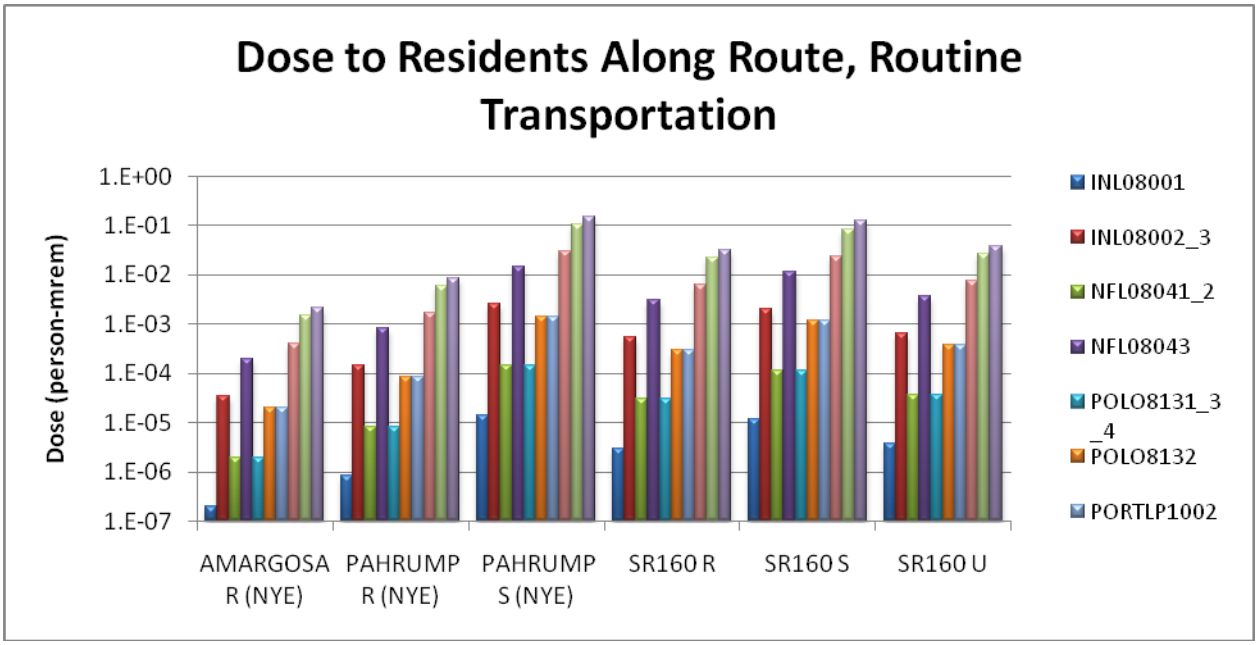

Figure 5. Dose to residents along the route: CA127 and SR160 routes.

Table 13b. Collective dose to occupants of vehicles sharing CA127 and SR160 routes (person-mrem)

	CA127			SR160 R		
	AMARGOSA RURAL (NYE)	**PAHRUMP RURAL (NYE)**	**AMARGOSA RURAL (NYE)**	**PAHRUMP RURAL (NYE)**	**AMARGOSA RURAL (NYE)**	**PAHRUMP RURAL (NYE)**
INL08001	4.67E-06	1.28E-05	5.38E-06	1.15E-04	4.84E-05	6.13E-06
INL08002_3	8.20E-04	2.25E-03	9.45E-04	2.01E-02	8.50E-03	1.08E-03
NFL08041_2	4.67E-05	1.28E-04	5.38E-05	1.15E-03	4.84E-04	6.13E-05
NFL08043	4.67E-03	1.28E-02	5.38E-03	1.15E-01	4.84E-02	6.13E-03
POLO8131_3_4	4.67E-05	1.28E-04	5.38E-05	1.15E-03	4.84E-04	6.13E-05
POLO8132	4.67E-04	1.28E-03	5.38E-04	1.15E-02	4.84E-03	6.13E-04
PORTLP1002	4.67E-04	1.28E-03	5.38E-04	1.15E-02	4.84E-03	6.13E-04
NFS100000302	9.63E-03	2.64E-02	1.11E-02	2.36E-01	9.97E-02	1.27E-02
NFS100000201	3.44E-02	9.43E-02	3.96E-02	8.44E-01	3.56E-01	4.52E-02
REGULATORY TI	4.67E-06	1.28E-05	5.38E-06	1.15E-04	4.84E-05	6.13E-06

Table 13c. Collective dose to two truck crew (person-mrem): CA127 and SR160 routes

	CA127			SR160 R		
	AMARGOSA RURAL (NYE)	**PAHRUMP RURAL (NYE)**	**AMARGOSA RURAL (NYE)**	**PAHRUMP RURAL (NYE)**	**AMARGOSA RURAL (NYE)**	**PAHRUMP RURAL (NYE)**
INL08001	3.87E-04	1.06E-03	2.12E-04	1.30E-03	1.62E-04	7.40E-06
INL08002_3	7.67E-02	2.10E-01	4.20E-02	2.57E-01	3.21E-02	1.46E-03
NFL08041_2	3.87E-03	1.06E-02	2.12E-03	1.30E-02	1.62E-03	7.40E-05
NFL08043	3.87E-01	1.06E+00	2.12E-01	1.30E+00	1.62E-01	7.40E-03
POLO8131_3_4	3.87E-03	1.06E-02	2.12E-03	1.30E-02	1.62E-03	7.40E-05
POLO8132	3.87E-02	1.06E-01	2.12E-02	1.30E-01	1.62E-02	7.40E-04
PORTLP1002	3.87E-02	1.06E-01	2.12E-02	1.30E-01	1.62E-02	7.40E-04
NFS100000302	1.05E+00	2.86E+00	5.74E-01	3.50E+00	4.40E-01	2.00E-02
NFS100000201	3.74E+00	1.02E+01	2.05E+00	1.25E+01	1.57E+00	7.14E-02
REGULATORY TI	3.87E-04	1.06E-03	2.12E-04	1.30E-03	1.62E-04	7.40E-06

Table 13d. Average individual dose (mrem): CA127 and SR160 routes

	CA127			SR160 R		
	AMARGOSA RURAL (NYE)	**PAHRUMP RURAL (NYE)**	**AMARGOSA RURAL (NYE)**	**PAHRUMP RURAL (NYE)**	**AMARGOSA RURAL (NYE)**	**PAHRUMP RURAL (NYE)**
INL08001	3.22E-09	3.20E-09	2.79E-09	4.11E-09	3.67E-09	3.30E-09
INL08002_3	5.68E-07	5.62E-07	4.89E-07	7.23E-07	6.45E-07	5.79E-07
NFL08041_2	3.22E-08	3.20E-08	2.79E-08	4.11E-08	3.67E-08	3.30E-08
NFL08043	3.22E-06	3.20E-06	2.79E-06	4.11E-06	3.67E-06	3.30E-06
POLO8131_3_4	3.22E-08	3.20E-08	2.79E-08	4.11E-08	3.67E-08	3.30E-08
POLO8132	3.22E-07	3.20E-07	2.79E-07	4.11E-07	3.67E-07	3.30E-07
PORTLP1002	3.22E-07	3.20E-07	2.79E-07	4.11E-07	3.67E-07	3.30E-07
NFS100000302	6.65E-06	6.60E-06	5.72E-06	8.49E-06	7.55E-06	6.81E-06
NFS100000201	2.38E-05	2.36E-05	2.04E-05	3.03E-05	2.70E-05	2.43E-05
REGULATORY TI	3.22E-09	3.20E-09	2.79E-09	4.11E-09	3.67E-09	3.30E-09

4.1.4 SR93 from Laughlin, NV, US 95 .

Table 14a. Collective dose to persons along SR93 (person-mrem)

	SR93R	SR93S	SR93U	HENDERSON R	HENDERSON S	HENDERSON U
INL08001	2.66E-06	1.14E-05	5.75E-07	3.93E-07	1.52E-05	3.90E-06
INL08002_3	4.68E-04	2.01E-03	1.01E-04	6.92E-05	2.68E-03	6.86E-04
NFL08041_2	2.66E-05	1.14E-04	5.75E-06	3.93E-06	1.52E-04	3.90E-05
NFL08043	2.66E-03	1.14E-02	5.75E-04	3.93E-04	1.52E-02	3.90E-03
POLO8131_3_4	2.66E-05	1.14E-04	5.75E-06	3.93E-06	1.52E-04	3.90E-05
POLO8132	2.66E-04	1.14E-03	5.75E-05	3.93E-05	1.52E-03	3.90E-04
PORTLP1002	2.66E-04	1.14E-03	5.75E-05	3.93E-05	1.52E-03	3.90E-04
NFS100000302	5.50E-03	2.36E-02	1.18E-03	8.12E-04	3.16E-02	8.03E-03
NFS100000201	1.96E-02	8.42E-02	4.21E-03	2.90E-03	1.13E-01	2.87E-02
REGULATORY TI	2.83E-02	1.21E-01	6.07E-03	4.18E-03	1.62E-01	4.13E-02

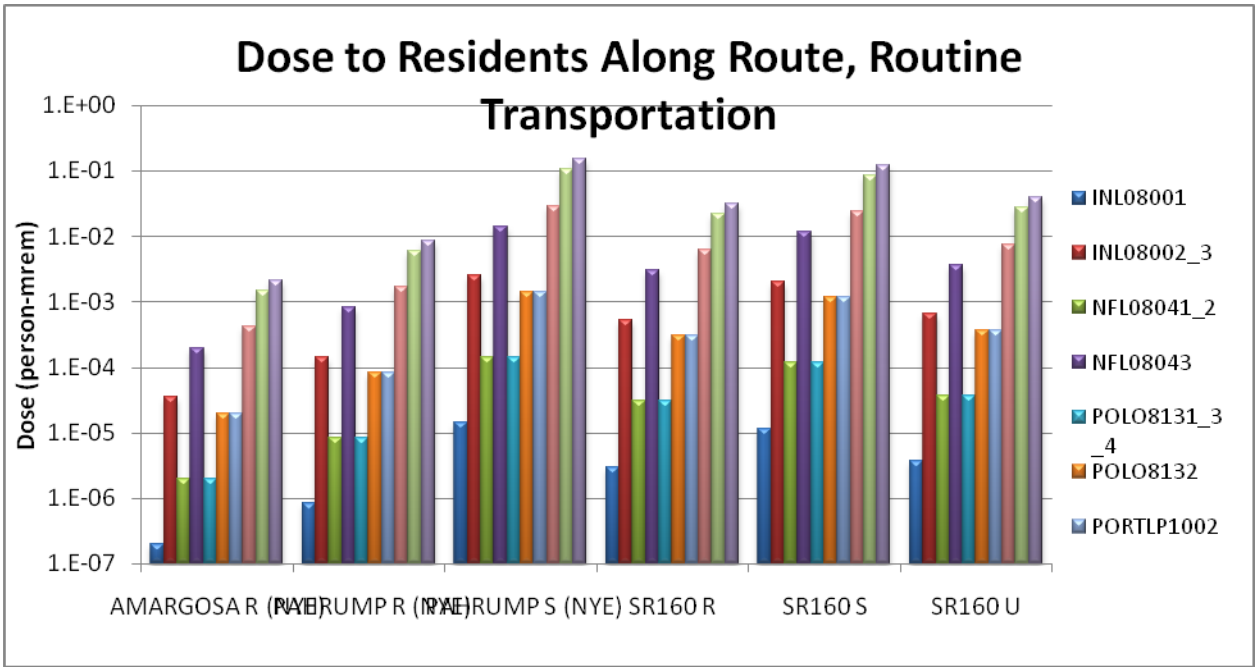

Figure 6. Dose to residents along SR93.

Table 14b. Collective dose to occupants of vehicles sharing SR93 (person-mrem)

	SR93R	SR93S	SR93U	HENDERSON R	HENDERSON S	HENDERSON U
INL08001	4.39E-05	1.27E-05	1.23E-05	1.58E-06	1.40E-05	8.19E-05
INL08002_3	7.68E-04	2.22E-04	2.15E-04	2.77E-05	2.45E-04	1.43E-03
NFL08041_2	4.39E-04	1.27E-04	1.23E-04	1.58E-03	1.40E-04	8.19E-04
NFL08043	4.39E-02	1.27E-02	1.23E-02	1.58E-01	1.40E-02	8.19E-02
POLO8131_3_4	4.39E-04	1.27E-04	1.23E-04	1.58E-03	1.40E-04	8.19E-04
POLO8132	4.39E-03	1.27E-03	1.23E-03	1.58E-02	1.40E-03	8.19E-03
PORTLP1002	4.39E-03	1.27E-03	1.23E-03	1.58E-02	1.40E-03	8.19E-03
NFS100000302	9.05E-02	2.62E-02	2.53E-02	3.27E-01	2.89E-02	1.69E-01
NFS100000201	3.23E-01	9.37E-02	9.04E-02	1.17E+00	1.03E-01	6.04E-01

Table 14c. Collective dose to two truck crew (person-mrem): SR93

	SR93R	SR93S	SR93U	HENDERSON R	HENDERSON S	HENDERSON U
INL08001	1.48E-03	1.18E-04	4.44E-05	4.95E-05	1.30E-04	2.72E-04
INL08002_3	2.93E-01	2.34E-02	8.79E-03	9.80E-03	2.57E-02	5.39E-02
NFL08041_2	1.48E-02	1.18E-03	4.44E-04	4.95E-04	1.30E-03	2.72E-03
NFL08043	1.48E+00	1.18E-01	4.44E-02	4.95E-02	1.30E-01	2.72E-01
POLO8131_3_4	1.48E-02	1.18E-03	4.44E-04	4.95E-04	1.30E-03	2.72E-03
POLO8132	1.48E-01	1.18E-02	4.44E-03	4.95E-03	1.30E-02	2.72E-02
PORTLP1002	1.48E-01	1.18E-02	4.44E-03	4.95E-03	1.30E-02	2.72E-02
NFS100000302	3.00E+00	2.39E-01	1.19E-01	1.33E-01	3.51E-01	7.35E-01
NFS100000201	1.07E+01	8.53E-01	4.26E-01	4.77E-01	1.25E+00	2.62E+00

Table 14d. Average individual dose along SR93

	SR93R	SR93S	SR93U	HENDERSON R	HENDERSON S	HENDERSON U
INL08001	3.21E-09	3.01E-09	6.21E-11	3.45E-09	3.00E-09	6.70E-11
INL08002_3	5.64E-07	5.30E-07	1.09E-08	6.06E-07	5.29E-07	1.18E-08
NFL08041_2	3.21E-08	3.01E-08	6.21E-10	3.45E-08	3.00E-08	6.70E-10
NFL08043	3.21E-06	3.01E-06	6.21E-08	3.45E-06	3.00E-06	6.70E-08
POLO8131_3_4	3.21E-08	3.01E-08	6.21E-10	3.45E-08	3.00E-08	6.70E-10
POLO8132	3.21E-07	3.01E-07	6.21E-09	3.45E-07	3.00E-07	6.70E-09
PORTLP1002	3.21E-07	3.01E-07	6.21E-09	3.45E-07	3.00E-07	6.70E-09
NFS100000302	6.63E-06	6.22E-06	1.27E-07	7.13E-06	6.23E-06	1.38E-07
NFS100000201	2.37E-05	2.22E-05	4.55E-07	2.55E-05	2.23E-05	4.93E-07

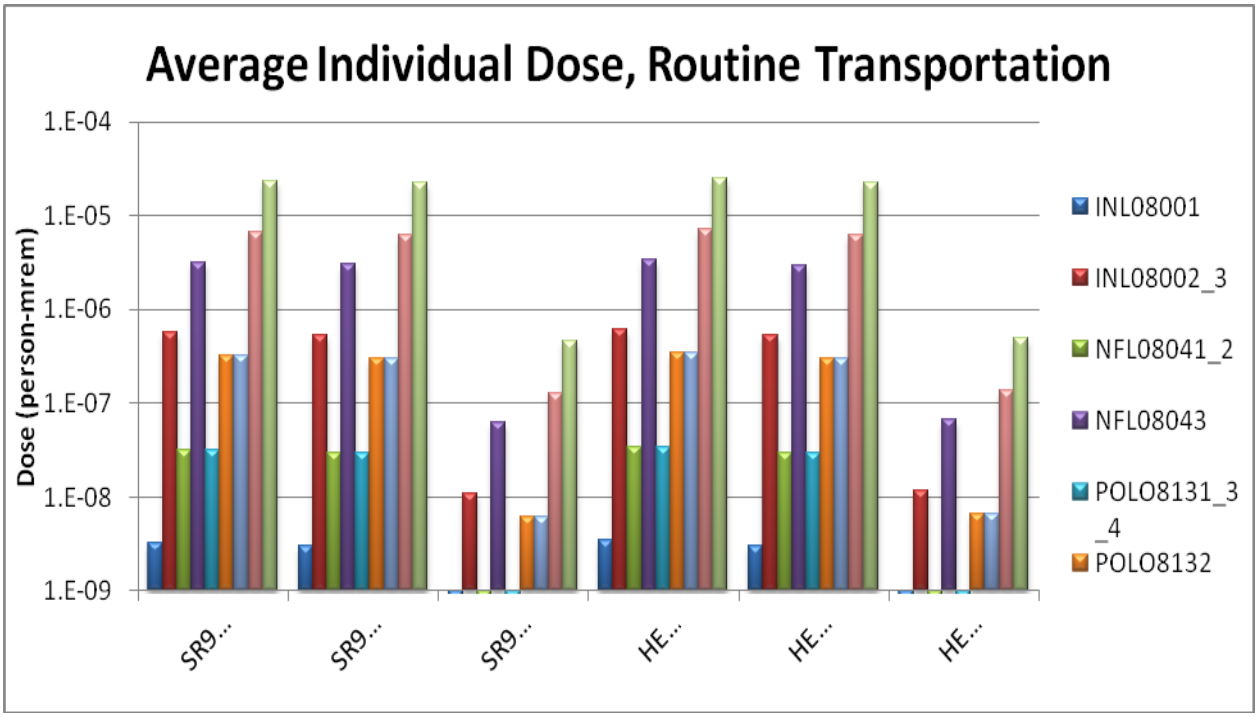

Figure 7. Average individual dose along SR93 (mrem).

4.1.5 Specific Scenarios

Doses to the receptors identified in Table 7 are presented in Table 15 and Figure 8.

Table 15. Doses to individuals in special scenarios (mrem).

	TRAFFIC JAM[a]	THRUTOWN[b]	STOPLIGHT[c]	FUELSTOP[d]	MEAL[e]	REST AREA[f]
INL08001	4.91E-04	7.60E-06	3.10E-05	9.27E-04	1.85E-03	1.48E-02
INL08002	1.01E-01	1.56E-03	6.36E-03	1.90E-01	3.81E-01	3.05E+00
INL08003	1.01E-01	1.56E-03	6.36E-03	1.90E-01	3.81E-01	3.05E+00
NFL08041	2.11E-03	3.26E-05	1.33E-04	3.98E-03	7.96E-03	6.36E-02
NFL08042	2.11E-03	3.26E-05	1.33E-04	3.98E-03	7.96E-03	6.36E-02
NFL08043	2.11E-01	3.26E-03	1.33E-02	3.98E-01	7.96E-01	6.36E+00
POL08131, 32, 34	2.11E-03	3.26E-05	1.33E-04	3.98E-03	7.96E-03	6.36E-02
POL08133	2.11E-02	3.26E-04	1.33E-03	3.98E-02	7.96E-02	6.36E-01
PORTLP0001002	2.02E-02	3.12E-04	1.27E-03	3.80E-02	7.62E-02	6.10E-01
NFS100000000302	5.66E-01	8.74E-03	3.56E-02	1.06E+00	2.13E+00	1.71E+01
NFS100000000201	2.02E+00	3.12E-02	1.27E-01	3.80E+00	7.62E+00	6.10E+01
REGULATORY TI	2.91E+00	4.49E-02	1.83E-01	5.47E+00	1.10E+01	8.78E+01
ANNUAL BACKGROUND	4.00E+02	4.00E+02	4.00E+02	4.00E+02	4.00E+02	4.00E+02

[a] Individual next to a truck in a traffic jam for a half hour (not in table 7).
[b] Truck travels slowly through past an individual on the sidewalk
[c] Individual parked next to a LLW truck at a stoplight
[d] Individual next to a refueling LLW truck

[e]Individual next to a window looking out on a curb where a LLW truck is parked
[f]Individual parked next to a LLW truck overnight

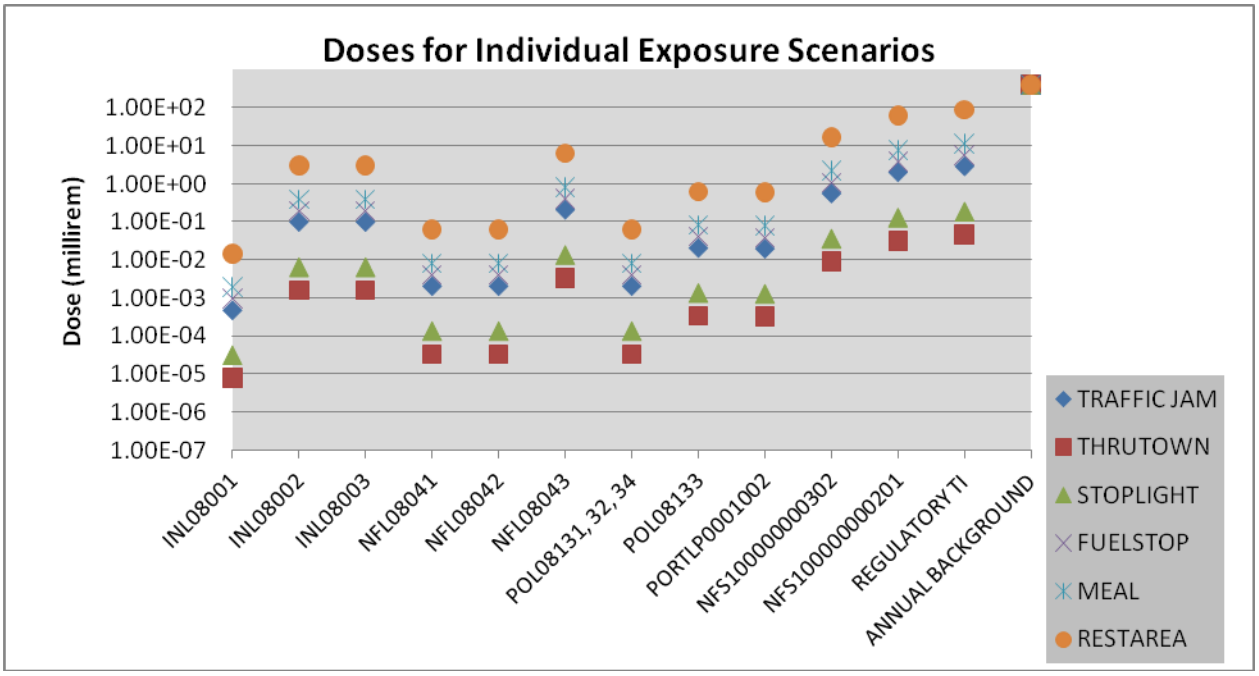

Figure 8. Individual doses for specific scenarios

4.2 Transportation Accidents

4.2.1 No-release Accidents

The most common type of truck traffic accident is one in which there is no release of material. This study estimated that 90% of the accidents that occur will not involve such a release, but will result in the truck immobilized for some period of time. Since the cargo emits ionizing radiation externally, there will be some collective dose to the nearby population. The collective dose (consequence) was calculated by assuming arbitrarily and conservatively that the truck in this type of accident was stranded for eight hours. Since dose is directly proportional to exposure time the resulting doses can be adjusted for any time period.

The probability of one of these shipments having an accident is generally assumed to be the observed accident, 3.6×10^{-6} per vehicle-km for Nevada (Table 10). The probability of routine, incident-free transportation is, by comparison, essentially 1.00 (100%). The conditional probability of a no-release accident is assumed to be 0.9 (90%; Table 9). The net probability that a truck will be in a no-release accident on any particular route segment is

$$P = (3.6 \times 10^{-6}/\text{vehicle-km})*(\text{route segment length (km)})*(0.9)$$

The *risk* from an accident is the product of the net probability and the dose, since the dose is the consequence. In RADTRAN this has historically been called “dose risk” because the units are the units of dose (probability is a unitless number). Dose risk is thus:

Dose risk =P*Dose = (3.6 x 10^{-6}/vehicle-km)*(route segment length (km))*(0.9)*Dose(mrem)

4.2.1.1 Southern Route: NV-160 (start point at entry to Nevada)

Tables 16a and 16b show the collective doses and dose risks, respectively, for a no-release accident, for the southern route. Figure 8 shows the collective doses. This is the only figure included for the no-release accident, because figures for the other routes are very much like this one.

Table 16a. Collective doses from a no-release accident (person-mrem): southern route

SHIPMENT	CLARK-RURAL	CLARK-SUBURBAN	CLARK-URBAN	NYE-RURAL	NYE-SUBURBAN	NYE-URBAN
INL08001	2.87E-05	1.05E-03	2.04E-04	1.97E-05	8.26E-04	1.69E-04
INL08002_3	5.05E-03	1.85E-01	3.59E-02	3.46E-03	1.45E-01	2.97E-02
NFL08041_2	2.87E-04	1.05E-02	2.04E-03	1.97E-04	8.26E-03	1.69E-03
NFL08043	2.87E-02	1.05E+00	2.04E-01	1.97E-02	8.26E-01	1.69E-01
POLO8131_3_4	2.87E-04	1.05E-02	2.04E-03	1.97E-04	8.26E-03	1.69E-03
POLO8132	2.87E-03	1.05E-01	2.04E-02	1.97E-03	8.26E-02	1.69E-02
PORTLP1002	2.87E-03	1.05E-01	2.04E-02	1.97E-03	8.26E-02	1.69E-02
NFS100000302	5.94E-02	2.18E+00	4.20E-01	4.06E-02	1.70E+00	3.47E-01
NFS100000201	2.12E-01	7.77E+00	1.50E+00	1.45E-01	6.08E+00	1.24E+00

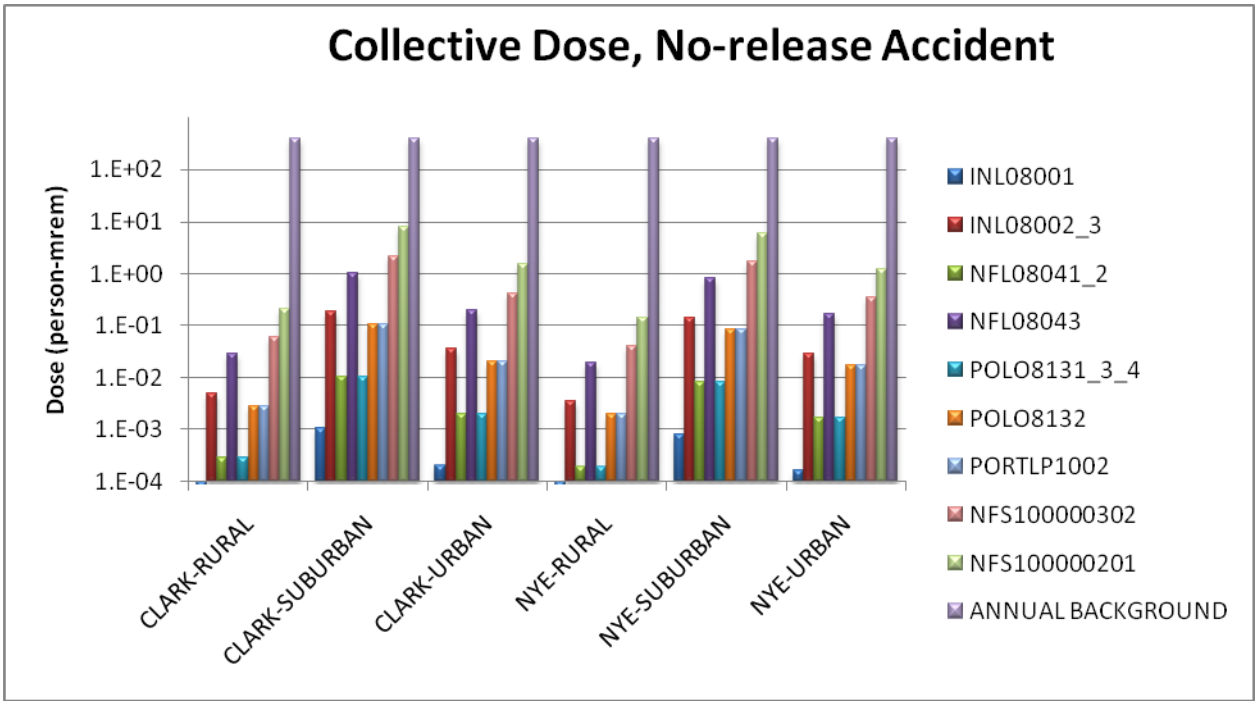

Figure 9. Collective doses from a no-release accident, southern route

Table 16b. Collective dose risks from a no-release accident (person-mrem): southern route

SHIPMENT	CLARK-RURAL	CLARK-SUBURBAN	CLARK-URBAN	NYE-RURAL	NYE-SUBURBAN	NYE-URBAN
INL08001	1.21E-08	7.65E-08	4.63E-09	8.68E-09	4.28E-08	1.10E-10
INL08002_3	2.13E-06	1.35E-05	8.14E-07	1.52E-06	7.52E-06	1.92E-08
NFL08041_2	1.21E-07	7.65E-07	4.63E-08	8.68E-08	4.28E-07	1.10E-09
NFL08043	1.21E-05	7.65E-05	4.63E-06	8.68E-06	4.28E-05	1.10E-07
POLO8131_3_4	1.21E-07	7.65E-07	4.63E-08	8.68E-08	4.28E-07	1.10E-09
POLO8132	1.21E-06	7.65E-06	4.63E-07	8.68E-07	4.28E-06	1.10E-08
PORTLP1002	1.21E-06	7.65E-06	4.63E-07	8.68E-07	4.28E-06	1.10E-08
NFS100000302	2.50E-05	1.59E-04	9.53E-06	1.79E-05	8.83E-05	2.25E-07
NFS100000201	8.93E-05	5.66E-04	3.40E-05	6.39E-05	3.15E-04	8.04E-07

4.2.1.2 Northern Route: I-80, US-93, US-6, US-95 (start point at entry to Nevada)

Tables 17a and 17b show the collective doses and dose risks, respectively, for a no-release accident, for the southern route.

Table 17a. Collective doses from a no-release accident (person-mrem): northern route

SHIPMENT	ELKO RURAL	ELKO SUBURBAN	WHITE PINE RURAL	WHITE PINE SUBURBAN	WHITE PINE URBAN	NYE RURAL
INL08001	9.25E-06	2.89E-04	1.18E-05	1.46E-03	1.21E-04	2.56E-06
INL08002_3	1.62E-03	5.07E-02	2.07E-03	2.56E-01	2.13E-02	4.49E-04
NFL08041_2	9.25E-05	2.89E-03	1.18E-04	1.46E-02	1.21E-03	2.56E-05
NFL08043	9.25E-03	2.89E-01	1.18E-02	1.46E+00	1.21E-01	2.56E-03
POLO8131_3_4	9.25E-05	2.89E-03	1.18E-04	1.46E-02	1.21E-03	2.56E-05
POLO8132	9.25E-04	2.89E-02	1.18E-03	1.46E-01	1.21E-02	2.56E-04
PORTLP1002	9.25E-04	2.89E-02	1.18E-03	1.46E-01	1.21E-02	2.56E-04
NFS100000302	1.91E-02	5.96E-01	2.43E-02	3.02E+00	2.50E-01	5.26E-03
NFS100000201	6.81E-02	2.13E+00	8.69E-02	1.08E+01	8.93E-01	1.88E-02

Table 17b. Collective dose risks from a no-release accident (person-mrem): northern route

SHIPMENT	ELKO RURAL	ELKO SUBURBAN	WHITE PINE RURAL	WHITE PINE SUBURBAN	WHITE PINE URBAN	NYE RURAL
INL08001	2.84E-09	4.68E-10	4.97E-09	2.70E-08	1.96E-10	1.85E-10
INL08002_3	4.98E-07	8.21E-08	8.72E-07	4.73E-06	3.45E-08	3.24E-08
NFL08041_2	2.84E-08	4.68E-09	4.97E-08	2.70E-07	1.96E-09	1.85E-09
NFL08043	2.84E-06	4.68E-07	4.97E-06	2.70E-05	1.96E-07	1.85E-07
POLO8131_3_4	2.84E-08	4.68E-09	4.97E-08	2.70E-07	1.96E-09	1.85E-09
POLO8132	2.84E-07	4.68E-08	4.97E-07	2.70E-06	1.96E-08	1.85E-08
PORTLP1002	2.84E-07	4.68E-08	4.97E-07	2.70E-06	1.96E-08	1.85E-08
NFS100000302	5.86E-06	9.66E-07	1.02E-05	5.58E-05	4.05E-07	3.80E-07
NFS100000201	2.09E-05	3.45E-06	3.66E-05	1.99E-04	1.45E-06	1.36E-06

4.2.1.3 CA-127 through Armargosa Valley (start point at entry to Nevada), CA-127 through Pahrump (start point at entry to Nevada), and SR160 route from Las Vegas.

Tables 18a and 18b show the collective doses and dose risks, respectively, for a no-release accident, for the CA-127 and SR160 routes

Table 18a. Collective doses from a no-release accident (person-mrem): CA127, SR160

	CA127			SR160 R		
	AMARGOSA RURAL (NYE)	PAHRUMP RURAL (NYE)	AMARGOSA RURAL (NYE)	PAHRUMP RURAL (NYE)	AMARGOSA RURAL (NYE)	PAHRUMP RURAL (NYE)
INL08001	7.29E-06	1.10E-05	9.50E-04	2.77E-05	8.32E-04	1.43E-04
INL08002_3	1.28E-03	1.93E-03	1.67E-01	4.86E-03	1.46E-01	2.52E-02
NFL08041_2	7.29E-05	1.10E-04	9.50E-03	2.77E-04	8.32E-03	1.43E-03
NFL08043	7.29E-03	1.10E-02	9.50E-01	2.77E-02	8.32E-01	1.43E-01
POLO8131_3_4	7.29E-05	1.10E-04	9.50E-03	2.77E-04	8.32E-03	1.43E-03
POLO8132	7.29E-04	1.10E-03	9.50E-02	2.77E-03	8.32E-02	1.43E-02
PORTLP1002	7.29E-04	1.10E-03	9.50E-02	2.77E-03	8.32E-02	1.43E-02
NFS100000302	1.50E-02	2.27E-02	1.96E+00	5.71E-02	1.72E+00	2.97E-01
NFS100000201	5.37E-02	8.10E-02	7.00E+00	2.04E-01	6.13E+00	1.06E+00

Table 18b. Collective dose risks from a no-release accident (person-mrem)

	CA127			SR160 R		
	AMARGOSA RURAL (NYE)	PAHRUMP RURAL (NYE)	AMARGOSA RURAL (NYE)	PAHRUMP RURAL (NYE)	AMARGOSA RURAL (NYE)	PAHRUMP RURAL (NYE)
INL08001	5.76E-10	2.38E-09	4.12E-08	6.82E-09	2.56E-08	1.85E-10
INL08002_3	1.01E-07	4.18E-07	7.25E-06	1.20E-06	4.49E-06	3.27E-08
NFL08041_2	5.76E-09	2.38E-08	4.12E-07	6.82E-08	2.56E-07	1.85E-09
NFL08043	5.76E-07	2.38E-06	4.12E-05	6.82E-06	2.56E-05	1.85E-07
POLO8131_3_4	5.76E-09	2.38E-08	4.12E-07	6.82E-08	2.56E-07	1.85E-09
POLO8132	5.76E-08	2.38E-07	4.12E-06	6.82E-07	2.56E-06	1.85E-08
PORTLP1002	5.76E-08	2.38E-07	4.12E-06	6.82E-07	2.56E-06	1.85E-08
NFS100000302	1.19E-06	4.92E-06	8.51E-05	1.41E-05	5.28E-05	3.85E-07
NFS100000201	4.25E-06	1.76E-05	3.04E-04	5.02E-05	1.89E-04	1.37E-06

4.2.1.4 SR93 from Laughlin.

Tables 19a and 19b show the collective doses and dose risks, respectively, for a no-release accident, for the SR93 route

Table 19a. Collective doses from a no-release accident (person-mrem): SR93

	SR93R	SR93S	SR93U	HENDERSON R	HENDERSON S	HENDERSON U
INL08001	2.55E-05	1.37E-03	1.84E-04	1.13E-04	1.66E-03	2.04E-04
INL08002_3	1.28E-02	6.85E-01	9.20E-02	5.65E-02	8.30E-01	1.02E-01
NFL08041_2	2.55E-04	1.37E-02	1.84E-03	1.13E-03	1.66E-02	2.04E-03
NFL08043	2.55E-02	1.37E+00	1.84E-01	1.13E-01	1.66E+00	2.04E-01
POLO8131_3_4	2.55E-04	1.37E-02	1.84E-03	1.13E-03	1.66E-02	2.04E-03
POLO8132	2.55E-03	1.37E-01	1.84E-02	1.13E-02	1.66E-01	2.04E-02
PORTLP1002	2.55E-03	1.37E-01	1.84E-02	1.13E-02	1.66E-01	2.04E-02
NFS100000302	7.14E-02	3.84E+00	5.15E-01	3.16E-01	4.65E+00	5.71E-01
NFS100000201	2.55E-02	1.37E+00	1.84E-01	1.13E-01	1.66E+00	2.04E-01

Table 19b. Collective dose risks from a no-release accident (person-mrem)

	SR93R	SR93S	SR93U	HENDERSON R	HENDERSON S	HENDERSON U
INL08001	7.72E-09	3.06E-08	1.55E-09	1.06E-09	4.09E-08	9.72E-09
INL08002_3	3.86E-06	1.53E-05	7.75E-07	5.31E-07	2.04E-05	4.86E-06
NFL08041_2	7.72E-08	3.06E-07	1.55E-08	1.06E-08	4.09E-07	9.72E-08
NFL08043	7.72E-06	3.06E-05	1.55E-06	1.06E-06	4.09E-05	9.72E-06
POLO8131_3_4	7.72E-08	3.06E-07	1.55E-08	1.06E-08	4.09E-07	9.72E-08
POLO8132	7.72E-07	3.06E-06	1.55E-07	1.06E-07	4.09E-06	9.72E-07
PORTLP1002	7.72E-07	3.06E-06	1.55E-07	1.06E-07	4.09E-06	9.72E-07
NFS100000302	2.16E-05	8.58E-05	4.34E-06	2.97E-06	1.14E-04	2.72E-05
NFS100000201	7.72E-06	3.06E-05	1.55E-06	1.06E-06	4.09E-05	9.72E-06

4.2.1.5 Maximum Individual Dose From a No-release Accident

The maximum individual dose from a no-release accident is independent of the route, and is shown in Table 20 and Figure 10. The “traffic jam” dose, the maximum individual dose, and the Nevada annual background dose are included in the table and figure for comparison.

Table 20. Maximum individual doses (mrem): no-release accident

	Routine Transport	Traffic Jam	No-release Accident
INL08001	6.65E-08	6.95E-04	1.55E-04
INL08002_3	1.17E-05	1.43E-01	2.72E-02
NFL08041_2	6.65E-07	6.95E-03	1.55E-03
NFL08043	6.65E-05	6.95E-01	1.55E-01
POLO8131_3_4	6.65E-07	6.95E-03	1.55E-03
POLO8132	6.65E-06	6.95E-02	1.55E-02
PORTLP1002	6.65E-06	6.95E-02	1.14E-02
NFS100000302	1.37E-04	1.67E+00	3.19E-01
NFS100000201	4.90E-04	5.97E+00	1.14E+00
ANNUAL BACKGROUND	400.00	400.00	400

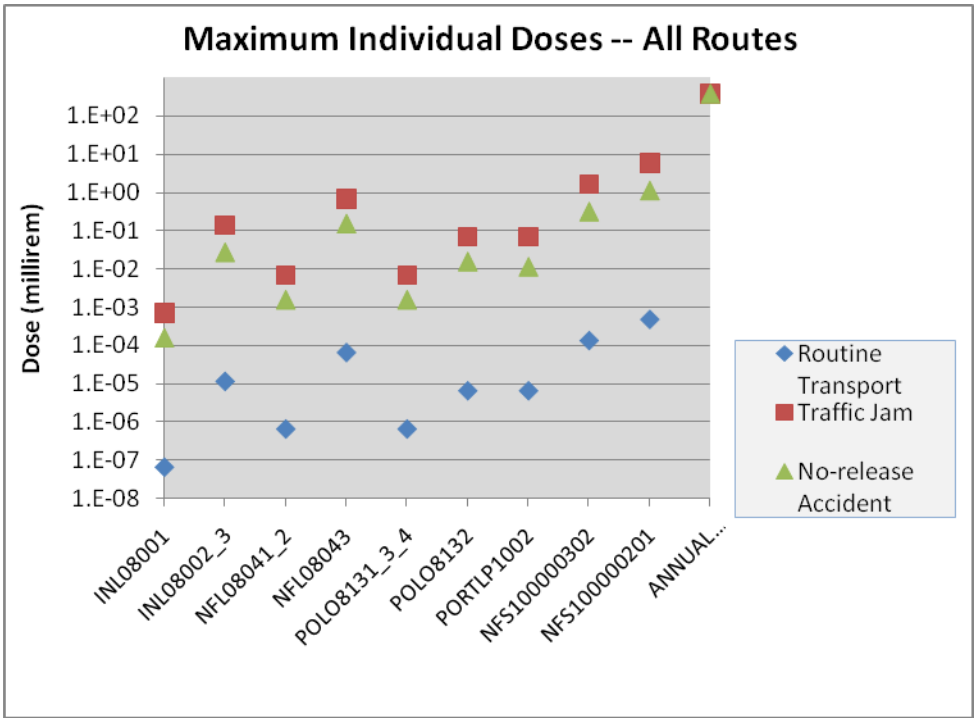

Figure 10. Maximum individual doses – all routes.

4.2.2 Accidents Involving a Release of Radioactive Material

When radioactive material is released to the environment, members of the public can receive external doses from material deposited on the ground and suspended in the air, and can receive internal doses from inhaled material. Ingested radioactive material can also deliver a dose, but members of the public exposed to an ingested dose are not those who live along the route but those who eat contaminated food – usually an entirely different population. Ingestion doses and dose risks are therefore reported separately.

The doses from incident-free transportation are external doses only, and are delivered to a receptor only while that person is exposed to the radiation source. On the other hand, radioactive material released in an accident can deliver both external and internal (committed) doses. Radioactive material that is inhaled or ingested can remain in the body for varying periods of time, during which a dose is delivered continuously. The time that radioactive material is retained depends on the physical and chemical properties of the particular radionuclide; e.g., Tc-99 dissolved in physiological saline solution (an injection routinely used for bone scans) has a retention half-life in the body of about four hours, injected I-131 has a retention half-life of about two weeks, and inhaled plutonium oxide has a retention half-life of a year. These differences among both pathways and radionuclides are incorporated in the dose conversion factor (DCF), the factor that relates the radioactivity inhaled or ingested (curies) to the delivered dose (rem).

Radioactive material released as very small particles, droplets, or gas is aerosolized and dispersible. RADTRAN uses a Gaussian dispersion model to calculate the amount of material to which a population of receptors is exposed. RADTRAN then calculates the doses delivered by each radionuclide released and each pathway to the receptor. The resulting dose (consequence)from each radionuclide is thus

Dose (rem) = (Dose/Ci)*Ci released
Dose/Ci = groundshine*exposure time + inhalation + resuspension + cloudshine

Groundshine (rem-m^2/µCi-day)=$DCF_{grdshine}$(rem/Ci)*(10^{-6}Ci/µCi)*area(m^2)/exposure time (day)
Inhalation (rem/Ci) = $DCF_{inhalation}$(rem/Ci)
Resuspension (rem/Ci) = K*Inhalation; K = proportionality factor <<1
Cloudshine (rem-m^3/Ci-sec) = $DCF_{immersion}$(rem/Ci)
"m^3/sec" is the equilibrium plume volume to which the receptor is exposed.

RADTRAN aggregates each dose (groundshine, inhalation, etc) for the radionuclides released for each accident severity. Collective dose is calculated by multiplying dose by the population exposed to the plume of released material. Dose risk is the calculated by multiplying dose for each accident severity by the conditional probability of that accident, adding those products, and multiplying the sum by the total accident probability:

Dose risk = $P_{acc}*\sum P_i*Dose_i$

where P_i is the accident probability along the route segment (km*accidents/km), P_i is the conditional probability of an accident of particular severity (i = 1, 2, 3,4 in the present case, see Table 9), and $Dose_i$ is the total dose associated with that particular accident.

4.2.2.1 Doses and Dose Risks From Accidents With Release of Radioactive Material

Tables 21a and 21b show groundshine and inhalation (including resuspension) dose risks for the southern route, and Tables 21c and 21d show the maximum individual dose risk and maximum individual dose (consequence) for the southern route. Tables 22a-d show the analogous risks and consequences for the northern route. Tables 23a-d show the analogous risks and consequences for the Ca127 and SR160 routes. Tables 24a-d show the analogous risks and consequences for the SR 93 route. Groundshine and cloudshine doses are external gamma doses only. Inhalation doses (including doses from resuspension of deposited material) are internal, and can include both gamma and alpha radiation.

The difference between Tables c and d for each route and set of routes is the difference between risk (Tables 21c, 22c, 23c and 24c) and consequence (The corresponding "d" tables), and illustrate the role of the probability term.

Ingestion doses affect a different population and would only result from releases in rural agricultural areas, so they are reported separately (Table 25).

Table 21a. Groundshine accident dose risk, southern route (person-mrem)

	CLARK-RURAL	CLARK-SUBURBAN	CLARK-URBAN	NYE-RURAL	NYE-SUBURBAN	NYE-URBAN
INL08001	1.05E-08	7.67E-08	6.49E-07	7.52E-09	4.27E-08	1.53E-08
INL08002_3	1.84E-03	1.35E-02	1.14E-01	1.32E-03	7.50E-03	2.69E-03
NFL08041	6.71E-06	4.90E-05	4.15E-04	4.80E-06	2.73E-05	9.79E-06
NFL08042	5.17E-06	3.78E-05	3.20E-04	3.70E-06	2.10E-05	7.55E-06
NFL08043	6.82E-06	4.98E-05	4.21E-04	4.88E-06	2.77E-05	9.95E-06
NFS100000302	1.46E-05	1.07E-04	9.05E-04	1.05E-05	5.95E-05	2.14E-05
NFS100000201	2.84E-06	2.07E-05	1.75E-04	2.03E-06	1.15E-05	4.14E-06

Table 21b. Total inhalation accident dose risk, southern route (person-mrem)

	CLARK-RURAL	CLARK-SUBURBAN	CLARK-URBAN	NYE-RURAL	NYE-SUBURBAN	NYE-URBAN
INL08001	6.82E-08	4.98E-07	4.21E-06	4.88E-08	2.77E-07	9.95E-08
INL08002_3	1.84E-03	1.35E-02	1.14E-01	1.32E-03	7.51E-03	2.70E-03
NFL08041	3.48E-05	2.54E-04	2.15E-03	2.49E-05	1.41E-04	5.08E-05
NFL08042	2.65E-05	1.94E-04	1.64E-03	1.91E-05	1.08E-04	3.87E-05
NFL08043	8.97E-05	6.55E-04	5.55E-03	6.42E-05	3.65E-04	1.31E-04
NFS100000302	7.66E-05	5.60E-04	4.74E-03	5.49E-05	3.12E-04	1.12E-04
NFS100000201	4.12E-05	3.01E-04	2.55E-03	2.95E-05	1.67E-04	6.02E-05

Table 21c. Maximum individual accident dose risk southern route (millirem)

	CLARK-RURAL	CLARK-SUBURBAN	CLARK-URBAN	NYE-RURAL	NYE-SUBURBAN	NYE-URBAN
INL08001	9.14E-07	3.76E-07	1.17E-07	2.27E-06	2.68E-07	3.35E-09
INL08002_3	5.88E-02	1.02E-02	3.16E-03	6.15E-02	7.24E-03	9.05E-05
NFL08041	1.09E-03	1.89E-04	5.86E-05	1.14E-03	1.34E-04	1.68E-06
NFL08042	8.32E-04	1.44E-04	4.49E-05	8.71E-04	1.03E-04	1.28E-06
NFL08043	4.91E-04	8.52E-05	2.65E-05	5.14E-04	6.05E-05	7.57E-07
NFS100000302	2.40E-03	4.15E-04	1.29E-04	2.51E-03	2.95E-04	3.69E-06
NFS100000201	2.26E-04	3.92E-05	1.22E-05	2.36E-04	2.78E-05	3.48E-07

Table 21d. Maximum individual accident dose (consequence), southern route (millirem)

	CLARK-RURAL	CLARK-SUBURBAN	CLARK-URBAN	NYE-RURAL	NYE-SUBURBAN	NYE-URBAN
INL08001	8.00E-05	1.38E-05	4.31E-06	8.37E-05	9.87E-06	1.23E-07
INL08002_3	2.17E+00	3.75E-01	1.16E-01	2.27E+00	2.67E-01	3.33E-03
NFL08041	4.02E-02	6.95E-03	2.16E-03	4.20E-02	4.94E-03	6.18E-05
NFL08042	3.06E-02	5.31E-03	1.65E-03	3.21E-02	3.78E-03	4.72E-05
NFL08043	1.81E-02	3.14E-03	9.78E-04	1.90E-02	2.23E-03	2.79E-05
NFS100000302	8.84E-02	1.53E-02	4.76E-03	9.26E-02	1.09E-02	1.36E-04
NFS100000201	8.32E-03	1.44E-03	4.48E-04	8.71E-03	1.02E-03	1.28E-05

Table 22a. Groundshine accident dose risk, northern route (person-mrem)

	ELKO RURAL	ELKO SUBURBAN	WHITE PINE RURAL	WHITE PINE SUBURBAN	WHITE PINE URBAN	NYE RURAL
INL08001	2.47E-09	4.67E-10	4.31E-09	2.69E-08	2.76E-08	1.60E-09
INL08002_3	4.33E-04	8.19E-05	7.56E-04	4.72E-03	4.83E-03	2.81E-04
NFL08041	1.58E-06	2.98E-07	2.75E-06	1.72E-05	1.76E-05	1.02E-06
NFL08042	1.21E-06	2.30E-07	2.12E-06	1.32E-05	1.36E-05	7.88E-07
NFL08043	1.60E-06	3.03E-07	2.80E-06	1.75E-05	1.79E-05	1.04E-06
NFS100000302	3.44E-06	6.50E-07	6.00E-06	3.75E-05	3.84E-05	2.23E-06
NFS100000201	6.66E-07	1.26E-07	1.16E-06	7.27E-06	7.44E-06	4.32E-07

Table22b. Total inhalation accident dose risk, northern route (person-mrem)

	ELKO RURAL	ELKO SUBURBAN	WHITE PINE RURAL	WHITE PINE SUBURBAN	WHITE PINE URBAN	NYE RURAL
INL08001	1.60E-08	3.03E-09	2.79E-08	1.74E-07	1.78E-07	1.04E-08
INL08002_3	4.34E-04	8.21E-05	7.57E-04	4.73E-03	4.84E-03	2.82E-04
NFL08041	8.18E-06	1.54E-06	1.43E-05	8.91E-05	9.13E-05	5.30E-06
NFL08042	6.23E-06	1.18E-06	1.09E-05	6.80E-05	6.97E-05	4.04E-06
NFL08043	2.11E-05	3.99E-06	3.68E-05	2.30E-04	2.36E-04	1.37E-05
NFS100000302	1.79E-05	3.41E-06	3.15E-05	1.97E-04	2.01E-04	1.17E-05
NFS100000201	9.68E-06	1.84E-06	1.69E-05	1.06E-04	1.08E-04	6.28E-06

Table 22c. Maximum individual accident dose risk, northern route (millirem)

	ELKO RURAL	ELKO SUBURBAN	WHITE PINE RURAL	WHITE PINE SUBURBAN	WHITE PINE URBAN	NYE RURAL
INL08001	1.58E-06	8.36E-09	2.17E-06	9.53E-08	8.36E-09	3.73E-06
INL08002_3	4.29E-02	2.26E-04	5.87E-02	2.58E-03	2.26E-04	1.01E-01
NFL08041	7.95E-04	4.18E-06	1.09E-03	4.78E-05	4.18E-06	1.87E-03
NFL08042	6.08E-04	3.20E-06	8.32E-04	3.65E-05	3.20E-06	1.43E-03
NFL08043	3.58E-04	1.89E-06	4.91E-04	2.16E-05	1.89E-06	8.43E-04
NFS100000302	1.75E-03	9.23E-06	2.40E-03	1.05E-04	9.23E-06	4.11E-03
NFS100000201	1.65E-04	8.69E-07	2.26E-04	9.91E-06	8.69E-07	3.87E-04

Table 22d. Maximum individual accident dose (consequence), northern route (millirem)

	ELKO RURAL	ELKO SUBURBAN	WHITE PINE RURAL	WHITE PINE SUBURBAN	WHITE PINE URBAN	NYE RURAL
INL08001	5.84E-05	3.08E-07	8.00E-05	3.51E-06	3.08E-07	1.37E-04
INL08002_3	1.58E+00	8.33E-03	2.16E+00	9.52E-02	8.33E-03	3.71E+00
NFL08041	2.93E-02	1.54E-04	4.01E-02	1.76E-03	1.54E-04	6.88E-02
NFL08042	2.24E-02	1.18E-04	3.06E-02	1.35E-03	1.18E-04	5.25E-02
NFL08043	1.32E-02	6.97E-05	1.81E-02	7.95E-04	6.97E-05	3.11E-02
NFS100000302	6.45E-02	3.40E-04	8.84E-02	3.88E-03	3.40E-04	1.51E-01
NFS100000201	6.07E-03	3.20E-05	8.31E-03	3.65E-04	3.20E-05	1.43E-02

Table 23a. Groundshine accident dose risk, CA127 and SR160 routes (person-mrem)

	CA127 AMARGOSA RURAL	CA 127 PAHRUMP RURAL	CA 127 PAHRUMP SUBURBAN	SR160 RURAL	SR160 SUBURBAN	SR160 URBAN	CA127 PAHRUMP	SR160
INL08001	5.01E-07	2.07E-06	4.11E-05	5.91E-06	2.56E-05	2.61E-05	4.32E-05	5.76E-05
INL08002_3	8.79E-05	3.63E-04	7.22E-03	1.04E-03	4.49E-03	4.57E-03	7.58E-03	1.01E-02
NFL08041	3.20E-07	1.32E-06	2.63E-05	3.78E-06	1.63E-05	1.66E-05	2.76E-05	3.67E-05
NFL08042	2.47E-07	1.02E-06	2.02E-05	2.91E-06	1.26E-05	1.28E-05	2.12E-05	2.83E-05
NFL08043	3.25E-07	1.34E-06	2.67E-05	3.84E-06	1.66E-05	1.69E-05	2.80E-05	3.73E-05
NFS100000302	6.98E-07	2.88E-06	5.73E-05	8.24E-06	3.56E-05	3.63E-05	6.02E-05	8.01E-05
NFS100000201	1.35E-07	5.59E-07	1.11E-05	1.60E-06	6.90E-06	7.04E-06	1.17E-05	1.55E-05

Table 23b. Inhalation accident dose risk, CA127 and SR160 routes (person-mrem)

	CA127 AMARGOSA RURAL	CA 127 PAHRUMP RURAL	CA 127 PAHRUMP SUBURBAN	SR160 RURAL	SR160 SUBURBAN	SR160 URBAN	CA127 PAHRUMP	SR160
INL08001	3.25E-09	1.34E-08	2.67E-07	3.84E-08	1.66E-07	1.69E-07	2.81E-07	3.74E-07
INL08002_3	8.81E-05	3.64E-04	7.23E-03	1.04E-03	4.50E-03	4.58E-03	7.60E-03	1.01E-02
NFL08041	1.66E-06	6.86E-06	1.36E-04	1.96E-05	8.47E-05	8.63E-05	1.43E-04	1.91E-04
NFL08042	1.27E-06	5.23E-06	1.04E-04	1.49E-05	6.46E-05	6.58E-05	1.09E-04	1.45E-04
NFL08043	4.28E-06	1.76E-05	3.52E-04	5.05E-05	2.19E-04	2.23E-04	3.70E-04	4.92E-04
NFS100000302	3.65E-06	1.51E-05	3.00E-04	4.32E-05	1.87E-04	1.91E-04	3.16E-04	4.20E-04
NFS100000201	1.97E-06	8.13E-06	1.61E-04	2.32E-05	1.00E-04	1.02E-04	1.69E-04	2.25E-04

Table 23c. Maximum individual accident dose risk, CA127 and SR160 routes (mrem)

	CA127 AMARGOSA RURAL	CA 127 PAHRUMP RURAL	CA 127 PAHRUMP SUBURBAN	SR160 RURAL	SR160 SUBURBAN	SR160 URBAN	CA127 PAHRUMP	SR160
INL08001	4.08E-07	1.12E-06	4.47E-07	2.54E-06	3.18E-07	1.34E-08	1.57E-06	2.87E-06
INL08002_3	1.10E-02	3.02E-02	6.05E-03	3.45E-02	4.30E-03	1.81E-04	3.63E-02	3.89E-02
NFL08041	2.05E-04	5.61E-04	1.12E-04	6.37E-04	7.96E-05	3.35E-06	6.73E-04	7.20E-04
NFL08042	1.56E-04	4.28E-04	8.58E-05	4.87E-04	6.08E-05	2.56E-06	5.14E-04	5.50E-04
NFL08043	9.24E-05	2.54E-04	5.06E-05	2.88E-04	3.60E-05	1.51E-06	3.04E-04	3.25E-04
NFS100000302	4.51E-04	1.24E-03	2.47E-04	1.40E-03	1.75E-04	7.38E-06	1.48E-03	1.59E-03
NFS100000201	4.25E-05	1.16E-04	2.33E-05	1.32E-04	1.65E-05	6.96E-07	1.40E-04	1.49E-04

Table 23d. Maximum individual dose (consequence), CA127 and SR160 routes (mrem)

	CA127 AMARGOSA RURAL	CA 127 PAHRUMP RURAL	CA 127 PAHRUMP SUBURBAN	SR160 RURAL	SR160 SUBURBAN	SR160 URBAN	CA127 PAHRUMP	SR160
INL08001	1.50E-05	4.12E-05	8.24E-06	4.68E-05	5.85E-06	2.47E-07	4.94E-05	5.29E-05
INL08002_3	4.07E-01	1.11E+00	2.23E-01	1.27E+00	1.58E-01	6.67E-03	1.34E+00	1.43E+00
NFL08041	7.53E-03	2.07E-02	4.13E-03	2.35E-02	2.93E-03	1.23E-04	2.48E-02	2.65E-02
NFL08042	5.76E-03	1.58E-02	3.16E-03	1.79E-02	2.24E-03	9.44E-05	1.89E-02	2.03E-02
NFL08043	3.40E-03	9.35E-03	1.86E-03	1.06E-02	1.32E-03	5.57E-05	1.12E-02	1.20E-02
NFS100000302	1.66E-02	4.55E-02	9.10E-03	5.17E-02	6.46E-03	2.72E-04	5.46E-02	5.84E-02
NFS100000201	1.57E-03	4.29E-03	8.57E-04	4.87E-03	6.08E-04	2.56E-05	5.14E-03	5.50E-03

Table 24a. Groundshine accident dose risk, SR93 routes (person-mrem)

	SR93R (CLARK)	SR 93 S (CLARK)	SR93 U (CLARK)	HENDERSON R (CLARK)	HENDERSON S (CLARK)	HENDERSON U (CLARK)	TOTAL SR93 RISK
INL08001	2.66E-06	1.14E-05	5.75E-07	3.93E-07	1.52E-05	3.90E-06	3.41E-05
INL08002_3	1.19E-03	5.39E-03	3.83E-02	1.62E-04	7.18E-03	2.41E-01	2.93E-01
NFL08041	4.28E-06	1.95E-05	1.39E-04	5.88E-07	2.61E-05	8.77E-04	1.07E-03
NFL08042	3.30E-06	1.51E-05	1.07E-04	4.53E-07	2.01E-05	6.76E-04	8.22E-04
NFL08043	5.72E-05	2.62E-04	1.86E-03	7.87E-06	3.49E-04	1.17E-02	1.42E-02
NFS100000302	9.32E-06	4.27E-05	3.04E-04	1.29E-06	5.70E-05	1.92E-03	2.33E-03
NFS100000201	1.81E-06	8.26E-06	5.88E-05	2.49E-07	1.10E-05	3.71E-04	4.51E-04

Table 24b. Inhalation accident dose risk, SR93 routes (person-mrem)

	SR93R (CLARK)	SR 93 S (CLARK)	SR93 U (CLARK)	HENDERSON R (CLARK)	HENDERSON S (CLARK)	HENDERSON U (CLARK)	TOTAL SR93 RISK
INL08001	4.39E-05	1.27E-05	1.23E-05	1.58E-06	1.40E-05	8.19E-05	1.66E-04
INL08002_3	1.17E-03	5.40E-03	3.82E-02	1.62E-04	7.18E-03	2.40E-01	2.92E-01
NFL08041	2.22E-05	1.02E-04	7.18E-04	3.05E-06	1.35E-04	4.52E-03	5.50E-03
NFL08042	1.69E-05	7.73E-05	5.50E-04	2.34E-06	1.03E-04	3.45E-03	4.20E-03
NFL08043	5.72E-05	2.62E-04	1.86E-03	7.87E-06	3.49E-04	1.17E-02	1.42E-02
NFS100000302	4.88E-05	2.24E-04	1.59E-03	6.72E-06	2.98E-04	9.96E-03	1.21E-02
NFS100000201	2.63E-05	1.20E-04	8.53E-04	3.62E-06	1.60E-04	5.36E-03	6.52E-03

Table 24c. Maximum Individual accident dose risk, SR93 routes (person-mrem)

	SR93R (CLARK)	SR 93 S (CLARK)	SR93 U (CLARK)	HENDERSON R (CLARK)	HENDERSON S (CLARK)	HENDERSON U (CLARK)	TOTAL SR93 DOSE RISK
INL08001	6.65E-08	6.65E-08	6.65E-08	6.65E-08	6.65E-08	6.65E-08	3.99E-07
INL08002_3	1.00E-01	3.11E-03	1.17E-03	1.31E-03	3.43E-03	6.62E-03	1.16E-01
NFL08041	1.86E-03	5.77E-05	2.17E-05	2.43E-05	6.36E-05	1.23E-04	2.15E-03
NFL08042	1.42E-03	4.41E-05	1.66E-05	1.86E-05	4.86E-05	9.37E-05	1.64E-03
NFL08043	8.38E-04	2.61E-05	9.84E-06	1.10E-05	2.87E-05	5.54E-05	9.69E-04
NFS100000302	4.09E-03	1.27E-04	4.79E-05	5.36E-05	1.40E-04	2.70E-04	4.73E-03
NFS100000201	3.85E-04	1.20E-05	4.51E-06	5.04E-06	1.32E-05	2.54E-05	4.46E-04

Table 24d. Maximum individual dose (consequence, SR93 routes (person-mrem)

	SR93R (CLARK)	SR 93 S (CLARK)	SR93 U (CLARK)	HENDERSON R (CLARK)	HENDERSON S (CLARK)	HENDERSON U (CLARK)	TOTAL SR93 DOSE RISK
INL08001	3.21E-09	3.01E-09	6.21E-11	3.45E-09	3.00E-09	6.70E-11	1.28E-08
INL08002_3	1.85E+00	5.73E-02	2.16E-02	2.42E-02	6.32E-02	1.22E-01	2.14E+00
NFL08041	2.87E-04	2.12E-05	7.99E-06	8.93E-06	2.34E-05	4.51E-05	3.94E-04
NFL08042	2.62E-02	8.12E-04	3.06E-04	3.42E-04	8.96E-04	1.73E-03	3.02E-02
NFL08043	1.54E-02	4.80E-04	1.81E-04	2.02E-04	5.28E-04	1.02E-03	1.78E-02
NFS100000302	7.54E-02	2.34E-03	8.82E-04	9.88E-04	2.58E-03	4.97E-03	8.71E-02
NFS100000201	7.10E-03	2.21E-04	8.30E-05	9.29E-05	2.43E-04	4.68E-04	8.20E-03

Table 25. Ingestion dose risks (person rem). All route segments are rural. The target population is throughout the U. S.

	SOUTHERN CLARK	**SOUTHERN NYE**	**NORTHERN ELKO**	**NORTHERN WHITE PINE**	**NORTHERN NYE**	**CA127 AMAR GOSA**	**CA127 PAHRUMP**	**SR160 CLARK**	**Sr93**
INL08001	2.31E-07	2.42E-07	1.69E-07	2.31E-07	3.90E-07	4.34E-08	1.19E-07	1.35E-07	1.71E-10
INL08002_3	4.92E-03	5.15E-03	3.59E-03	4.91E-03	8.43E-03	9.24E-04	2.53E-03	2.88E-03	3.65E-06
NFL08041	1.05E-04	1.10E-04	7.68E-05	1.05E-04	1.80E-04	1.98E-04	5.42E-05	6.16E-05	7.78E-08
NFL08042	8.37E-05	8.76E-05	6.11E-05	8.37E-05	1.43E-04	1.57E-05	4.31E-05	4.90E-05	6.01E+08
NFL08043	1.30E-03	1.36E-03	9.46E-04	1.30E-03	2.22E-03	6.68E-04	7.59E-04	1.27E-04	9.63E-07
NFS100000302	2.29E-04	2.39E-04	1.67E-04	2.28E-04	3.92E-04	4.29E-05	1.18E-04	1.34E-04	1.70E-07
NFS100000201	5.64E-04	5.58E-04	3.89E-04	5.33E-04	9.14E-04	1.00E-04	2.75E-04	3.12E-04	4.17E-07

Figures 11-14 are presented as examples, since the relative dose risks are the same for all routes. The vertical scale on these figures is logarithmic because it is otherwise not possible to show all of these data on one graph.

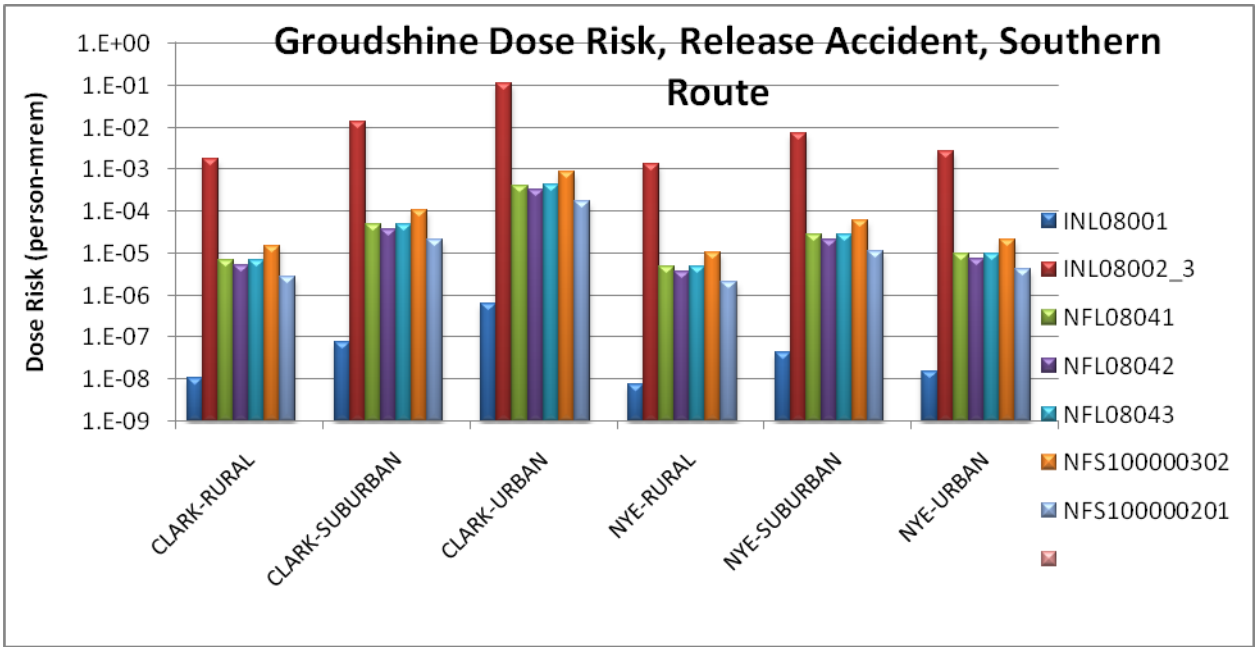

Figure 11. Groundshine dose risk

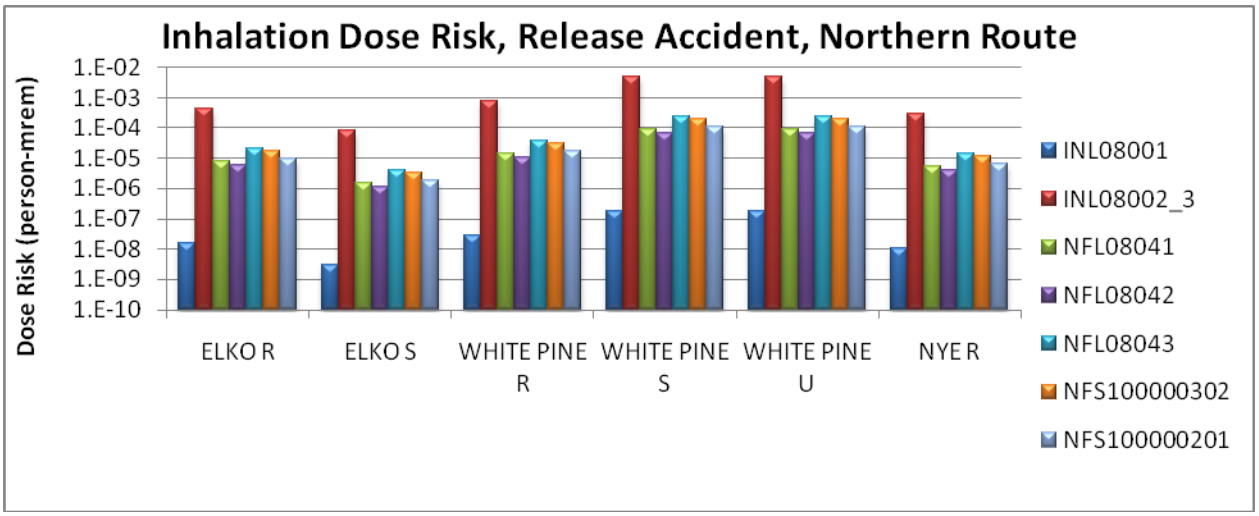

Figure 12. Inhalation dose risk, release accident, northern route.

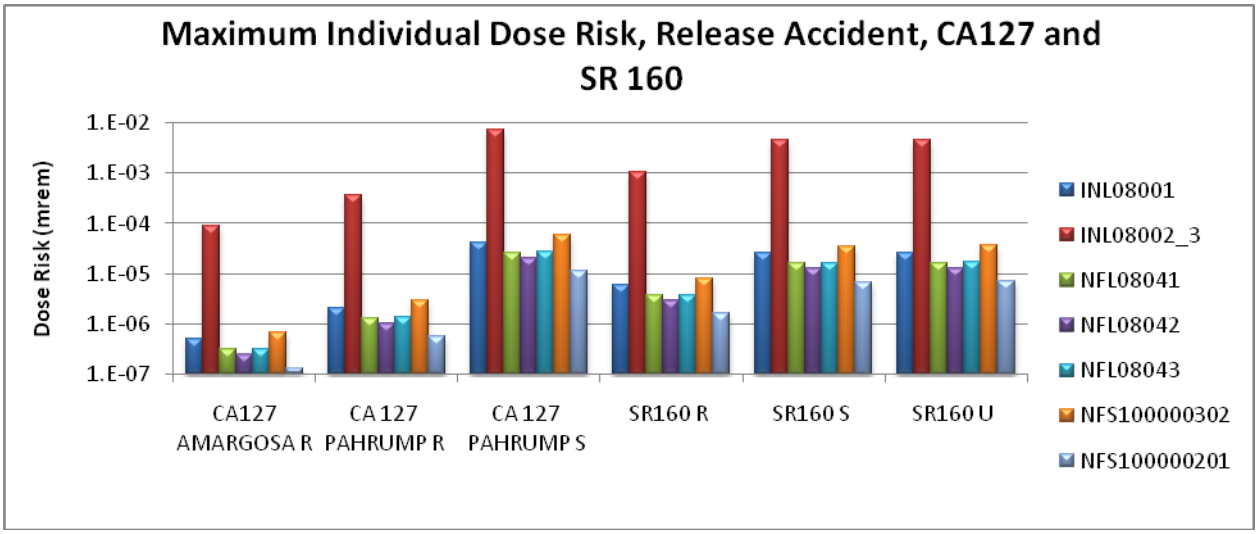

Figure 13. Maximum individual dose risk, release accident, CA127 and SR160 routes.

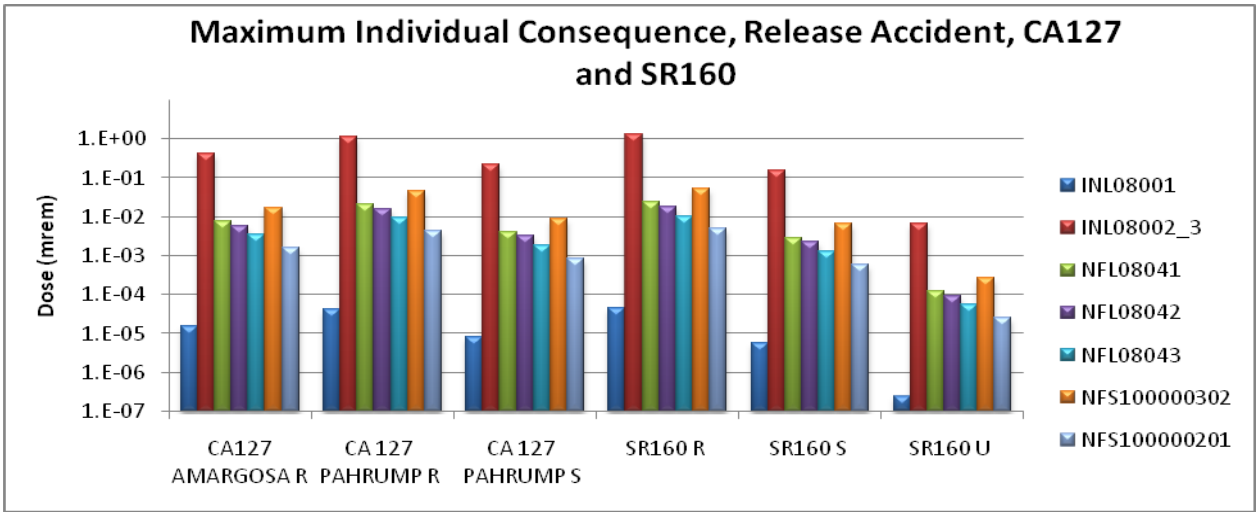

Figure 14. Maximum individual consequence, release accident, CA127 and SR160 routes.

Figures 15 and 16 compare the groundshine and inhalation dose risks for the routes.

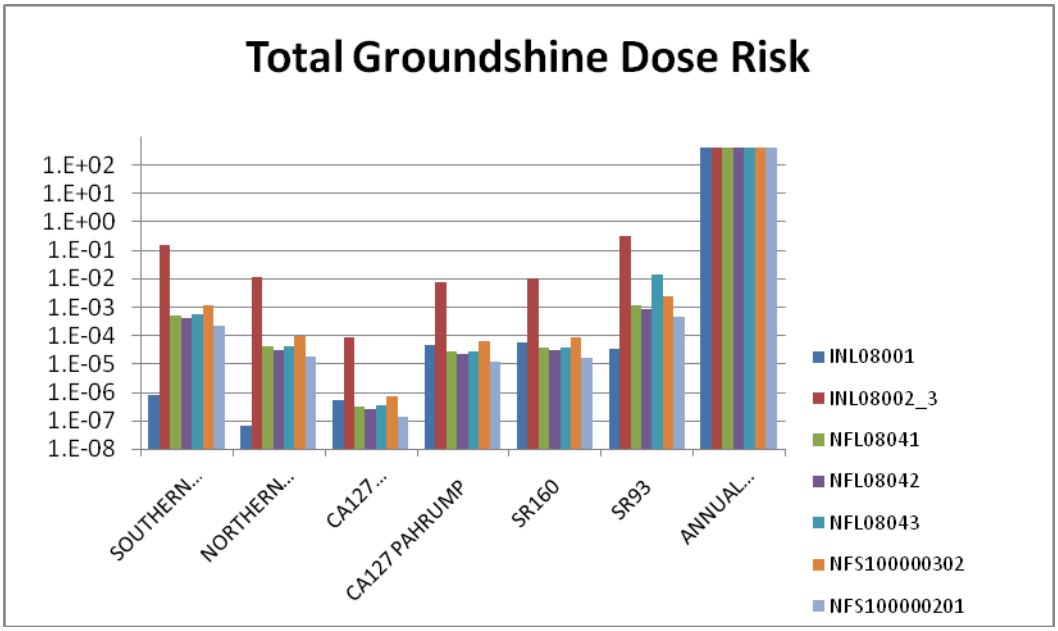

Figure 15. Total groundshine dose risk

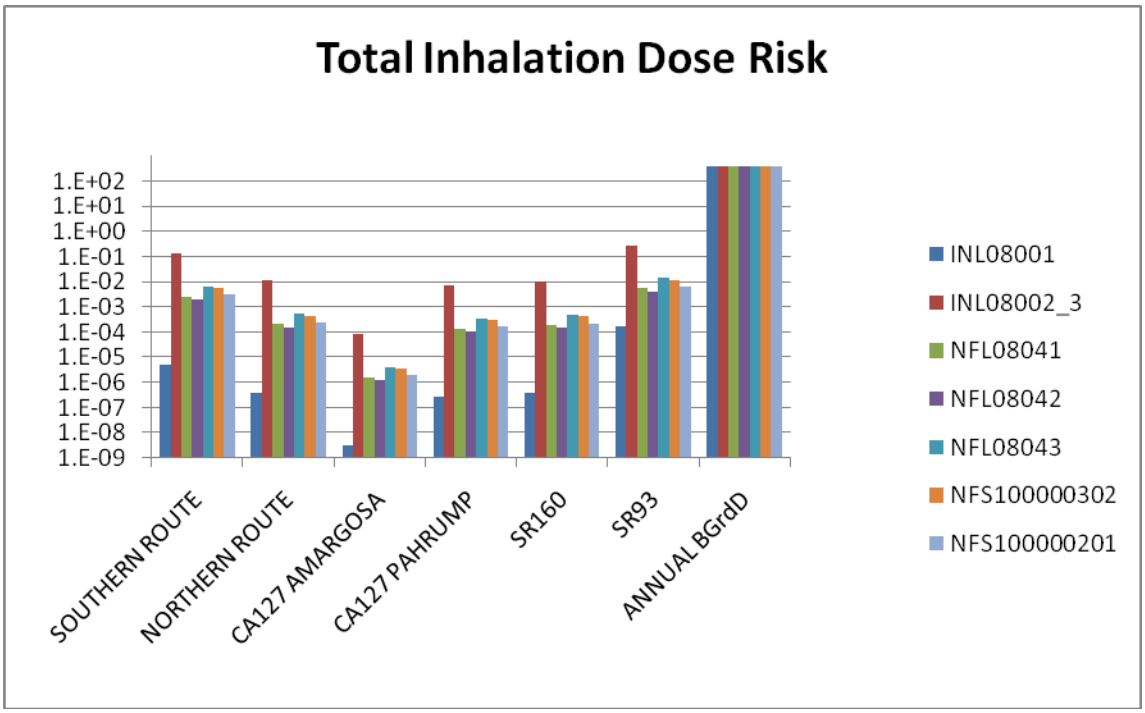

Figure 16. Total inhalation dose risk.

4.2.2.2 Transportation (Traffic) Accidents and Fatalities

Table 23 shows the potential accidents and fatalities on each route segment and for each total route. The sources of the data are provided in USDOT (2002). The Nevada state accident rate and the U.S. fatality-to-accident ratio for large trucks with semi-detached trailers were used to

calculate the potential accidents and fatalities summarized in Table 26. The USDOT data are validated before being posted.

Table 26. Transportation (traffic) accidents and fatalities

ROUTE SEGMENT	COUNTY	ACCIDENTS	FATALITIES
SOUTHERN R CLARK	Clark	4.68E-04	1.65E-06
SOUTHERN S CLARK	Clark	8.10E-05	2.86E-07
SOUTHERN U CLARK	Clark	2.52E-05	8.90E-08
SOUTHERN R NYE	Nye	4.89E-04	1.73E-06
SOUTHERN S NYE	Nye	5.76E-05	2.03E-07
SOUTHERN U NYE	Nye	7.20E-07	2.54E-09
TOTAL SOUTHERN ROUTE		**1.12E-03**	**3.96E-06**
NORTHERN R ELKO	Elko	3.41E-04	1.20E-06
NORTHERN S ELKO	Elko	1.80E-06	6.35E-09
NORTHERN R WHITE PINE	White Pine	4.68E-04	1.65E-06
NORTHERN S WHITE PINE	White Pine	2.06E-05	7.26E-08
NORTHERN U WHITE PINE	White Pine	1.80E-06	6.35E-09
NORTHERN R NYE	Nye	8.01E-04	2.83E-06
TOTAL NORTHERN ROUTE		**1.63E-03**	**5.77E-06**
CA127 AMARGOSA R (NYE)	Nye	8.79E-05	3.10E-07
CA 127 PAHRUMP R (NYE)	Nye	2.41E-04	8.51E-07
CA 127 PAHRUMP S (NYE)	Nye	4.82E-05	1.70E-07
TOTAL CA127 ROUTE		**3.77E-04**	**1.33E-06**
SR160 R (CLARK)	Clark	2.73E-04	9.65E-07
SR160 S (CLARK)	Clark	3.42E-05	1.21E-07
SR160 U (CLARK)	Clark	1.44E-06	5.10E-09
TOTAL SR 160 ROUTE		**3.09E-04**	**1.09E-06**
SR 93 R (CLARK)	Clark	3.36E-04	1.19E-06
SR 93 S (CLARK)	Clark	2.48E-05	8.77E-08
SR 93 U (CLARK)	Clark	9.36E-06	3.00E-08
HENDERSON R (CLARK)	Clark	1.04E-05	3.69E-08
HENDERSON S (CLARK)	Clark	2.74E-05	9.66E-08
HENDERSON U (CLARK)	Clark	5.29E-05	1.87E-07
TOTAL SR 93 ROUTE		**4.61E-04**	**1.63E-06**

4.2.2.3 LCF Risk

Table 27 compares the risk of traffic accidents and traffic fatalities with the calculated LCF risks for each route. Background ionizing radiation is included in the calculation. The annual background in Nevada for non-DOE activities was estimated to be 400 mrem/year (HPS, 2009) and the exposure time, estimated to be equivalent to exposure to the accident fallout, was eight hours. The LCF/rem risk factor used is 6 x 10^{-4}/rem (ISCORS, 2002).

Table 27. Comparison of traffic accidents and fatalities with LCF from an accidental release and from background ionizing radiation.

	SOUTHERN	NORTHERN	CA127-A	CA127-P	SR160	SR 93
ACCIDENTS	1.12E-03	1.63E-03	8.79E-05	2.89E-04	3.09E-04	4.61E-04
FATALITIES	3.96E-06	5.77E-06	3.10E-07	1.02E-06	1.09E-06	1.63E-06
LCF: INL08001	3.61E-09	2.84E-10	3.03E-10	2.61E-08	3.48E-08	1.20E-07
LCF:INL08002_3	1.69E-04	1.33E-05	1.06E-07	9.11E-06	1.21E-05	3.51E-04
LCF:NFL08041	1.90E-06	1.50E-07	1.19E-09	1.02E-07	1.36E-07	3.94E-06
LCF:NFL08042	1.45E-06	1.15E-07	9.11E-10	7.82E-08	1.04E-07	3.01E-06
LCF:NFL08043	4.42E-06	3.50E-07	2.76E-09	2.39E-07	3.18E-07	1.70E-05
LCF:NFS100000302	4.18E-06	3.30E-07	2.61E-09	2.25E-07	3.00E-07	8.67E-06
LCF:NFS100000201	2.02E-06	1.59E-07	1.26E-09	1.09E-07	1.45E-07	4.18E-06
LCF:8-HR BACKGROUND	4.59E-01	3.39E-01	2.82E-04	4.27E-02	3.46E-01	3.65E-01

5.0 **DISCUSSION**

The doses of ionizing radiation from the shipments considered are exceedingly small. As shown in the tables and figures of Section 3.1, collective doses to residents along the routes and to occupants of vehicles sharing the route are of the order of one person-millirem or less – usually less. The average individual dose to a resident along the route varies from about five billionths (5×10^{-9}) of a millirem to about 5/100,000 of a millirem (e.g., figure 3). The largest dose to a member of the public along the route is a little less than one millionth of a millirem (6.65×10^{-7} mrem); this dose is independent of the route and depends on the external radiation from the shipment, the speed of the vehicle, and the distance of the receptor from the moving vehicle.

Several scenarios were suggested in which the shipment was about a meter (about 39 inches) from a member of the public. Doses to that person are shown in Table 14. The largest doses are at the rest area, since the receptor there is exposed for the longest time, , but even in this case the largest dose from any shipment is 61 millirem – about 1/6 of biannual background. Table 14 provides a comparison between using measured transport indices (TIs) and using the regulatory maximum. The regulatory maximum external dose rate is 10 mrem/hr at two meters laterally from the cargo. This is equivalent to 14 mrem/hr at one meter from the cargo when RADTRAN is used for the calculation. The dose from the regulatory shipment is 1.44 times the dose from NFS100000000201, which is the ratio of the TIs. In this case the TI is the dominant parameter.

An accident in which there is no release is equivalent to having the vehicle stop for a period of time and expose members of the public. The primary difference between this scenario and the "rest area" scenario is that the accident is assumed to take place 30 meters (a lane width) from the nearest member of the public. Collective doses from this accident are summarized in Tables 15a, 16a, and 17a, and are all less than 10 person-millirem. These collective doses depend more on the size of the exposed population than on any other parameter. The maximum individual dose from a no-release accident is presented in Table 18 and compared to one of the special scenarios: the individual stuck in a traffic jam next to the cargo. The difference in doses is primarily the difference in distance between the cargo and the receptor.

The collective (population) effects from a release accident are reported as "dose risks" that include the probability of release in a particular accident as well as the dose from the release. Given the uncertainties is the concept of collective dose (Ryan, 2005) combined with uncertainties of effects at very small individual doses, the collective consequences are not reported. Maximum individual dose, however, is reported, as well as maximum individual dose risk (e.g., Tables 20c and 20d). The maximum individual dose is no more than a few millirem. The ratio of results for "worst case" dispersion conditions (Pasquill E stability) to national average weather conditions is 1.1. Cloudshine doses are not reported in these results because they are always several orders of magnitude smaller than other doses and collective doses, and can be considered negligible.

Traffic accidents and fatalities are compared appropriately to health effects: latent cancer fatalities (LCF) in the case of shipments of radioactive materials. Table 24 presents this comparison. Since all of the routes considered are relatively short, and since the probability of accidents depends on route length (accidents/km * km of route length), accidents and fatalities and LCF are all much less than unity, and are all considerably smaller (two to six orders of magnitude) than the LCF calculated from 8-hour exposure to background ionizing radiation.

6.0 GLOSSARY

Alpha	particle of ionizing radiation that has the atomic mass (4) and charge (+2) of a helium nucleus
Dose rate	dose/unit time (e.g., rem/hour)
Gamma	a form of radiation like x-rays; a beam of energy that has no mass or electric charge
Gaussian	a curve shaped like a normal data distribution
Gray (Gy)	energy concentration of one joule/kg of absorber
Kilo-	a prefix meaning 1000 (1 kilogram (kg) = 1000 grams)
Kilometer (km)	1 km = 0.6217 mile
LLW	low-level radioactive waste
Micro-	a prefix meaning 10^{-6} (1 microrem (µrem) = 0.000001 rem)
Milli-	a prefix meaning 0.001 (I millirem (mrem) = 0.001 rem)
Order of magnitude	a factor of ten
Rad	energy concentration of one erg/gram of absorber
Radionuclide	a radioactive atom
Radioisotope	a radioactive form of an element that has a different number of neutrons in the nucleus than stable forms of the element
Rem	a unit of radiation dose equivalent to the biological damage done by one rad of gamma radiation
Sievert (Sv)	100 rem

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