Fallon Impact Report

Transportation of Spent Nuclear Fuel to the Proposed Repository at Yucca Mountain, Nevada

Route 50 Corridor through Fallon

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Executive Summary

If a high-level waste repository opens at Yucca Mountain, a number of rail and truck shipments of nuclear waste are expected to pass through Churchill County and the city of Fallon. These shipments of nuclear waste would lead to a radiation dose to the public even if the transport is incident-free, because no shielding material can reduce direct gamma radiation by 100 %. As a result, residents, drivers, pedestrians and workers will get a radiation dose, which depends on the recipient's exposure proximity and duration. Depending on the population estimate, the population dose due to incident-free transportation of the entire waste that is planned to pass Fallon is as high as 61.57 person-rems. Even though this dose and the resulting population risk are relatively small, it nevertheless increases the risk to develop cancer.

In the previously prepared Churchill County Impact Report (Feb. 2006), population and maximum-exposed individual doses were assessed for both incident-free and accident scenarios for shipments passing through the Fallon/Churchill County region from both eastern and western reactors along the north/south route, US 95. This report considers the alternate routing of spent fuel shipments through Fallon on US 50 and US 95S and provides an economic estimation of remediative costs for the west-central Nevada region, in the event of the most probable accident scenario. Trucks from western reactors and the Department of Energy's Hanford facility are assumed to enter Fallon on US50 before heading south on US95 (S. Taylor St.). Trucks from the east would go south on US95. Alternative routes from the east to the proposed Yucca Mountain repository are possible, but not evaluated in this report. Since rail shipments would not enter Fallon itself, they are also not evaluated in this report.

In the case of a severe accident involving a nuclear truck shipment, the dose to individuals and the population will be much higher. In contrast to incident-free transportation, such an accident would cause both acute and long-term exposures, because radioactive particulates would be dispersed in the environment and continue to lead to radiation exposures. A severe transportation accident leading to a release of radioactive particulates is possible and credible. It could be caused by high impact, long duration fire or sabotage. Such an accident would lead to high radiation exposures due to inhalation (acute dose) and ground shine (long-term dose). Additional exposure to radiation would arise from ingestion of food, water and soil, even though the dose due from the ingestion pathway is very small in comparison to the inhalation and ground shine pathways. However, since food produced in the Fallon area is exported to and consumed in large parts of Nevada and California, an accident in Fallon could have health impacts throughout the region, if this food source is not interdicted.

Without remediation and assuming a long-term exposure of 50 years, about 2% of the present population of Fallon would develop fatal cancer as a consequence of the accident, depending on the location and severity of the accident. This means that either a thorough remediation or a permanent evacuation will have to take place. In order to comply with EPA's Protective Action Guide (PAG) or CERCLA cleanup standards, an area of 4.5 – 9.2 km^2 would have to be remediated. Although we omit the exposure and cost to cleanup workers in this report, we do assess the remediative costs for various contamination levels throughout the Churchill County region. DOE shipments are insured under Price-Anderson insurance, but the timing of the payouts is problematic since this requires a Congressional authorization.

The federal government should ensure that shipping casks are designed to withstand all likely accidents that could take place on highways or by rail. Casks are presently designed to withstand a 30 mph crash into an unyielding object, and a fire of 1,475° F for 30 minutes and in any case are not physically tested. Local government could undertake several measures. Pressure by local government could be brought to bear on Congress and federal agencies to improve the safety of shipping containers. Several mitigating actions can be undertaken on the local level. Emergency personnel should be trained and equipped to handle radiation-related accidents, so that the hazard can be quickly evaluated and emergency measures, including evacuation and interdiction of the food supply, taken.

Introduction

Background

This report is a supplement to the "Fallon Impact Report: Transportation of Spent Nuclear Fuel to the Proposed Repository at Yucca Mountain, Nevada," completed by Radioactive Waste Management Associates (RWMA) in February 2006[1]. This report includes revised numbers for shipments passing through Churchill County and the city of Fallon based on mostly truck and mostly rail shipping scenarios provided by the Department of Energy (DOE) in the Final Environmental Impact Statement (FEIS) prepared for the proposed repository at Yucca Mountain[2]. Updated traffic count, commodity flow, and US Census data are all included in comparisons of incident-free dose to both the maximum-exposed individual and Fallon population for both scenarios. Finally, the remediative costs following a severe accident are assessed based on prior estimates given certain levels of radiation exposure.

In the event that the proposed geologic repository at Yucca Mountain, Nevada begins accepting waste, Churchill County would be affected by potential rail and truck routes, with its largest city and County seat, Fallon, containing a major truck route for waste shipments. In this report, two transportation scenarios are analyzed; transportation of spent nuclear fuel by mostly rail and by mostly truck. On April 2, 2004, the Department of Energy signed a Record of Decision announcing its selection, both nationally and in the State of Nevada, of the mostly rail scenario analyzed in the "Final Environmental Impact Statement for a Geologic Repository for the Disposal of Spent Nuclear Fuel and High-Level Radioactive Waste at Yucca Mountain, Nye County, Nevada." While many of the generator sites, especially those in the west, are not directly served by rail we thought it likely that truck shipments would be used to ship waste from these locations. This would have increased the current estimate of truck shipments needed under the mostly rail scenario. However, because of the need to decommission reactors (and therefore to empty the fuel pool) or due to the delay in opening the Yucca mountain repository, utilities have opted to store nuclear fuel in large storage casks. These can only be transported by heavy-haul truck for short distances and by rail. Humboldt Bay, Rancho Seco, Diablo Canyon and Trojan are four Western reactors presently using large dry storage casks.

Waste could potentially travel though the county on rail lines that traverse Churchill County approximately ~12.5 miles west of Fallon and this may occur. The DOE is presently investigating extending the rail lines from Hawthorne south to the proposed Yucca Mountain repository. This report will only focus on truck shipments for both transportation scenarios that will pass directly through the city of Fallon. However, truck shipments under the mostly truck scenario as well as those that are still needed under the mostly rail scenario could pass directly through the city of Fallon on US 50 and on US 95

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[1] Resnikoff M, and Biglin, K., *Fallon Impact Report: Transportation of Spent Nuclear Fuel to the Proposed Repository at Yucca Mountain, Nevada*, February, 2006.

[2] USDOE, 2002. *Final Environmental Impact Statement for a Geologic Repository for the Disposal of Spent Nuclear Fuel and High-Level Radioactive Waste at Yucca Mountain, Nye County, Nevada*. pp 6-37.

South (S. Taylor St.). Waste traveling east through the county would come from generator sites in California, Oregon and Washington while waste shipments traveling west could originate from all eastern locations in the United States, assuming no shipments are allowed to pass through the Las Vegas area. While the eastbound truck shipments through Fallon are likely, westbound truck shipments would likely bypass Fallon entirely by taking US93 and US6 through Ely. Therefore, the impact calculations in this report should be considered an upper bound.

Previous studies[3] have estimated the likely number of rail and truck shipments through Churchill County. In this study, we use these estimates to predict the incident-free doses likely to be incurred by residents near the roadway, motorists sharing the roadway with the shipments, and transients lodging near the roadway within Fallon. Also, we calculate the dose resulting from a severe accident involving a nuclear shipment.

City of Fallon and Surroundings

Churchill County is located in northern Nevada approximately one hour east of Reno. In 2000 the population was estimated at 23,982[4]. The city of Fallon is located 60 miles east of Reno and 70 miles east of the California border at the junction of Highways 50 and 95, with US95 forming its main street running straight from north to south. Its elevation is 3,963 feet above sea level. In 2000, Fallon had a population of 7,536, approximately 31% of the county's total[5]. For population densities (persons/square kilometer) in Fallon and along the shipping corridors, we take the population of Fallon and divide by the town area. The population and population densities are shown in Table 1 below.

Table 1 - Population estimates for Fallon

Year	**Town of Fallon Population**	**Population Density (per/sq km)**
2000	7,536	649
2010	9,359	806
2020	13,290	1,145

Number of Shipments Expected to Pass Through Fallon

The most variable estimate concerns the number of shipments expected to travel through Churchill County en route to Yucca Mountain. Estimates will vary depending on the expected number of truck vs. rail shipments, the number of shipments expected to take

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[3] Massey R, RCS, *Churchill County Impact Report*, August 2001, p. 15

[4] US Census 2000

[5] *Ibid*

the US 50 to US 95S route rather than another alternative, reactor license renewals, etc. Under the mostly rail scenario, truck shipments will still occur because there are a number of generator sites around the country that do not have rail access. The end result for the mostly rail scenario will be a combination of truck and rail shipments. Because no rail line to Yucca Mountain exists that passes through Fallon, rail shipments west or east are assumed to be zero in all cases and are thus omitted from our incident-free and accident deliberations. The numbers for West- and East-bound shipments appear in Table 2.

The FEIS estimates that under the Proposed Action for the mostly rail scenario a total of 10,725 waste shipments would traverse Churchill County, which calls for shipments of 70,000 metric tons of heavy metal (MTHM) including 63,000 MTHM of commercial spent nuclear fuel (CSNF) to the facility from 2010 through 2033. If the expansion of Yucca Mountain (known as Modules I & II) is approved, the Churchill County Impact Report estimated the number of shipments for the mostly rail scenario to increase to 22,057 between the years 2010 and 2048. However, in all cases, because no rail shipments will traverse the Fallon town limits, those shipment numbers and impact are omitted from the parameters of this study. Under the mostly rail scenario, there will therefore be 1,079 – 3,122 truck shipments whereas, under the mostly truck scenario, a total of 52,786 – 108,544 truck shipments will be made.

Previous studies[6] have estimated the likely number of rail and truck shipments through Churchill County. In this study, we use these estimates to predict the incident-free doses likely to be incurred by residents near the roadway, motorists sharing the roadway with the shipments, and transients lodging near the roadway. Table 2 summarizes various waste shipment scenarios for Churchill County. Only the truck shipments will pass directly through the city of Fallon and are analyzed in this report.

Table 2 - Churchill County Waste Shipment Scenarios

	Mostly Rail[1]		***Mostly Truck***	
	Truck[2]	Rail	Truck[2]	Rail
<u>Scenario - East bound</u>				
Proposed Action	0	807	4,223	300
Mod I & II	0	3,594	18,781	355
<u>Scenario - West bound</u>				
Proposed Action	1,079	8,839	48,563	0
Mod I & II	3,122	15,341	89,763	0
<u>Total</u>				
Proposed Action	1,079	9,646	52,786	300
Mod I & II	3,122	18,935	108,544	355

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[6] Massey R, RCS, *Churchill County Impact Report*, August 2001, p. 15

[1]As mentioned previously, many generator sites do not have direct rail access. But it is likely that these sites will ship by rail, using heavy-haul transport to the closest rail head. Nevertheless, we consider both mostly rail and mostly truck scenarios possible and consider both in our analysis.

[2]Assumes all truck shipments from west are made on US 50 to US 95S corridor and from east are made on US95

It should be noted that the estimates in Table 2 that are used in this study are the minimal number of shipments that will be necessary to transport all of the SNF from reactor sites. The nation's inventory of commercial SNF evaluated in DOE's FEIS is expected to exceed the 63,000 MTHM estimate used for this analysis, as the proposed action in Table 2. Many of the nuclear reactors have already applied for license renewals and others intend on doing so. Mod II estimates assume all presently operating commercial reactors have 10-year license extensions. However, license renewals granted by the Nuclear Regulatory Commission (NRC) have customarily been for an additional 20-year operational period. These renewals would therefore increase the total amount of commercial SNF above the Mod II estimates, increasing the number of shipments needed, and thus increasing the expected dose.

A previous study estimated the total commercial SNF inventory that could be generated from existing nuclear power plants including the license renewals[7]. The study developed three scenarios: 1) no granting of any license renewals[8]; 2) granting of all license renewals from reactors expected to apply for renewal over the next six years, according to the NEI[9] and 3) granting of all license renewals. These estimates can be seen in Table 3. In addition, the federal government has generated high-level waste that is expected to lift the total requiring disposal at Yucca Mountain to 210,000 MTHM. Though Yucca Mountain, by law, can only accept 70,000 MTHM, this is a Congressionally-mandated limit and not the physical limit of the proposed Yucca Mountain repository. This legal limit can be changed by Congress.

Table 3 - Commercial spent nuclear fuel inventory under three license renewal scenarios

	Spent Fuel Mass (MTHM)			
Scenario	**BWR Fuel**	**PWR Fuel**	**Sum**	**DOE Over Quota**
1: No renewals[9]	29,500	54,800	84,300	21,300
2: 46 renewals	33,482	65,571	99,052	33,052
3: All plants renewed	44,250	82,200	126,450	63,450

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[7] Resnikoff and Lamb, "Spent Fuel Inventory and Location with Time", August 2001.

[8] Note: there have already been 6 license extensions granted, and 14 applications for renewals have been filed. Scenario 1 ignores these.

[9] Note: includes reactors already granted extensions as well as those that have already filed for renewal.

Incident-Free Dose Calculation

For the calculation of expected doses to the population of Fallon under routine shipment conditions, the RISKIND[10] computer program was used. In the following, we present the calculation of the most important input parameters. The unit of measurement used to calculate the incident-free dose is rem. Rem is a unit used in radiation protection to measure the amount of damage to human tissue from a dose of ionizing radiation. A person-rem is the total dose to all persons within the affected population.[11]

Population and Population Density

Only persons living within 1 mile of the proposed shipment routes were considered in this calculation. It was also assumed that all eastbound shipments would proceed on US 50 to US 95 South through Fallon. All westbound shipments would go directly south on US95. Thus, all truck shipments would meet at the intersection of US50 and US95 and travel south on US95 to the Fallon city limits.

We limit the incident-free dose calculation to the US50 route from the western city limits of Fallon to S Taylor St and from Fallon's northern city limits on US 95 to the S. Taylor St/US 50 intersection, and then the one mile distance along US95S to Fallon's southern town limit. We neglect any dose to the corridor population more than 1-mile from these two stretches of highway. We obtain the population density by dividing the town's population by the town's area surrounding these travel routes.

In addition to the dose to the corridor resident population, we include the transient tourist population, and the "on-link" population of motorists. According to the Churchill County Impact Report, about 200,000 visitors stay overnight in local motels and RV parks in Fallon each year. Nearly all of these facilities are within 1 mile of the highway. Therefore, we assume a steady visitor population in Fallon of 200,000/365, or 548 per day. No credit is taken for the likely increase in this figure with time.

An estimate of the "on link" population (average number of people in the street and in cars that is exposed to radiation from transportation casks) is made based on traffic figures given in the Churchill County Impact Report[12]. These are given for the years 1999 and 2020, so interpolation was used to estimate the traffic density for 2010. The densities are based on the average of the densities in Table 2-6 of the Impact Report for traffic on US 50 to 95S in the center of Fallon. These estimates are given in Table 4.

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[10] USDOE, Argonne National Laboratory, RISKIND-A Computer Program for Calculating Radiological Consequences and Health Risks from Transportation of Spent Nuclear Fuel, ANL/EAD-1, November 1995.

[11] If 1000 persons each receive a dose of 10 rems, the total dose to the population would be 10,000 person-rems.

[12] Churchill County Yucca Mountain US 50/95 Corridor Study Radiation Risk Assessment. March 2006

Table 4 – Traffic through Fallon

Year	Estimated Downtown Traffic Volume
2000	10,550
2010	19,010
2020	26,700

It is assumed that vehicles contain an average of 2 persons for the dose calculations. We also take into account the average present and projected stop times for trafiic lights and stop signs.

RISKIND Inputs

The RISKIND computer program was used to calculate the incident-free dose to the maximally exposed individual (MEI) and to the population of Fallon and immediate surroundings as a result of the truck shipping campaign through the city. Table 5 shows the inputs used in RISKIND. The program has to be run separately to calculate the dose to the MEI in rem/y and total rem, and to the population in person-rem/y, and total person-rem for both the mostly rail and mostly truck scenarios. The rem unit of measurement incorporates the health risks from radiation. Only truck shipments that are still needed under the mostly rail scenario were used to determine the incident-free dose to the MEI for the mostly rail scenario in Fallon.

Dose to the Maximally Exposed Individual (MEI)

The MEI is assumed to be located at the intersection of Williams and Taylor Streets, the intersection of US95 and US50, at a distance of 15 feet for every shipment. Four separate calculations were performed, to consider a person for both scenarios, both indoors and outdoors. We take the average traffic density over a 24-hour period, and also the increased traffic densities with time, from the year 2000 to the year 2020. For the year 2000, we assume that the MEI will be exposed to a stopped shipment at the traffic light for an average of 2 minutes, since this is the cycle duration of the traffic light at the US50/US95 intersection. These stop times would be greater in the year 2020, with increased population densities, but we assume the same stop time duration. We also assume that the MEI will be exposed to every shipment. This is obviously an overestimate, but it gives us an upper bound. For passing shipments, it is assumed that the trucks will travel at 25 mph near the intersection, since this is the posted speed limit. The speed of trucks passing through downtown Fallon will vary and will likely decrease with time, as traffic density increased. However the posted speed limit, 25 mph, is used for the dose calculations. The Riskind inputs appear in Table 5.

RISKIND calculates the dose per truck. We therefore multiply this dose with 1,079 – 3,122 for the mostly rail scenario and with 7,604 – 20,479 west-bound and 45,182 –

88,065 east-bound shipments for the mostly truck scenario to obtain the total dose in mrem. We then divide this dose by 24 and 39 y to calculate the annual dose in mrem/y for the "Proposed Action" and "Modules I & II" alternatives, respectively. The annual and lifetime dose of the MEI for both scenarios can be seen in Table 6.

Table 5 – Input parameters used for RISKIND for incident-free transport

Variable	Value	Comments
Distance from shipping route	15 feet to 1 mile	Exposure at distances greater than 1 mile is not significant
Corridor resident population density (persons/km^2)	649 (2000) 806 (2010) 1145 (2020)	Dividing the Fallon population by the area, 11.6 sq km
Tourist population density (persons/km^2)	47.2	Average of 548 tourists, distributed over Fallon area
Distance traveled	East-bound US50: 2.5 km to US 95 South-bound US95: 1.45 km to US50 + 1.45 km from US50/95	Calculated dose within Fallon
Fraction of population indoors	0	Used to obtain upper-bound, no-shielding estimate
1-way traffic density US50 (vehicles/hour)	433.3 (2003) 1154.2 (2010) 1695.8 (2020)	Based on a 24-hour day average traffic density US50 near US95
1-way traffic density US95 (vehicles/hour)	225 (2003) 585.4 (2010) 856.3 (2020)	Based on a 24-hour day average traffic density US95 near US50
People per vehicle	2	
Number of stops	US 50: 4 US 95S: 3	
Stop duration US50 (sec)	2003: 63.3; 2020: 145.7	Total average stop time on US50 for traffic lights
Stop duration US95 (sec)	2003: 45.6; 2020: 86.5	Average stop time on US95 for 2 traffic lights, 1stop sign
Number of people exposed during stop	50	20 people in nearby cars or pedestrians, 30 in nearby businesses/residences
Exposure distance of rail cars & trucks	2 to 90 meters	Assumption, RISKIND defaults
Average truck speed	25 mph	Average speed through downtown Fallon when moving
# lanes 1-way	2	
Lane width	3.7 meters	Assumption

Table 6 – Dose to the Maximally-Exposed Individual (MEI) from incident-free transportation (mrem)

		Mostly Rail Scenario		*Mostly Truck Scenario*	
Dose	**Scenario**	15 ft, outdoors	15 ft, indoors	15 ft, outdoors	15 ft, indoor
Yearly Dose (mrem)	Proposed Action	4.58	1.85	223.90	90.40
	Modules II	8.15	3.29	283.33	114.39
Lifetime Dose (mrem)	Proposed Action	109.84	44.35	5373.61	2169.50
	Modules I & II	317.82	128.31	11,049.78	4461.16

Population Dose Results

Again, RISKIND calculates the population dose per truck, and we therefore multiply the output with 1,079 – 3,122 west-bound shipments for the mostly rail scenario and 4223 – 18,781 east-bound and 48,563 – 89,763 west-bound shipments for the mostly truck scenario to obtain the total dose in person-rem. For the annual dose in person-rem/y, we divide the total dose by 24 and 39 years for the “Proposed Action” and “Modules I & II” scenario, respectively. The doses are calculated separately for three highway segments within Fallon and combined for the estimates that appear in Tables 7 and 8. The three highway segments are Eastbound on US 50 to S Taylor St, south on US 95 to US 50, and south on US 95 from US 50 to the Fallon city limits.

The incident-free dose to the population for the mostly rail scenario is given in Table 7 for the city of Fallon and immediate surroundings, based on the three population projections from 2000, 2010, and 2020. The dose population numbers for the mostly truck scenario are given in Table 8. It is broken down into categories of persons: residents, tourists, hose sharing the roadway with the shipment and stop times. Unlike the dose to the maximally exposed individual, which describes a worst-case scenario for a single person, the population dose is the expected average dose that is received by the population in Fallon and surroundings.

Table 7 - Incident-free dose rate to the population (person-rem/year) for the mostly rail scenario, using population estimates from 2000, 2010, and 2020

Receptors	Annual dose (person-rem/y) 2000	2010	2020
Proposed Action Scenario			
Off-link residents	0.0014	0.0018	0.0025
Tourists	0.0001	0.0001	0.0001
On-Link	0.0044	0.0114	0.0166
Stop Lights	0.0015	0.0017	0.0019
Total dose	0.0074	0.0149	0.0211
Expected LCF	0.0000	0.0000	0.0000
Modules I and II Scenario			
Off-link residents	0.0025	0.0032	0.0045
Tourists	0.0002	0.0002	0.0002
On-Link	0.0078	0.0202	0.0295
Stop Lights	0.0026	0.0030	0.0033
Total dose	0.0131	0.0266	0.0375
Expected LCF	0.0000	0.0000	0.0000

Table 8 - Incident-free dose rate to the population (person-rem/year) for the mostly truck scenario

Receptors	Annual dose (person-rem/y)		
	2000	2010	2020
Proposed Action Scenario			
Off-link residents	0.0715	0.0893	0.1267
Tourists	0.0052	0.0052	0.0052
On-Link	0.2335	0.6090	0.8889
Stop Lights	0.0791	0.0945	0.1099
Total dose	0.3893	0.7980	1.1307
Expected LCF	0.0004	0.0008	0.0011
Modules I and II Scenario			
Off-link residents	0.0935	0.1166	0.1655
Tourists	0.0068	0.0068	0.0068
On-Link	0.3246	0.8493	1.2410
Stop Lights	0.1096	0.1376	0.1655
Total dose	0.5346	1.1103	1.5788
Expected LCF	0.0005	0.0011	0.0016

In addition to the dose in person-rem, we also calculate the number of expected latent cancer fatalities (LCF) due to such a radiation dose. The Yucca Mountain FEIS used a population dose-to-cancer conversion factor of 2000 person-rem per latent cancer fatality. This number is based on a conversion factor of 0.0005 latent cancer fatalities per person-rem[13], which is a recommendation by the International Commission on Radiological Protection (ICRP)[14]. This ICRP report uses a Dose and Dose Rate Effectiveness Factor (DDREF) of 2 for exposure to low doses of radiation, which effectively cuts the probability of developing cancer from a given population dose in half. More recent data on cancer risk at low doses among Atomic Bomb survivors[15] suggest that using this DDREF may underestimate the actual risk from low radiation dose exposure. Without the DDREF, the radiation dose that on average causes one fatal cancer in an irradiated population is 1,000 rem. This radiation dose is called the *fatal cancer dose*.

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[13] USDOE, 2002. *Final Environmental Impact Statement for a Geologic Repository for the Disposal of Spent Nuclear Fuel and High-Level Radioactive Waste at Yucca Mountain, Nye County, Nevada*. pp 6-37.

[14] ICRP (International Commission on Radiological Protection) 1991. *1990 Recommendations of the International Commission on Radiological Protection.* Volume 21, No. 1-3 of *Annals of the ICRP*. ICRP Publication 60. New York, New York: Pergamon Press. TIC: 235864. pp 20-22.

[15] Pierce and Preston, 2000. "Radiation-Related Cancer Risks at Low Doses among Atomic Bomb Survivors." *Radiation Research* 154, 178-186.

The fatal cancer dose depends both on gender and age. Values for the estimated cancer dose, i.e. the dose that on average causes one fatal cancer, vary from source to source. Depending on the model used, the cancer dose is very low for children and extremely high for older people (Gofman)[16], or more stable across the ages (BEIR V[17], Pierce[18]). For male 1-y-olds, Gofman[19] gives a cancer dose of 65 rem. This dose increases to 200 rem at age 20, and 538 rem at age 40. After that, the cancer dose sharply increases, reaching 2,000 rem at age 46 and 13,434 at age 50. For higher ages, the cancer dose is even higher. This is due to the Gofman model, which contends that cancer incidence has a peak percent occurrence value 40 years after irradiation.

Other authors assume different models, and, as a consequence, obtain different results. The cancer dose for 5-y-old males, as given by BEIR V[20], is 858 rem. This dose reaches 1,041 by the age of 20, and 2,008 rem by the age of 40. The highest cancer dose given is for age 65, with a value of 3,448 rem. Pierce et al[21] provide similar numbers that are somewhat lower for young ages (556 rem at age 10) and higher for older males (3,781 rem at age 65), but the increasing trend of the cancer dose with age is evident in the results from all authors.

These numbers, taken together, support the fatal cancer dose of 1,000 rem obtained by not including the DDREF applied by ICRP. Using this result, we divide the total dose in Table 7 and 8 by 1,000 and obtain the number of expected LCF.

Dose due to a Severe Accident

In this section, we calculate the dose to individuals (in rem) and to the population (in person-rem) due to a severe accident involving a nuclear transportation truck cask, and the expected latent cancer fatalities. Rem is once again used as the unit of measurement to determine the amount of damage to human tissue from a dose of ionizing radiation. In a "severe accident", the cask is breached open upon impact or a long-duration fire, and radionuclides are released to the environment.

This section does not outline the consequences due to a severe rail accident as there are no rail lines that pass through Fallon that could be used to transport spent nuclear fuel to Yucca Mountain. Although the impacts of an accident involving rail casks carrying spent nuclear fuel may be more severe than that of a truck cask, the rail lines passing through Churchill County are located ~ 12.5 miles from the western boundary of Fallon's populated region. The sole rail line that does enter within the town's limits terminates near the center of town and would serve no purpose as a detour in SNF shipment. As

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[16] Gofman JW, *Radiation & Human Health*, Sierra Book Club, 1981.

[17] National Academy of Sciences, *Health Effects of Exposure to Low Levels of Ionizing Radiation*, BEIR V (Committee of the Biological Effects of Ionizing Radiation), National Academy Press, 1990.

[18] Pierce DA, Shimizu Y, Preston DL, Vaeth M and Mabuchi K, *Studies of the Mortality of Atomic Bomb Survivors, Report 12, Part I. Cancer: 1950-1990,* Radiation Research 146, 1-27, 1996.

[19] Gofman 1981, p. 285-88.

[20] BEIR V, p. 175.

[21] Pierce 1996, p. 13.

such, within this report, we consider only the acute and long-term doses due to a severe truck accident within the Fallon town limits.

Selection of a Hypothetical Accident Location

When performing a consequence assessment, it is vital to consider whether a severe accident could occur at a specific location. The location must have the characteristics necessary to produce a severe accident (e.g., high speeds, high drop-offs, steep gradients, potential for long-duration fire, presence of bridge abutments, etc.). Pinpointing the exact location and exact conditions surrounding a proposed accident is clearly impossible.

For the case of a truck shipment, there are relatively few areas near Fallon where a truck accident could be severe enough to result in the release of radioactive material. There are no highway overpasses or rocky outcroppings which could lead to the potential for a high-speed impact onto a rigid surface. Some concrete structures exist on the side of the highways, but none appear to be massive enough to have the potential to breach the cask. A severe accident would require a fairly high-speed collision or long duration fire, something that would only be likely within Fallon if caused by a collision with a gasoline tanker or explosion at a gas station. As such, The Gas Store, located at the intersection of Venturacci Lane and West Williams Ave./US 50 was determined to be the worst-case potential accident location.

For bounding purposes, this location is also valuable due to the region's prevailing northerly wind flow, which would result in the most significant doses to the population. The posted speed limit along the stretch of US 50 preceding this location is 35 miles per hour.

Another possibility for a severe accident may arise from the proximity of the Hawthorne Army Ammunition Depot. Ammunition is trucked to Fallon Naval Air Station (FNAS) on US 95. The potential for a severe accident could exist if a collision occurred between a truck carrying explosives and ammunition and a spent fuel truck, if some of the explosives were to detonate, possibly breaching the spent fuel confinement and leading to a significant release of radioactive material, perhaps in a fire. Accidents involving explosive military equipment (ammunition, missiles, bombs etc) have occurred several times. On August 4, 1985, in Checotah, Oklahoma, an automobile collided with a tractor-semi trailer transporting bombs, causing several explosions and a prolonged fire. The Army Corps estimated that 371 residences within a radius of 6,200 feet were damaged; 22 homes needed major reconstruction and 11 homes needed to be rebuilt. The explosion also destroyed a fire truck, two eastbound lanes of I-40 and the right shoulder of the highway. Approximately 3,382 tons (1,700 cubic yards) of material was used to fill the crater. There are other examples of accidents involving explosives: Roseville, California April 28, 1973 (18 RR boxcars of bombs) and Benson, Arizona, May 24, 1973 (12 RR boxcars of bombs). The Safety Board has also investigated two other munitions accidents. The first took place on August 1, 1984 when a Navy torpedo overturned at the intersection of two major highways in Denver. Enough fuel spilled to cause an explosion, but the fire department put out the fire before an explosion. The second was on May 10, 1985, when a tractor trailer carrying munitions struck a parked vehicle on I-85 near Bonnieville, KY resulting in a fiery accident. C-4 plastic explosives ignited and burned intensely, but did not explode. In addition, on June 4, 1971, an automobile collided with a tractor-trailer transporting non-military explosives near Macon, Georgia. Gasoline and diesel fuel leaked from the vehicle fuel tanks, a fire quickly engulfed both vehicles and the cargo exploded. Two firemen, a wrecker-operator and two bystanders were killed and 33 persons injured. We consider this accident within the realm of possibility, but a much less likely scenario. It is therefore not included it in our dose assessment.

Severity of an Accident

Once an accident location was chosen, the most severe accident that could plausibly occur at the site was estimated. It is important to note that the current-generation truck casks, which will likely be shipping fuel to the proposed repository at Yucca Mountain, have never been physically tested. Thus, the estimates of cask response to severe accident conditions are subject to error.

We base our cask response assumptions on the conclusions drawn from the Modal Study[22,23] with important exceptions as discussed below. We decided not to use the release estimates from the more recent NRC-commissioned study on spent fuel transportation risks, NUREG/CR-6672, for a number of reasons. The NUREG/CR-6672 estimates (1) are non-conservative, (2) contain many assumptions within accident scenarios which are subject to significant scientific criticism, and (3) provoke issues we have raised concerning its methodology and have yet to be addressed (Lamb, M., and Resnikoff, M., "Review of NUREG/CR-6672, Reexamination of Spent Fuel Shipment Release Estimates," prepared on behalf of Clark County, Nevada, October 2000). Until these matters are addressed, we will continue to use the previous study with certain modifications.

The accident severity was determined by examining the types of conditions that could plausibly occur at the location chosen. To begin, we classified the twenty cask response regions developed in the Modal Study into 6 release groups, as had been done by the Department of Energy in the DEIS for the Yucca Mountain facility. Structural response to accident conditions was determined in the Modal Study by an estimate of the percentage strain on the cask inner wall during duress. A category 5 accident, for example, was one in which the cask inner strain caused by impact conditions was between 2% and 20%. The Modal Study predicted this to occur at speeds of 20-60 mph, depending on cask type, orientation, and surface hardness. This type of accident is reasonable considering the conditions at the postulated accident location.

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[22] NUREG/CR-4929. Fisher *et al. Shipping Container Response to Severe Highway and Rail Accident Conditions.* Lawrence Livermore National Laboratory, 1987.

[23] NUREG/CR-6672. Sprung *et al. Reexamination of Spent Fuel Shipment Risk Estimates*. Sandia National Laboratories, 2000.

According to the modal study, the most severe accident severities require long-duration, hot fires (causing the cask mid-thickness temperature to exceed 1050°F), or strain rates exceeding 30%. These are truly catastrophic accident conditions. It is unlikely that the current-generation truck cask could achieve the 30% strain rates necessary for classification as a category-6-accident at locations in Fallon. Also, for a sustained, hot fire, large quantities of fuel are needed. It is unclear where such fuel could originate in the accident postulated in Fallon, unless a fuel truck slams into a nuclear transportation truck, which is extremely unlikely, since the accident location is off the highway, or a fire occurs at a gas station. It is important to note that a recent study by Greiner shows that the location of a shipping cask within a fire is an important consideration[24]. The hottest temperature within a fire is generally at the boundary where the most oxygen is present. If the cask seals, not the cask mid-thickness, are located at the fire boundary, they may degrade at much lower temperatures.

Spent Fuel Release Fraction Estimates

Below is a more detailed discussion of the various estimates made in determining the release fraction. The release fraction refers to the fraction of the nuclide inventory that is rapidly released, in this case due to a severe accident.

Fuel Inventory

We use the assumptions made by DOE in the Final Environmental Impact Statement (FEIS) for the proposed Yucca Mountain Facility[25]. The FEIS included a dose calculation for the MEI due to an accident or an attack on a fuel transport.

The FEIS assumes that fuel from a pressurized water reactor (PWR) is shipped in GA-4 truck casks, which have a radius of 0.508 m and a length of 4.4 m. There are 4 assemblies of 424 kg each of uranium per cask (4 PWR fuel assemblies). The average age of the spent fuel is 15 years, with an assumed burn up of 50,000 MWD/MTU.

Fuel Matrix

For a release of radioactive materials from a cask to take place, three barriers must be breached - fuel matrix, rod cladding, and cask. The fuel matrix contains the fissionable material and is surrounded by the rod cladding, which serves to confine and protect the fuel. This combined structure is further contained within a cask. When fuel is heated in reactors, a percentage of volatile radionuclides, such as cesium, will migrate out of the fuel matrix under the influence of temperature gradients and concentrate in the fuel-clad

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[24] Greiner M, Chalasani NR, and Suo-Antilla A, “Thermal Protection Provided by Impact Limiters to Containment Seal Within a Truck Package”, July 2005.

[25] USDOE, 2002. Final Environmental Impact Statement for a Geologic Repository for the Disposal of Spent Nuclear Fuel and High-Level Radioactive Waste at Yucca Mountain, Nye County, Nevada. (Cited here as YMFEIS)

gap, the space between the fuel pellet and the surrounding tube (see PNL-10540, 1995. Gray and Wilson, *Spent Fuel Dissolution Studies, FY1994 to 1994*. Pacific Northwest Laboratories, p vi.). This “gap cesium” inventory is directly related to the release fraction in the event of an accident because it can be released in the event of any cladding breach. Almost all of the cesium released in the event of a spent fuel shipping accident will be this “gap cesium.” For the fuel matrix, the Modal Study assumes 0.3% of the cask inventory of cesium will be present between the cladding and the fuel pellet. However, we believe that the estimate made by Gray et al (9.9% gap cesium inventory) is on more solid experimental ground. Assuming the cesium release fraction is directly proportional to the gap inventory, we intend to increase the release fraction posted in the Modal Study by a factor of 33. For particulates and gases, other release fractions apply, as discussed below.

In addition, the Modal Study does not adequately consider CRUD spallation, or fragmentation, in the event of an accident. CRUD resides on the external surfaces of fuel assemblies and it is more easily dislodged and dispersed in a severe accident. We will assume an independent estimate for this source term, using the average CRUD surface density given for PWR reactors in the RISKIND User’s Manual.

Cask Opening

The Modal Study assumes all material within the cavity is released if a leak path exists, and it further assumes a leak path exists for any accident with maximum strain greater than 0.2%. According to the Modal Study, Category 5 accidents produce greater than a 2% strain on the cask inner wall. The Modal Study estimated that a 2% strain on the cask inner wall could occur in an end-on impact with an unyielding target at a velocity of 46 mph. For a truck cask, a 30% strain on the cask inner wall could occur in an end-on impact with an unyielding target at a velocity of 76 mph (Modal Study, p. 7-5). A 2% strain assuming a side impact with a train sill (or similar immovable object such as a bridge abutment) could occur at a speed of 20 mph. In our opinion, these accident speeds are plausible at the chosen accident location.

Rod Cladding Breach

Rod cladding surrounds the fuel matrix and serves to confine and protect the fuel from being released. A breach of the cladding will cause a release of harmful radiation to the atmosphere. This could be caused by an impact or internal rod pressure due to high temperature. Since we do not assume a hot fire in an accident in Fallon, as discussed above, we concentrate on breach due to impact.

The Modal Study assumes the rods are most susceptible to breach in an end-on impact (p. 8-7). Fig. 8-3 of that study shows that 3% break occurs in an impact resulting in 0.2% strain (at an acceleration < 40g), 10% break in an impact resulting in 2% strain (40-100g), and 100% break in an impact resulting in 30% strain, >100g. However, other studies (in particular, the one relied on by Holtec in its SAR for the HI-STAR 100 cask)[26] show that a sideways impact greater than 63g is sufficient to shatter the cladding. All impact accidents we consider here have a deceleration greater than 63g, so we assume 100% of the cladding is shattered by impact.

Postulated Release Fractions

For the postulated fractions of radioactive inventory released, we take the results from the Modal Study for accidents corresponding to severity category 5, correcting for cesium and CRUD, as is presented in the following table:

Table 9 – Postulated Severe Truck Accident Release Fractions

Inert Gas	Iodine	Cesium	Ruthenium	Particulates	CRUD
3.30E-01	2.50E-03	6.60E-03	2.70E-05	2.00E-05	1.00E+00

Meteorological Conditions

It is impossible to predict the exact meteorology at the location of a postulated accident. In fact, the choice of a specific meteorological profile is rather arbitrary for a consequence assessment.

For the dose to the maximally exposed individual in the centerline of the plume, we calculate the dose that would not be surpassed in 95 % of all weather conditions. This means that for the individual dose, we did not input the wind speed and direction, but used average weather data and took the results for 95 %-weather conditions.

For the population dose calculation, we have decided to use average weather data from the closest available monitoring station. There is not a single predominant wind direction. The most predominant wind direction between January 2001 and February 2002 was north[27]. The average wind speed in this period was[28] 2.35 mph or 1.06 m/s.

For the Pasquill stability class (measure of the air mixing or diffusion ability of meteorological conditions), we apply Class D.

Exposure Times

Our analysis assumes an acute exposure time of 24 hours. The choice of this length of time was made based on research into evacuation times for disaster situations along with the unique challenges presented by the postulated Fallon accident.

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[26] UCID-21246. Chun, Witte and Schwartz, "Dynamic Impact Effects on Spent Fuel Assemblies." Lawrence Livermore National Laboratory, 1987.

[27] http://www.gpick.com/wea, accessed on April 18, 2002

[28] ibid

It is assumed that the postulated accident is severe enough to prevent evacuation along US 50 West, effectively preventing a major evacuation route. Given the prevailing meteorological wind conditions, the wisest direction away from the accident effects would be to the north on US 95 and east on US 50. The inability to utilize southern and western evacuation highways would significantly restrict the number of egress routes in the event of the postulated accident, causing for relatively difficult evacuation conditions.

A 24-hour evacuation time estimate is appropriate for a township such as Fallon. While it may be possible that an evacuation could take place in a shorter period of time, this would require significant emergency planning above that which currently exists in many small towns.

For the long-term exposure, we calculate the dose to individuals and the population after 1 and 50 years. The nature of the long-term exposure is different from that of acute exposure. Whereas the acute radiation dose is mainly due to inhalation of radioactive airborne particulates, direct gamma radiation from deposited particulates (ground shine) is the most important factor for long-term exposure.

Methodology

In addition to RISKIND, the computer program HotSpot[29] was used to obtain contaminant plumes for later inclusion onto a map of Fallon and its surroundings. Besides calculating an incident-free dose (see above), RISKIND is also designed to provide risks and consequences of spent fuel shipping accidents. HotSpot was developed at Lawrence Livermore and is used to estimate levels of radioactive contamination following an accident. Both use standard Gaussian plume dispersion equations to estimate airborne concentrations and ground deposition of radionuclides.

We calculate the dose for individuals living at different distances downwind from the accident in the centerline of the contamination plume, and for the population living within the contamination plume calculated with HotSpot.

The dose calculation for individuals was carried out exclusively with RISKIND. Also, we used RISKIND to calculate the released radionuclides that served as an input for HotSpot for the population dose calculation.

The population dose was calculated by superimposing acute-dose-isopleths onto a map of Fallon and its surroundings. With the average dose (rem) between two isopleths, and the respective population density (persons/km^2) and area (km^2), we calculated the population dose in person-rem. Rem is a unit used in radiation protection to measure the amount of damage to human tissue from a dose of ionizing radiation. Population densities and areas were taken from the U.S. Census 2000 for the City of Fallon and Churchill County.

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[29] "Hotspot Health Physics Code, Version 1.06." Lawrence Livermore National Laboratory. Steven G. Homann, contact.

Areas and population densities between plumes, inside and outside of Fallon, were calculated using the plume maps.

HotSpot provides estimates of ground deposition and acute dose only. However, because acute and long-term dose are directly proportional, we used correlation factors derived from RISKIND to multiply with the acute population dose in order to obtain the long-term population dose.

Table 10 shows the parameters that were used as inputs for RISKIND and HotSpot. Most values were taken from the Yucca Mountain Final Environmental Impact Statement (YM FEIS), Chapter 6 and Appendices A and J. For parameters that we did not specify here, we used default values.

Table 10 – Inputs into RISKIND and HotSpot

Parameter	**Value**	**Comments**
RISKIND:		
Acute Exposure	24 h	Estimated evacuation time
Long-term exposure	1 and 50 yr	Exposure range
Shielding	none	Default
Food pathway	off	Not enough information
Water pathway	off	Not enough information
Cask dimensions	length 4.4 m radius .508 m	From YM FEIS
Burnup	50,000 MWD/MTU	From YM FEIS
Cooling time	15 y	From YM FEIS
Total uranium in cask	1.696 MT	YM FEIS; 4 assemblies of 424 kg
Cask cavity surface area	39 m^2	Default
Crud surface activity	140 $micCi/m^2$	From YM FEIS
Mixing height	400-1600 m	Default
Temperature	283 K	Default
Anemometer height	10 m	Default
Rainfall	none	Default
Release height	1 m	Default
Release fractions:		
Particulates	0.00002	Modal Study
Ru	0.000027	Modal Study
Cs	0.0066	Value from Modal Study, multiplied by 33
I	0.0025	Modal Study
Gas	0.33	Modal Study
Heat release	500 ca/s	Default for accident without heavy fire
Parameter	**Value**	**Comments**
HotSpot:		
Dispersion model	General plume	
Released radionuclides	2.5 Ci of Sr-90; 1,210 Ci of Cs-137; .219 Ci of Pu-238; .0145 Ci of Pu-239; .0251 Ci of Pu-240; 2.68 Ci of Pu-241; .101 Ci of Am-241; .152 Ci of Cm-244; 7.82 Ci of Co-60; 21.8 Ci of Cs-134	Output from RISKIND
Deposition velocity	1 cm/s	Output from RISKIND
Wind speed	1.1 m/s	Average wind speed 2003-2004
Wind direction	N	Dominant direction (1984-92)
Stability class	D	Most frequent stability class

Results

Receptors and pathways

In a severe truck accident, airborne radioactive particulates would be released and transported downwind. The population downwind would then inhale these particulates and receive a radiation dose. Particulates would settle on the ground, plants and surface streams. Radiation emanating from the ground (ground shine) due to gamma rays would also give rise to a radiation dose that increases with the ground concentrations and the length of time a person remained in the contaminated area. Because we lack detailed data about hydrological aspects and food production/consumption in Fallon, we exclude the dose due to ingestion of contaminated water and food from the analysis.

RISKIND calculates a radiation dose to individuals who live straight downwind from the accident along the plume centerline, at different distances. We chose the distances of 50 m, 100 m, 200 m, 500 m, 1 km, 2 km, 5 km, 10 km, 20 km and 50 km.

Dose to individual

The acute (24 h) dose in rem to an individual directly downwind from the accident location was calculated for 95 % of all weather conditions. This means that there is only a chance of 5 % that the dose would even be higher, due to extreme weather. The results are shown in Table 11. The rem unit of measurement incorporates the health risks from radiation. All calculated doses are without any remediation and assume an individual remains in the unremediated area. The very high long-term doses dictate a cleanup or a permanent evacuation, since they are not acceptable. The question remains as to what area has to be remediated. We discuss this matter below in the section, “population dose.”

Table 11 - Dose to individual living downwind from accident

Distance Downwind (km)	Acute Dose[1] (rem)	1-y-Dose[2] (rem)	50-y-Dose[3] (rem)
0.05	544	4,900	91,000
0.1	188	1,690	31,400
0.2	107	963	17,900
0.5	69.1	622	11,600
1	22.8	205	3,810
2	5.61	50.5	939
5	0.726	6.54	122
10	0.201	1.81	33.6
20	0.0475	0.428	7.95
50	0.00555	0.05	0.929

[1] Acute Dose -- a single, fairly large dose that persists for a very short time, yet produces adverse effects
[2] 1 Year Dose -- the combined dose due to inhalation, ground shine, and cloud shine for a period of one year
[3] 50 Year Dose -- the combined dose due to inhalation, ground shine, and cloud shine for a period of 50 years

Obviously, the acute dose cannot be avoided by remediation. Therefore, assuming immediate and perfect remediation, this is the minimum dose that individuals living along the center of the contamination plume would receive in case of a category-5-accident.

Acute dose to the population

The next step was to superimpose plume diagrams on the map of Fallon to estimate the amount and extent of contamination and dose from a severe truck accident. Plumes for acute dose and ground deposition concentration were obtained from the HotSpot computer model and plotted in a Geographic Information System (GIS), examples of which are illustrated in Figures 2 through 4.

Because the population density inside of Fallon is very different from that outside, we differentiate between the city and the (rural) surroundings. In Figure 2, the blue outlined area encloses the city boundary of Fallon. Using the population estimates from Table 1, we arrive at a population density in Fallon of 967, 1,201 and 1,706 people per km^2 for the years 2000, 2010 and 2020, respectively (Table 12). The population density of Churchill County, excluding Fallon, therefore becomes 1.26, 1.57 and 2.23 p/km^2..

Table 12 - Population density of Fallon and Churchill County

Region	Pop. 2000	Pop. 2010	Pop. 2020	Area (km^2)	Dens. 2000 (p/km^2)	Dens. 2010 (p/km^2)	Dens. 2020 (p/km^2)
Churchill County	23,982	29,784	42,294	13,010.00	1.84	2.29	3.25
Fallon	7,536	9,359	13,290	7.79	967.39	1,201.41	1,706.03
Churchill County excl. Fallon	16,446	20,425	29,004	13,002.00	1.26	1.57	2.23

The population dose (person-rem) is calculated by multiplying the average dose (rem) of a dose zone with the respective population (persons). The dose zones are the areas between two neighboring dose isopleths. The dose zone population is calculated from the population density and the surface of each dose zone. The isopleths of the highest acute doses are completely inside of Fallon, whereas the ones with acute doses below 500 mrem are partially outside. By measuring the plumes on the map and applying basic geometric calculations of ellipse segments, we calculate the area of each dose zone inside and outside of Fallon (Table 13).

For example, the second dose zone listed in Table 13 is the area between the 100 rem plume and the 50 rem plume (Figure 1). The average dose in this area is calculated as (100+75)/2 = 75 rem. We then multiply this number by the plume area (km^2) and the respective population density ($persons/km^2$) to determine the acute population dose (person-rem), [75 rem*0.004 km^2* 967.39 p/km^2 (2000) = 290.2 person-rem]. This number represents the average dose to the population for the area between the 100 rem and 50 rem plumes.

Table 13 - Acute dose to the population from truck accident

Dose zone between isopleths	Average Dose in dose zone (rem)	Total (km^2)	within Fallon (km^2)	outside Fallon (km^2)	2000 (person-rem)	2010 (person-rem)	2020 (person-rem)
inside 100	>100	0.007	0.007	0	677.2	841.0	1,194.2
100 to 50	75	0.007	0.007	0	507.9	630.7	895.7
50 to 10	30	0.065	0.065	0	1,886.4	2,342.7	3,326.8
10 to 5	7.5	0.091	0.091	0	660.2	820.0	1,164.4
5 to 3	4	0.14	0.14	0	541.7	672.8	955.4
3 to 2	2.5	0.19	0.19	0	459.5	570.7	810.4
2 to 1	1.5	0.6	0.287	0.313	417.1	517.9	735.5
1 to .5	0.75	1.6	0.287	1.313	209.5	260.1	369.4
.5 to .4	0.45	0.8	0.287	0.513	125.2	155.5	220.8
.4 to .3	0.35	1.5	0.287	1.213	97.71	121.3	172.3
.3 to .2	0.25	3.3	0.287	3.013	70.36	87.38	124.1
.2 to .1	0.15	10.7	0.287	10.413	43.61	54.17	76.9
outside .1	< .1	N/A	N/A	N/A	omitted	omitted	omitted
Total					5,696.39	7,074.42	10,045.84

Long-term population dose and latent cancer fatalities

1-year and 50-year long-term dose estimates were made for the combined dose due to inhalation, ground shine, and cloud shine. For long-term population doses, ground shine due to deposited cesium is the major contributor. Other potential pathways, namely food and water ingestion, were not included in this calculation. Instead, this is discussed later on in this paper.

The methodology of arriving at population dose estimates utilizes the fact that long-term dose estimates are directly proportional to acute dose estimates. Estimating a long-term dose estimate then simply becomes an exercise in finding the correct multiplier. This was done using RISKIND, which provides estimates of both acute and long-term dose. Examining the dose estimates at given distances, it was determined that a 1-year long term dose was ~3.3 times greater than the corresponding acute dose, and a 50-year dose was ~61.4 times greater than the acute dose. The results for the long-term population dose estimates are given in Table 14.

To calculate the number of expected latent cancer fatalities (LCF), we again divide the population dose by 1,000 rem, as was done in the incident-free dose calculation.

Table 14 – Latent cancer fatalities due to population dose

	Truck Accident		
	Population Estimate		
	2000	**2010**	**2020**
Acute population dose in 24 h (rem)	2,363	2,934	4,167
LCF	2.36	2.93	4.17
Long-term population dose in 1 y (rem)	7,726	9,595	13,626
LCF	7.73	9.60	13.63
Long-term population dose in 50 y (rem)	145,075	180,170	255,846
LCF	145.08	180.17	255.85

The long-term population doses are theoretical doses to which the population would be exposed if no remediation and/or evacuation took place. If a severe accident takes place in 2020, no cleanup takes place and people live in Fallon for another 50 years, then the there would be 256 expected latent cancer fatalities. This would be approximately 1% of Fallon's corridor population in the year 2020. It therefore follows that evacuation and remediation is imperative for category-5-accident scenarios involving nuclear waste transport.

In case of a full evacuation, followed by perfect remediation, the population dose would effectively be the acute dose, likely between 2.36 and 4.17 fatalities. However, perfect remediation is not possible. Therefore, the acute dose and the corresponding LCF have to be understood as a lower bound. Due to the necessarily imperfect remediation, the actual population dose in case of an accident would be higher in any case.

Estimated area requiring remediation

There is currently no universally accepted decontamination level for areas subjected to radioactive contamination. However, there are a few general guidelines. For example, the Environmental Protection Agency set a cleanup level at an above background effective dose of 15 mrem/year for Superfund sites[30], including exposures from all pathways. The Nuclear Regulatory Commission specifies a cleanup level of 25 mrem/y in its Radiological Criteria for License Termination. The EPA has also issued a Protective Action Guide[31] that states the doses in any single year after the first must not exceed 0.5 rem and that the cumulative dose over 50 years (including the 1st and 2nd years) must not exceed 5 rem. For this analysis, we will use both the EPA criteria for Superfund sites and the EPA Protective Action Guides to estimate the area requiring

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[30] OSWER 9200.4-18, "Establishment of Cleanup Levels for CERCLA Sites with Radioactive Contamination," Aug. 22, 1997.

[31] EPA 400R-92-001. "Manual of Protective Action Guides and Protective Actions for Nuclear Incidents." US EPA Office of Radiation Programs, 1992.

remediation. Rem is once again used as the unit to measure the amount of damage to human tissue from a dose of ionizing radiation.

This is clearly a prohibitive cleanup action. In addition to the region outside of Fallon that be remediated, a major part of the city would have to be scraped - buildings, streets, grass, and so on, the costs of which are explored in the ensuing section.

Using the EPA Protective Action Guides, Table 15 shows that the locations on the 100 mrem acute-dose isopleth correspond to a first-year dose of 327 mrem, the 50-year dose of which, 6.14 rem, exceeds the Protective Action Guide limit for remediation. The area that would consequently require remediation under this guideline is 4.5 km^2. Most of this area is outside of Battle Mountain, but the EPA cleanup standards remain valid outside the town.

For the first year after the postulated accident, we see that a person living along the 50 mrem acute-dose-isopleth would receive a first-year dose of 163.5 mrem due to ground shine, cloud shine, and inhalation. If instead we take the 50-year individual dose and divide by 50 to get an average annual long-term dose, the 50 mrem plotted isopleth corresponds to an average yearly dose of 61 mrem/y, exceeding the EPA cleanup level for Superfund sites. According to this threshold, it is therefore necessary to remediate the area within the 50 mrem acute-dose-isopleth. This corresponds to a total area of 9.2 km^2. Therefore, under this incident scenario, the likely area of remediation will range somewhere between 4.5 – 9.2 km^2.

Table 15 - Area in need of remediation

Isopleth of acute dose (rem)	Total area within isopleth (km^2)	1-y-dose on isopleth (rem)	50-y-dose on isopleth (rem)	Average annual dose for 50-y-dose (rem)
100	0.004	327	6,140	122.8
50	0.008	163.5	3,070	61.4
10	0.038	32.7	614	12.28
5	0.078	16.35	307	6.14
3	0.13	9.81	184.2	3.684
2	0.2	6.54	122.8	2.456
1	0.41	3.27	61.4	1.228
0.5	0.86	1.635	30.7	0.614
0.4	1.1	1.308	24.56	0.491
0.3	1.5	0.981	18.42	0.368
0.2	2.2	0.654	12.28	0.246
0.1*	4.5	0.327	***6.14***	0.123
0.05**	9.2	0.1635	3.07	***0.061***
0.01	39	0.0327	0.614	0.0123
0.0015	175	0.004905	0.0921	0.0018
0.001	236	0.00327	0.0614	0.0012

* Boundary of region in need of remediation using EPA Protective Action Guides levels
** Boundary of region in need of remediation using EPA Superfund cleanup level

Ingestion of soil, water and food

In our analysis, we neglected the dose due to ingestion of contaminated soil, water and food. The Fallon area sits in the middle of the Newlands Irrigation Project, which covers about 60,000 acres of surface irrigated crop land. This area produces vegetables, corn, alfalfa and more. About 13,000 milking cows are kept in the area, and the Newlands Project provides about 1/3 or the milk consumed in northern Nevada and the eastern slope of the Sierra Nevada in California. In addition, the area produces meat for local and regional consumption. In short, agriculture is very important in the Fallon area, and its products are not only used locally, but also distributed in a large region. Large-spread ground contamination due to a severe transportation accident would therefore have impacts in an area much larger than Churchill County.

A previous study[32] used the RESRAD[33] computer code to calculate the dose due to ingestion pathway. The main RESRAD input was taken from the Hotspot ground contamination output. The contamination was assumed to be contained within the uppermost 15 cm of the soil (default plant root depth) with a soil density of 1.5 g/cm³.

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[32] Resnikoff M, Hintermann B and Lamb M, "Fallon Impact Report: Transportation of Spent Nuclear Fuel by Highway to Yucca Mountain", August 2002.
[33] "RESRAD, Version 6.3." Argonne National Laboratory. Dr. Charley Yu, contact.

Each radionuclide's soil concentration was then found by calculating its fraction of the total released activity, using the release totals from RISKIND. 99.75 % of the total contamination was due to Cs-137, 0.2 % due to Sr-90, and the remaining fraction was due to all other released radionuclides. Also, as in the case of a shallow aquifer, an unsaturated zone thickness of 2 m was applied. The results showed that the first-year dose due to ingestion of contaminated food, water and soil was 40.6 mrem for the 100 µCi/m², which covered an area of 0.84 km². This dose was also the maximum annual dose. The dose was exclusively due to water-independent pathways. The groundwater pathway does not contribute to the total dose until >100 years after the accident, at which point the total dose is very small.

In comparison, the first-year dose due to ground shine on the 500 mrem acute-dose-isopleth, which encloses an area comparable in size to that of the 100 μCi/m^2-isopleth, is 1.9 rem (Table 15). This means that the dose due to inhalation and ground shine is about 47 times greater than that due to ingestion of food, water and soil. The ingestion dose is therefore negligible for local residents in comparison to the acute dose (mainly inhalation) and long-term dose (mainly ground shine) that they will receive in case of an accident. However, the dose due to ingestion of food is "exported" to other regions, i.e. it reaches people that live far away from the accident location, if agricultural production is not halted after an accident or the contaminated region remediated. Since remediation would be necessary in any case due to the otherwise unacceptable population dose and resulting LCF as presented in Table 14, we do not consider the export of contaminated food as an important health risk to the region. However, it is another argument for the necessity of large-scale remediation in case of an accident involving a nuclear shipment in Fallon.

Cost of Remediation

As has been previously discussed, many of the latent effects of such accidents could be prevented with proper evacuation and decontamination. There is, however, an enormous monetary expense associated with this proper decontamination.

Previous estimates of the duration of decontamination following a plutonium dispersal accident were made by Chanin & Murfin[34]. Their study estimated the activities likely to be involved in the decontamination of an accident involving the dispersal of plutonium. Although the radioactive materials they studied is different than the spent fuel accidents discussed in this study, the methodology and conclusions used by Chanin & Murfin to estimate decontamination costs are directly useful. For example, their study estimates the cost of decontamination as a function of the level of cleanup required to achieve an acceptable level. The cleanup level is assigned a decontamination factor (DF) of 1, meaning that no cleanup is needed to meet the criteria. Areas contaminated up to 5 times the cleanup level are considered to be lightly contaminated. Areas with levels between 5 and 10 times the cleanup level are considered to be moderately contaminated, and areas exceeding 10 times the cleanup level are considered to be heavily contaminated. For

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[34] Chanin & Murfin, 1996

each level (light, moderate, heavy), certain cleanup assumptions are made and a cost is estimated for both rural and urban environments. Further, the costs associated with cleanup assumed in the Chanin & Murfin study are relatively non-specific with respect to the type of contamination. For example, they estimate the cost involved with scrubbing sidewalks and buildings in order to remove contamination, which would occur in the aftermath of a spent fuel accident involving the release of radioactive particulates. Therefore, we use these criteria to estimate cleanup costs. In addition, we use the estimates made by Chanin & Murfin with regard to the duration of decontamination, applying the contaminated areas estimated here to their values.

In order to estimate the extent of contamination and the required cleanup, an estimate of the acceptable cleanup level is required. While the actual cleanup criteria adopted after a severe accident may ultimately be dictated by local concerns, Price-Anderson insurance, and Congressional activity, the EPA's Protective Action Guide (PAG) states that relocation is warranted when the first year dose will exceed 2 rem. Any yearly dose after the first year should not exceed 0.5 rem, and a cumulative total of 5 rem is set as the limit for a 50-year exposure period. The study by Chanin & Murfin estimated that for an urban or mixed-use area, remediative costs would be approximately \$394 million/km^2 to for heavy contamination (greater than 10 times the cleanup criteria), \$182 million/km^2 for medium contamination (between 5 and 10 times the cleanup criteria), and \$128 million/km^2 light contamination (between 1 and 5 times the cleanup criteria). For rural and western rangeland regions, these costs are significantly lower (~\$37.5 - \$38 million/km^2). The area measure is based on the impacted Fallon urban area (in this case, ~.313 km^2) and the price differential between these land use types is incorporated into the final cost assessment. These values must be adjusted for inflation and are given in Table 18 in 2005 dollars.

Table 16 - Remediative costs/km^2 of EPA contamination levels

Year	Highly Contaminated Urban (10x EPA Decontamination Threshold)	Moderately Contaminated Urban (10-5x EPA Decontamination Threshold)	Lightly Contaminated Urban (5-1x EPA Decontamination Threshold)	Western Rangeland
1996	\$ 394,000,000	\$ 182,000,000	\$ 128,000,000	\$ 37,500,000
2005	\$ 478,246,721	\$ 220,915,998	\$ 155,369,493	\$ 46,656,366

It is important to note that the Chanin & Murfin cost estimates are based on assumed urban land use characteristics and population density. However, many of the costs associated with decontamination are "fixed," not influenced by population density. For example, demolition and restoration costs are relatively independent of population density, as are decontamination costs for streets and sidewalks. Using the EPA's PAG and the cost estimates made in the Chanin & Murfin study, we estimate the cleanup costs following the hypothetical accident in Tables 17.

Table 17 - Remediative costs for truck accident in Fallon based on EPA Protective Action Guideline and Superfund cleanup thresholds

	Remediative Costs ($)	
Isopleth of acute dose (rem)	**Based on EPA Protective Action Guidelines**	**Based on EPA Superfund Threshold**
100	$1,912,987	$1,912,987
50	$3,825,974	$3,825,974
10	$18,173,375	$18,173,375
5	$37,303,244	$37,303,244
3	$62,172,074	$62,172,074
2	$95,649,344	$95,649,344
1	$154,389,527	$73,742,079
0.5	$94,737,443	$74,195,169
0.4	$85,392,697	$85,392,697
0.3	$104,055,243	$104,055,243
0.2	$136,714,699	$136,714,699
0.1	$244,024,341	$244,024,341
0.05	****	$463,309,261
0.01	****	****
0.0015	****	****
0.001	****	****

**** Below EPA-ascribed contamination threshold

Conclusion

This report calculated the radiation dose to the maximally exposed person at the intersection of S Taylor St and US50, and also calculated the average dose to the population under incident-free conditions.

We have also shown that a severe transportation accident leading to a release of radioactive particulates is both possible and credible. Such an accident would lead to high radiation exposures due to inhaling and ingesting radioactive particulates and from ground shine. Ingestion would arise from contamination of food and water. Remediation of the contamination plume to EPA CERCLA cleanup standards involves an area 4.5 – 9.2 km^2, extending 20– 38 km downwind. Although we have not included in our assessment the radiation exposure to clean-up workers, the economic costs of a remediation of such an incident has been illustrated to be significant. DOE shipments are insured under Price-Anderson insurance, but the timing of the payouts is problematic since this requires a Congressional authorization.

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Figures

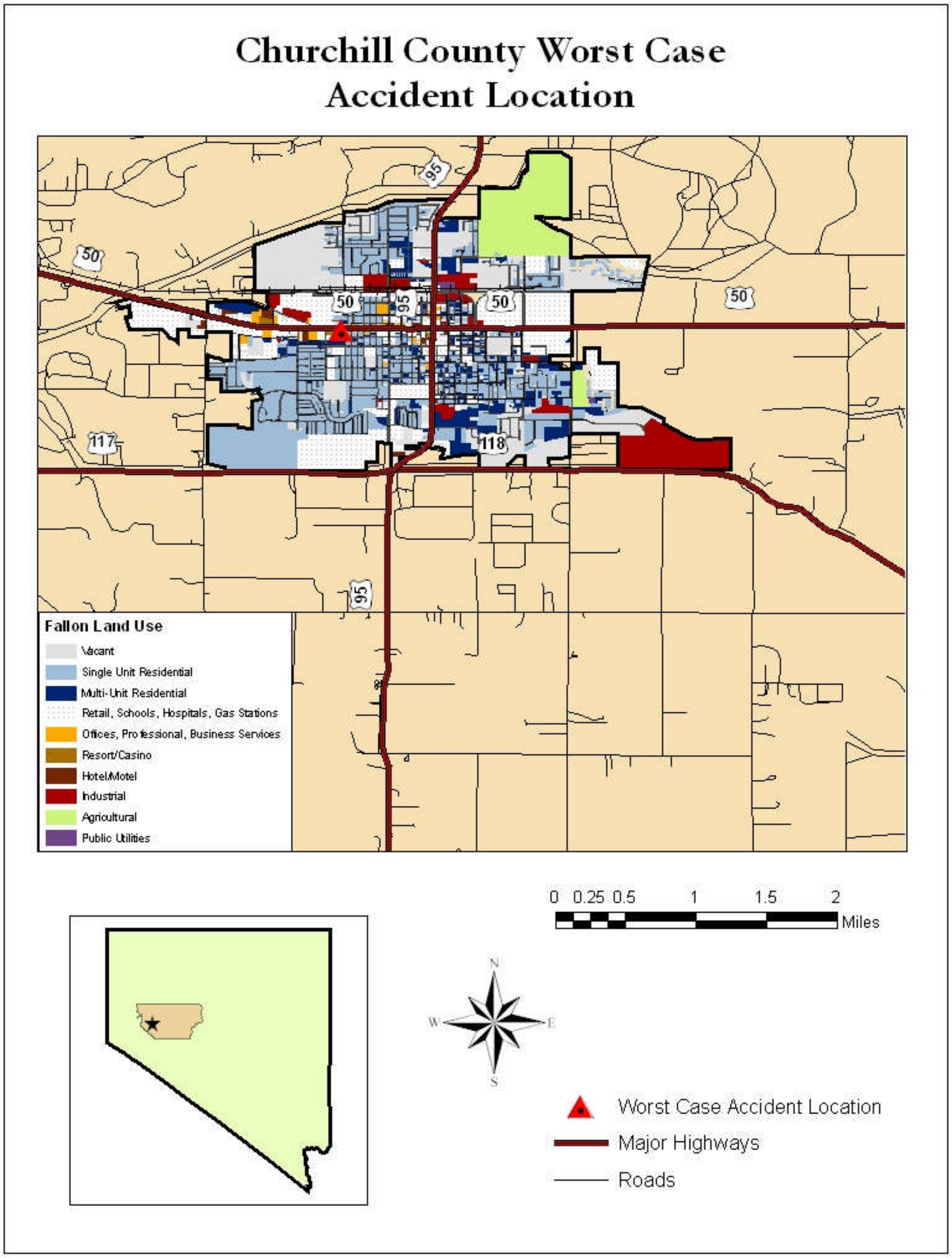

Figure 1 - Worst Scenario Accident Location for Churchill County

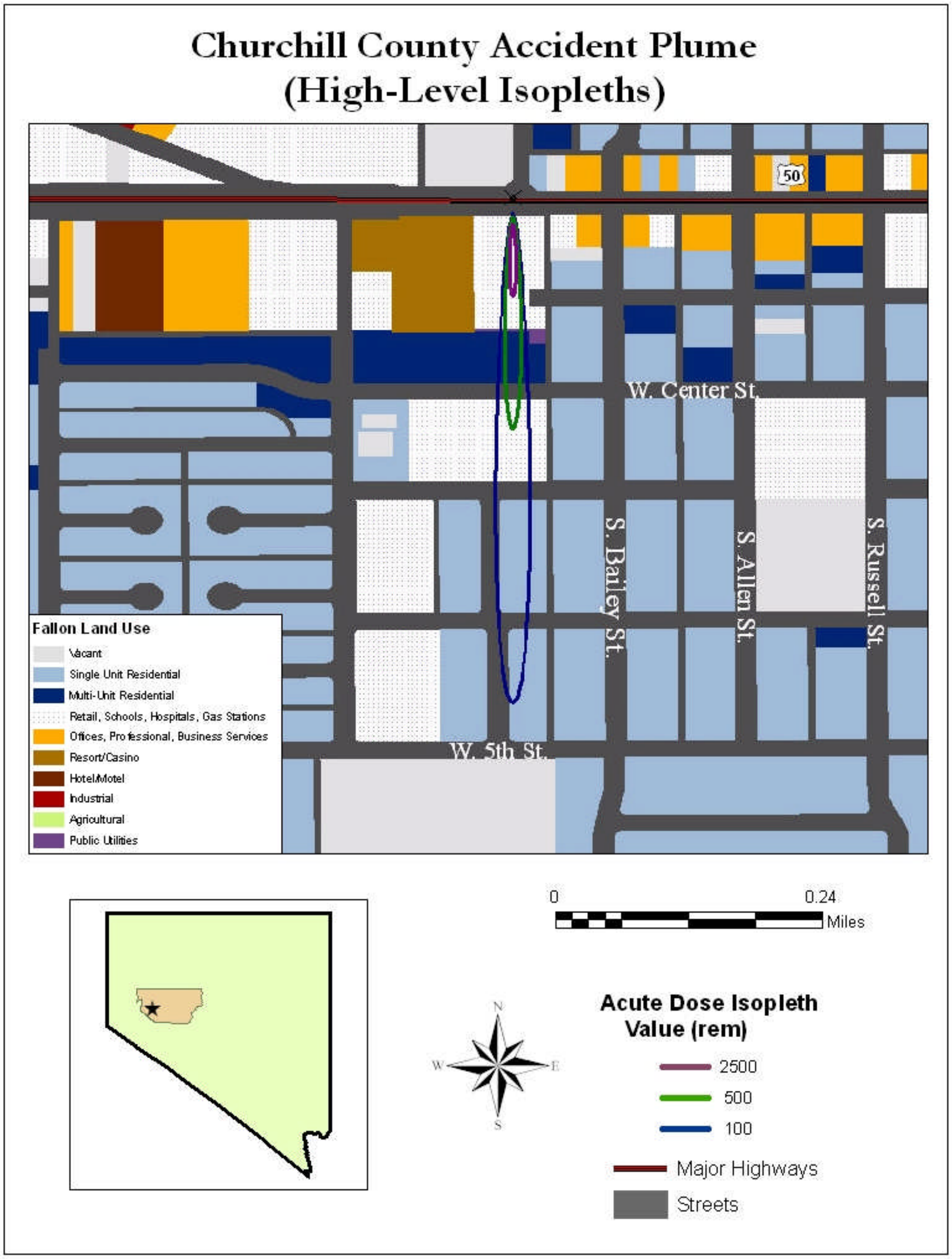

Figure 2 - High-scale acute dose isopleths for Fallon accident

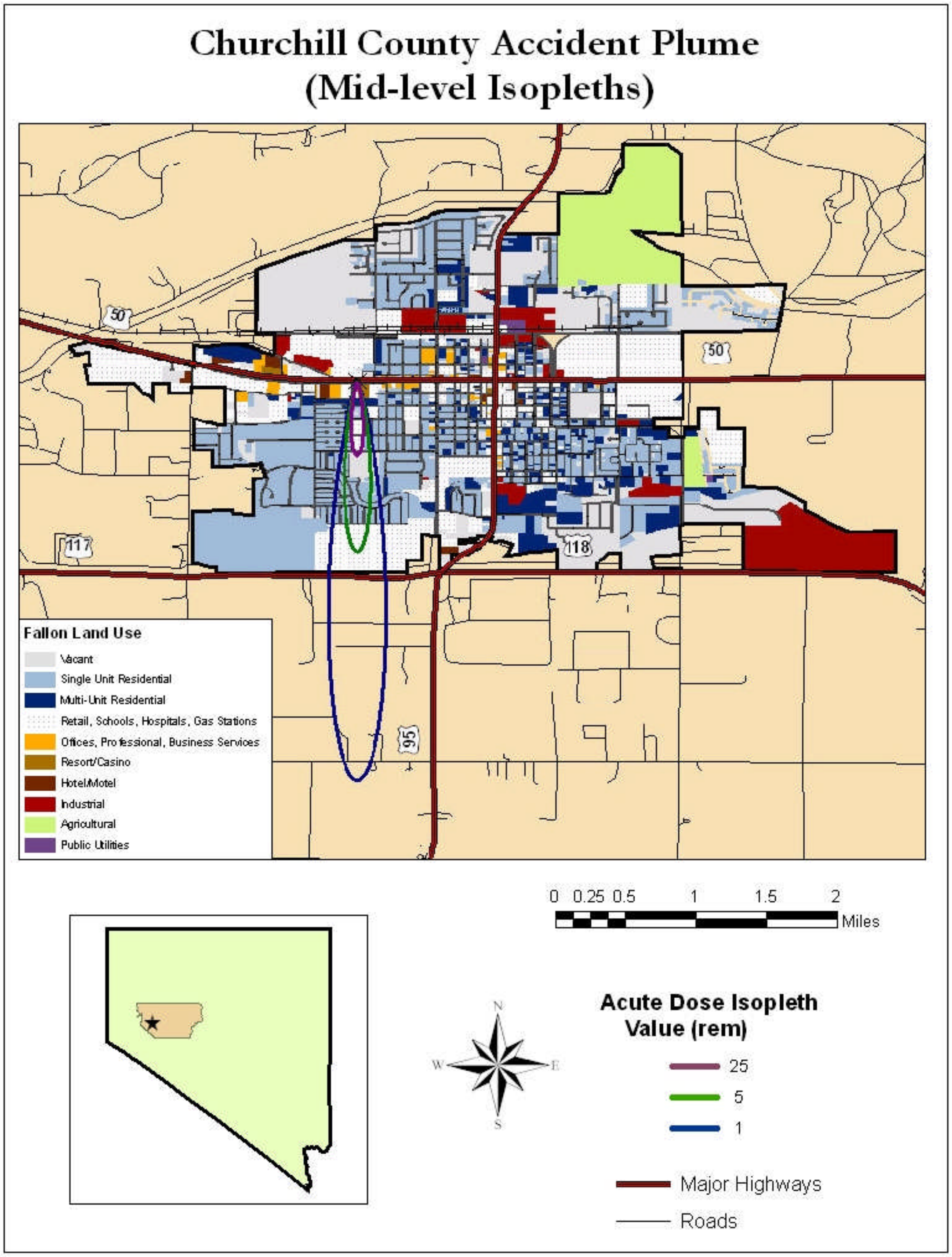

Figure 3 - Medium-scale acute dose isopleths for Fallon accident

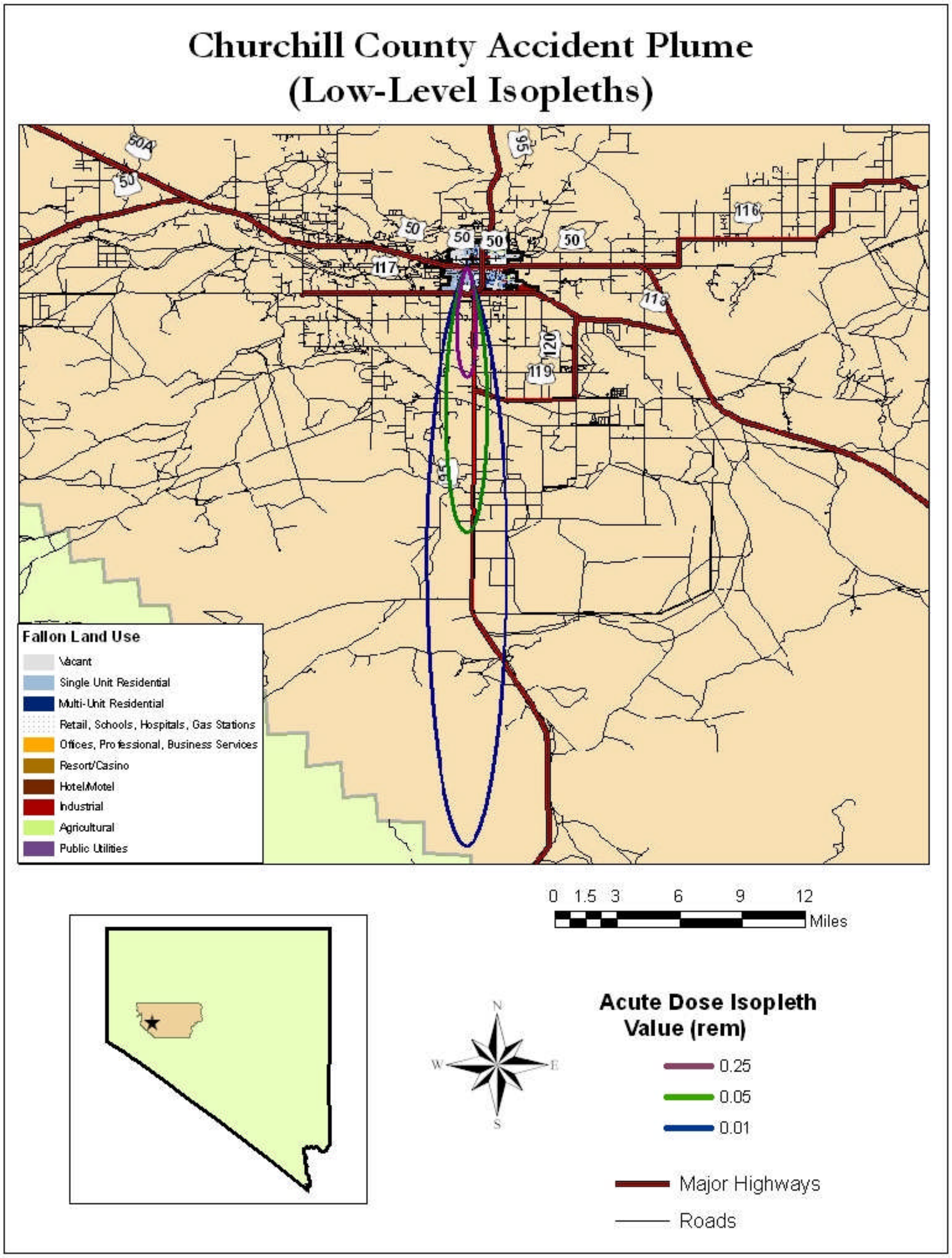

Figure 4 - Low-scale acute dose isopleths for Fallon accident

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