Hawthorne Impact Report

Transportation of Spent Nuclear Fuel by Highway to Yucca Mountain

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Executive Summary

If a high-level waste repository opens at Yucca Mountain, south of Hawthorne on US 95, a large number of truck shipments of nuclear waste are expected on US 95. Truck shipments of nuclear waste through populated areas lead to a radiation dose to the public even if the transport is incident-free, because no shielding material can entirely eliminate direct gamma and neutron radiation. As a result, residents, vacationers, drivers, pedestrians and workers will get a radiation dose, which depends on the recipient's proximity and exposure time. Depending on the population estimate used, the population dose due to incident-free transportation of all waste shipments that are planned to pass Hawthorne will be as high as 1.55 person-rem. Even though this dose and the resulting population risk are relatively small, it nevertheless increases the risk to develop cancer.

In case of a severe accident involving a nuclear 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 accident, 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 small in comparison to the inhalation and ground shine pathways.

Without remediation and assuming a long-term exposure of 50 years, a large part (up to 40 %) of the population of Hawthorne would develop fatal cancer as a consequence 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 37km^2 to 353 km^2 would have to be remediated. We have not calculated the radiation exposure of clean-up workers, and the economic costs of such an accident, which would be considerable. DOE shipments are insured under Price-Anderson insurance, but the timing of the payouts is problematic since this requires a Congressional authorization.

Local government could undertake several measures. Shipping casks should be 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, but in any case are not physically tested. 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 taken, including evacuation and interdiction of the food supply,

Introduction

Background

In the event that the proposed geologic repository at Yucca Mountain, Nevada, begins accepting waste, the State of Nevada will have the option of designating preferred routes for transportation of spent nuclear fuel and high-level radioactive waste to the facility. There is evidence that, if truck shipments are used to transfer spent fuel to Yucca Mountain, the State of Nevada will designate US95 as a preferred route, connecting Interstate 80 with the southern part of the state. Mineral County would be affected by this potential route, with its largest city and County seat, Hawthorne, located at the intersection of US95 with County Road 359.

Previous studies by Churchill County have estimated the likely number of truck shipments along US95. In this report, 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. Also, we calculate the dose resulting from a severe accident involving a nuclear shipment.

City of Hawthorne and Surroundings

Hawthorne (the county seat) is located in Mineral County southeast of Reno between Fallon and Tonopah along US95, about 5 miles from Walker Lake. US95 forms its main street, entering the town form the northwest, then turning south until reaching the center, where it turns east to leave the city.

Located at 1,200 feet above sea level, Hawthorne is the largest population center of the sparsely populated Mineral County. According to the *Mineral County Impact Report*, it had an estimated population of 3,875 in the year 2000. The population is estimated to grow to 4,739 by 2010.

Number of Shipments Expected to Pass Through Hawthorne

The most variable estimate concerns the number of shipments expected to travel the US95 corridor 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 the US95 route rather than another alternative, etc.

The Mineral County Impact Report estimates that 5,450 truck shipments would traverse Mineral County and Hawthorne on US95 under the Proposed Action in the Yucca Mountain EIS, which calls for shipments of 63,000 MTHM of CSNF to the facility between 2010 and 2033. If the expansion of Yucca Mountain (known as Modules I and II) is approved, the Churchill County Impact Report, the number of shipments increases to 19,193 from 2010-2048.

It is possible that shipments from California could use US50 to US 95 and then turn south. This would increase the number of shipments through Hawthorne. We have not included this possibility in our report. If trucks were indeed to take this route, then the incident-free dose would be greater. However, nothing would change for the accident scenario, since the truck route would remain unchanged.

Incident-Free Dose Calculation

For the calculation of doses expected to the population of Hawthorne under routine shipment conditions, the RISKIND[1] computer program was used. In the following, we present the calculation of the most important input parameters.

Population and Population Density

Mineral County had a population of 5,071 in 2000[2]. The majority of the population resides in a 1-mile corridor (0.5 miles on each side of US95) extending approximately 12.4 miles between the towns of Walker Lake and Hawthorne[3] (*Impact Report, 9)*. Extrapolation of population to future years is based on a 2% growth rate. Table 1 gives population estimates for Mineral County, Hawthorne and in the corridor between Hawthorne and Walker Lake.

In order to calculate the population that effectively will be exposed to radiation in case of nuclear shipments along US95, we include the average number of visitors staying either in hotels or RV parks along the corridor. For the calculation of doses expected to the population of Hawthorne and Mineral County under routine shipment conditions, only this “effective” corridor population was considered, because the population in other areas of Mineral County is relatively sparse.

Table 1. Population estimates for Mineral County

Region	**2000**	**2010**	**2020**
Mineral County	5,071	6,202	7,559
Hawthorne	3,875	4,739	5,776
Corridor between Hawthorne and Walker Lake	4,287	5,228	6,373
Effective Corridor Population	4,778	5,824	7,099

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[1] 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.
[2] US Census 2000.
[3] Mineral County, Office of Nuclear Projects, *Mineral County Impact Report*, prepared by Massey R, RCS, July 2001.

We obtain the corridor population density by dividing the corridor population by the area (12.4 miles x 1 miles) 12.4 square miles, or about 32.1 km^2. The resulting effective corridor population density for the years 2000, 2010 and 2020 is 148.8, 181.3, 221.1, respectively.

In addition to the corridor population, we include the “on-link” population of motorists, which is the number of people in the street exposed to the nuclear shipments. An estimate of the “on link” population is made based on traffic figures given in the Mineral County Impact Report. These are given for the years 1999 and 2010, so extrapolation was used to estimate the traffic density for 2020, and are based on the values in Table 2-4 of the Mineral County Impact Report. These estimates are presented in Table 2.

Table 2. Traffic in Hawthorne

Year	Estimated Average Daily Traffic (one way)	Vehicles/hour, 17-hour day
1999	5,500	324
2010	6,705	394
2020	8,173	481

For the dose calculation, we assume that vehicles contain an average of 2 persons.

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 Hawthorne and surroundings as a result of a shipping campaign through the city. Table 3 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.

Table 3. Input parameters used for RISKIND for incident-free transport

Variable	**Value**	**Comments**
Distance from shipping route	15 feet to 0.5 miles	Population concentrated within 0.5 miles of US95
Corridor population density (persons/km^2)	148.8 (1999), 181.3 (2010), 221.1 (2020)	Based on a 1 x 12.4-mile-corridor, and effective corridor population from Table 1
Distance traveled	12.4 miles	Route between Lake Walker and Hawthorne
Fraction of population indoors	0	Used to obtain upper-bound, no-shielding estimate
1-way traffic density (vehicles/hour)	324 (1999); 394 (2010); 481 (2020)	Based on 17-hour day, average of traffic density on US95 in both directions
People per vehicle	2	
Number of stops	1	
Stop duration	30 seconds	Assumed stop time in Hawthorne for traffic light
Number of people exposed during stop	30	5 cars with 2 persons each, 2 pedestrians and 18 in nearby residences and businesses
Exposure Distance, stopped truck	2 to 90 meters	Assumption; RISKIND defaults
Average vehicle speed	49 mph	Average speed in corridor
# lanes 1-way	1-2	
Lane width	3.7 meters	Impact Report

Dose to the Maximally Exposed Individual (MEI)

The Maximally Exposed Individual is assumed to be located at the only traffic light in Hawthorne, between 15 and 30 feet from the road, for every shipment. 4 separate calculations will be performed, to consider a person both indoors and outdoors at each distance. It is assumed that the MEI will be exposed to a stopped shipment for 30 seconds per shipment, as it waits at the traffic light, and that the MEI will be exposed to every shipment. For passing shipments, it is assumed that the trucks will travel at 10 mph near the intersection. Table 4 shows the annual and lifetime dose of the MEI.

RISKIND calculates the dose per truck. We therefore multiply this dose with 5,450 – 19,193 to obtain the total dose in mrem, and 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. Table 4 shows the annual and lifetime dose of the MEI.

Table 4. Dose to the Maximally Exposed Individual (MEI) from incident-free transportation (mrem)

Dose	**Scenario**	**Distance from stop and location (indoors or outdoors)** 15 ft, outdoors	 15 ft, indoors	 30 ft, outdoors	 30 ft, indoors
Yearly Dose	Proposed Action	6.9	2.2	2.9	0.9
	Modules I&II	14.9	4.9	6.3	2.0
Lifetime Dose	Proposed Action	164.6	54.0	69.2	21.7
	Modules I&II	579.6	190.0	243.8	76.6

Population Dose Results

Again, RISKIND calculates the population dose per truck, and we therefore multiply the output with 5,450 – 19,193 trucks 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 incident-free dose to the population is given in Table 5 for the Hawthorne – Walker Lake corridor, based on the three population projections from 1999, 2010, and 2020. It is broken down into two categories of persons: residents, (including average number of tourists), and those sharing the roadway with the shipment.

Table 5. Incident-free dose to the population

Receptors	**Annual dose (person-rem/y)** **1999**	 **2010**	 **2020**	**Total dose (person-rem)** **1999**	 **2010**	 **2020**
			Proposed Action			
Effective residents	0.0067	0.0082	0.0100	0.162	0.197	0.241
On-Link	0.0043	0.0043	0.0043	0.104	0.104	0.104
Stop Lights	0.0040	0.0040	0.0040	0.095	0.095	0.095
Total dose	0.015	0.016	0.018	0.36	0.40	0.44
			Modules I and II			
Effective residents	0.0146	0.0178	0.0218	0.570	0.695	0.848
On-Link	0.0094	0.0094	0.0094	0.365	0.365	0.365
Stop Lights	0.0086	0.0086	0.0086	0.334	0.334	0.334
Total	0.033	0.036	0.040	1.27	1.39	1.55

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 Hawthorne and surroundings. This is the reason why the annual population dose is less than the annual dose to the MEI.

Using the 2020 population estimate, the total population dose due to incident-free transportation is 1.55 person-rem.

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 cask, and the expected latent cancer fatalities. In a "severe accident", the cask is breached open upon impact or a long-duration fire, and radionuclides are released to the environment.

Selection of a Hypothetical Accident Location

Based on truck accident statistics, we know that out of 50,000 truck shipments, several hundred accidents of varying severity will take place over the life of the repository. Pinpointing the exact location and exact conditions surrounding a proposed accident is clearly impossible. When performing a consequence assessment, it is vital to consider whether a severe accident could occur at a specific location. The location must have 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.).

For the case of a truck shipment, a severe accident would require a fairly high-speed collision, something that could not be easily accomplished on the city streets of Hawthorne. Instead, a location at an intersection at the northern edge of the town was selected. Trucks could arrive at high speeds, collide with other traffic and subsequently slam into a building, or directly hit a strong concrete structure in an accident that would not involve other traffic. The location at the northern border of the town is a reasonable scenario, because the waste is transported north-south on US95. Traffic is generally much faster while entering a town than while leaving it. This means that transports carrying nuclear wastes are moving fast at the northern edge, whereas the trucks entering Hawthorne from the east are returning from Yucca Mountain and are therefore empty.

A long duration fire is also possible and could be caused by a collision with a gasoline tanker or explosion at a gas station. Sabotage could also lead to a release of radioactive material.

[The proximity of Fallon Naval Air Station (FNAS) to US95 and US 50 may also give rise to a severe accident. Ammunition is trucked to FNAS from Hawthorne Army Ammunition Depot in Hawthorne, Nevada, on US95. 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. The collision caused a fire and resultant explosions. 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, 2 eastbound lanes of I-40, the right

shoulder of the highway. Approximately 3,382 tons (1,700 cubic yards) of material were used to fill the crater.
Other 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: August 1, 1984 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. And May 10, 1985, 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 2 bystanders were killed and 33 persons injured. However, we consider an accident involving intense fire a possible, but not very likely scenario, and we therefore do not include it in our dose calculations.]

Severity of an Accident

Once the 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 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[4,5], 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 several 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

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[4] NUREG/CR-4829. Fisher *et al. Shipping Container Response to Severe Highway and Rail Accident Conditions.* Lawrence Livermore National Laboratory, 1987.
[5] NUREG/CR-6672. Sprung *et al. Reexamination of Spent Fuel Shipment Risk Estimates*. Sandia National Laboratories, 2000.

type of accident is reasonable considering the conditions at the postulated accident location.

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 Hawthorne. 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 Hawthorne, unless a fuel tanker 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. Therefore, we consider this event less likely and omit it in our accident analysis.

Spent Fuel Release Fraction Estimates

Below is a more detailed discussion of the various estimates made in determining the release fraction.

Fuel Inventory

We use the assumptions made by DOE in the Final Environmental Impact Statement (FEIS) for the proposed Yucca Mountain Facility[6]. 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 diameter 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 burnup 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. 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 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

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[6] 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)

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 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

A rod cladding breach 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 Hawthorne, 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)[7] 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.

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

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 6: Postulated Severe Truck Accident Release Fractions

Inert gas	Iodine	Cesium	Ruthenium	Particulates	CRUD
3.3E-01	2.5E-03	6.6E-03	2.7E-05	2.00E-05	1

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 are two different predominant wind directions, depending on the season. From March through September, the predominant wind direction is northwest, whereas for the remaining 5 months of the year, the wind usually comes from south[8].

For our analysis, we assume a wind from northwest. During the seven months with this predominant wind direction, the average wind speed is 7.86 mph or 3.54 m/s. For the stability class, we apply Class D, the most frequent of such classes. Stability class is a measure of the air mixing or diffusion ability of meteorological conditions.

Exposure Times

Our analysis assumes a 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 Hawthorne accident.

It is assumed that the postulated accident is severe enough to prevent evacuation along US95 going north from Hawthorne. This effectively cuts off 1/3 of the evacuation pathways. Second, the meteorological conditions assumed at the time of the accident are such that the plume generally travels toward the southeast, crossing US95 again at towards the exit of the town. Given the choice, residents would most likely choose to

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[8] Weather Underground Inc, available at www.wunderground.com, accessed on May 2, 2002

vacate the area in a direction away from the plume, making evacuation to the east on US95 unlikely. County Rd 359, leaving Hawthorne to the south, would be the most likely means of egress. Because of this very limited number of egress routes in the event of the postulated accident, evacuation would be in relatively difficult.

A 24-hour evacuation time estimate is appropriate for a township such as Hawthorne. 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[9] was used to obtain contaminant plumes for later inclusion onto a map of Hawthorne 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 individual 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 Hawthorne 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. Population densities and areas were taken from the Mineral County Impact report and from the U.S. Census 2000 Mineral County. Areas and population densities between plumes, inside and outside of Hawthorne, were calculated using the plume maps.

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

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 7 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 7. Inputs into RISKIND and HotSpot

Parameter	**Value**	**Comments**
RISKIND:		
Acute exposure	24 h	Estimated evacuation time
Long-term exposure	1 and 50 y	Exposure range
Shielding	none	Default
Food pathway	off	Not enough information
Water pathway	off	Not enough information
Cask dimensions	length 4.4 m, radius 0.508 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	400-1,600 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 form Mod.St., multiplied by 33
I	0.0025	Modal Study
Gas	0.33	Modal Study
Heat release	500 ca/s	Default for accident without heavy fire
HotSpot:		
Dispersion model	General plume	
Released radionuclides	2.5 Ci of Sr-90; 1,210 Ci of Cs-137; 0.219 Ci of Pu-238; 0.0145 Ci of Pu-239; 0.0251 Ci of Pu-240; 0.101 Ci of Pu-241; 0.152 Ci of Cm-244	Output from RISKIND
Deposition velocity	1 cm/s	Output from RISKIND
Wind speed	3.54 m/s	Average wind speed March-Sept.
Wind direction	NW	Average wind direction March-Sept.
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 Hawthorne, 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 50m, 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 8. All calculated doses are without any remediation. 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 8. Dose to Individual living downwind from accident

Distance downwind (km)	Acute Dose (rem)	1-y-Dose (rem)	50-y-Dose (rem)
0.05	543	4,890	90,800
0.1	188	1,690	31,400
0.2	107	960	17,800
0.5	40.8	367	6,820
1	13	117	2,180
2	3.54	31.9	592
5	0.66	5.92	110
10	0.18	1.63	30.2
20	0.05	0.44	8.25
50	0.01	0.09	1.72

Obviously, the acute dose cannot be avoided by remediation. Therefore, assuming immediate and perfect remediation, the acute dose 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 Hawthorne to estimate the amount and extent of contamination and dose. Plumes for acute dose and ground deposition concentration were obtained from the HotSpot computer model and plotted onto the ArcView map shown in Figures 1-4.

Because the population density inside of Hawthorne is very different from that outside, we differentiate between the city and the (rural) surroundings. In Figure 1-4, the rectangle denominated Area H encloses all of Hawthorne. The rectangle measures about 1.66 by 2.14 km and therefore has a surface of 3.55 km^2. Using the population estimates from Table 1, we arrive at a population density in Hawthorne of 1,092, 1,335 and 1,627 people per km^2 for the years 2000, 2010 and 2020, respectively (Table 9). The population density of Mineral County, excluding Hawthorne, is 0.12, 0.15 and 0.18 p/km^2, respectively.

Table 9. Population density of Hawthorne and surroundings

Region	Pop.2000	Pop.2010	Pop.2020	Area (km^2)	Population Dens.2000 (p/km^2)	Population Dens.2010 (p/km^2)	Population Dens.2020 (p/km^2)
Mineral County	5,071	6,202	7,559	9,876	0.51	0.63	0.77
Hawthorne	3,875	4,739	5,776	3.55	1,092	1,335	1,627
Mineral C. excl. Haw.	1,196	1,463	1,783	9,872	0.12	0.15	0.18

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 Hawthorne (Area H), whereas the ones with acute doses below 1 rem 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 Area H (Table 10). Depending on the year and corresponding residence population, the population dose is 922 – 1,375 person-rem.

Table 10. Acute dose to the population

Dose zone between isopleths	Av. Dose in dose zone (rem)	Surface of dose zone			Acute population dose[a]		
		Total (km^2)	in Area H (km^2)	outside Area H (km^2)	2000 (person-rem)	2010 (person-rem)	2020 (person-rem)
inside 100	100	0.0009	0.0009	0	98.2	120.1	146.4
100 to 50	75	0.0011	0.0011	0	90.1	110.1	134.2
50 to 10	30	0.009	0.009	0	294.7	360.4	439.3
10 to 5	7.5	0.011	0.011	0	90.1	110.1	134.2
5 to 3	4	0.017	0.017	0	74.2	90.8	110.6
3 to 2	2.5	0.022	0.022	0	60.0	73.4	89.5
2 to 1	1.5	0.069	0.069	0	113.0	138.2	168.4
1 to 0.5	0.75	0.17	0.077	0.093	63.0	77.1	94.0
0.5 to 0.4	0.45	0.09	0.020	0.070	9.8	12.0	14.6
0.4 to 0.3	0.35	0.15	0.015	0.135	5.7	7.0	8.6
0.3 to 0.2	0.25	0.35	0.033	0.317	9.0	11.0	13.4
0.2 to 0.1	0.15	1.21	0.076	1.134	12.5	15.2	18.6
0.1 to 0.05	0.075	2.8	0.022	2.778	1.8	2.2	2.7
outside 0.05	<0.05	N/A	N/A	N/A	omitted	omitted	omitted
Total					922	1,128	1,375

a: Dose calculated with population density estimates for 2000, 2010 and 2020

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. 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 35 times greater than the corresponding acute dose, and a 50-year dose was 485 times greater than the acute dose. The results for the long-term population dose estimates are given in Table 11.

We then calculate the total dose for the population in person-rem and 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 2,000 person-rem per latent cancer fatality. This number is based on a conversion factor of 0.0005 latent cancer fatalities per person-rem[10], which is a recommendation by the International Commission on Radiological Protection (ICRP)[11]. 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[12] 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 cancer dose.

Also, the 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)[13], or more stable across the ages (BEIR V[14], Pierce[15]). For male 1-y-olds, Gofman[16] 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[17], 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[18] 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.

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[10] 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.

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[15] 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.

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

[17] BEIR V, p. 175.

[18] Pierce 1996, p. 13.

These numbers, taken together, support the cancer dose of 1,000 rem obtained by not including the DDREF applied by ICRP.

Table 11. Latent cancer fatalities due to population dose

Exposure time	**Population estimate** **2,000**	 **2,010**	 **2,020**
Acute population dose in 24 h (rem)	922	1,128	1,375
LCF	0.9	1.1	1.4
Long-term population dose in 1 y (rem)	32,278	39,474	48,112
LCF	32.3	39.5	48.1
Long-term population dose in 50 y (rem)	447,274	547,002	666,698
LCF	447.3	547.0	666.7

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 Hawthorne for another 50 years, then the expected latent cancer fatalities are 667. This would be about 40 % of Hawthorne's estimated 2020-population of 1,627. From this it obviously follows that evacuation and remediation is absolutely necessary in the case of a category-5-accident involving a nuclear waste shipment in Hawthorne.

In case of a full evacuation, followed by perfect remediation, the population dose would be reduced to the acute dose, with an estimated number of latent cancer fatalities of 0.9 – 1.4 cases. This is 0.08 % of the respective city population of Hawthorne. 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[19], including exposures

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

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[20] that states the doses in any single year after the first will not exceed 0.5 rem and that the cumulative dose over 50 years (including the 1st and 2nd years) will 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 remediation.

Looking at Fig. 4 and Table 12, for the first year after the postulated accident, we see that a person living along the 1.5 mrem acute-dose-isopleth would receive a yearly dose of 53 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 last plotted isopleth (1 mrem acute dose) corresponds to an average yearly dose of 15 mrem/y, the same as the EPA cleanup level for superfund sites. Therefore, according to this threshold, the entire area under the 1.5 mrem acute-dose-isopleth will have to be remediated. This corresponds to a total area of 353 km^2. Most of this area is outside of Hawthorne, but the EPA cleanup standards are valid also outside of the city.

This is clearly a prohibitive cleanup action. In addition to the vast region outside of Hawthorne that would have to be remediated, a major part of the city would have to be scraped - buildings, streets, grass, and so on. We have not estimated here the considerable economic costs of evacuating and remediating the Hawthorne area, including the cost of waste disposal, lost business and property devaluation, though we have made estimates for urban areas for the State of Nevada.

Using the EPA Protective Action Guides, Table 12 shows that the locations on the 10 mrem acute-dose isopleth correspond to a first-year dose of 0.35 rem and 4.85 rem over 50 years, just below the Protective Action Guide limit. Hence, the area that would require remediation is 37 km^2. Thus, the area needing clean up is somewhere between 37 and 353 km^2.

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

Table 12. Area in need of remediation

Acute-dose isopleth (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	0.0009	3,500	48,500	970
50	0.002	1,750	24,250	485
10	0.011	350	4,850	97
5	0.022	175	2,425	49
3	0.039	105	1,455	29
2	0.061	70	970	19
1	0.13	35	485	10
0.5	0.30	18	243	5
0.4	0.39	14	194	4
0.3	0.54	10.5	145.5	2.9
0.2	0.89	7.0	97.0	1.9
0.1	2.10	3.5	48.5	1.0
0.05	4.90	1.75	24.25	0.49
0.01[a]	**37**	0.35	**4.85**	0.10
0.0015[b]	**353**	0.053	0.728	**0.015**
0.001	549	0.035	0.485	0.010

a: Boundary of region in need of remediation using EPA Protective Action Guides levels, due to the 50-y total dose.
b: Boundary of region in need of remediation using EPA superfund cleanup level, due to the average annual dose rate.

Ingestion of soil, water and food

In our analysis, we neglected the dose due to ingestion of contaminated soil, water and food. We did so because the ingestion pathway is negligible in comparison to the inhalation and direct radiation pathways. To demonstrate this, we calculate the dose due to ingestion of contaminated food, water and soil, assuming the Hawthorne area grows 100 % of its own food and uses groundwater both for irrigation and drinking purposes.

Hotspot does not calculate a dose due to ingestion pathway. We use the RESRAD computer code to calculate this dose. As the main input into RESRAD, we use the ground contamination output from Hotspot. Similar to dose isopleths that are defined by all points with the same acute dose (in rem), Hotspot also calculates surface contamination isopleths (in μCi/m^2). As a bounding scenario, we assume that this contamination is contained within the uppermost 15 cm of the soil (default plant root depth) with a soil density of 1.5 g/cm^3, and calculate a soil concentration in pCi/g soil.

This value can be inserted into RESRAD. As another bounding assumptions, we apply a thickness of the unsaturated zone of 2 m, which would be the case with a shallow aquifer.

We calculate the dose due to ingestion of food, water and soil for a point located on the 100 μCi/m^2 isopleth, which covers an area of 0.36 km^2. The resulting soil concentration is (100 μCi / 0.15 m^3) 667 μCi/m^3 or 444 pCi/g. We obtained each radionuclide's soil concentration by calculating its fraction of the total released activity, using the release totals Table 7. 99.75 % of the total contamination is due to Cs-137, 0.2 % due to Sr-90, and the remaining fraction is due to all other released radionuclides. Using RESRAD default parameters, the first-year dose due to ingestion of contaminated food, water and soil is 40.6 mrem. This dose is also the maximum annual dose. The dose is 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 400-mrem acute-dose-isopleth, which encloses an area comparable in size to that of the 100 μCi/m^2-isopleth, is 14 rem (Table 12). This means that the dose due to inhalation and ground shine is about 350 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 can be "exported" to other regions, i.e. it could reach 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 11, 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 Hawthorne.

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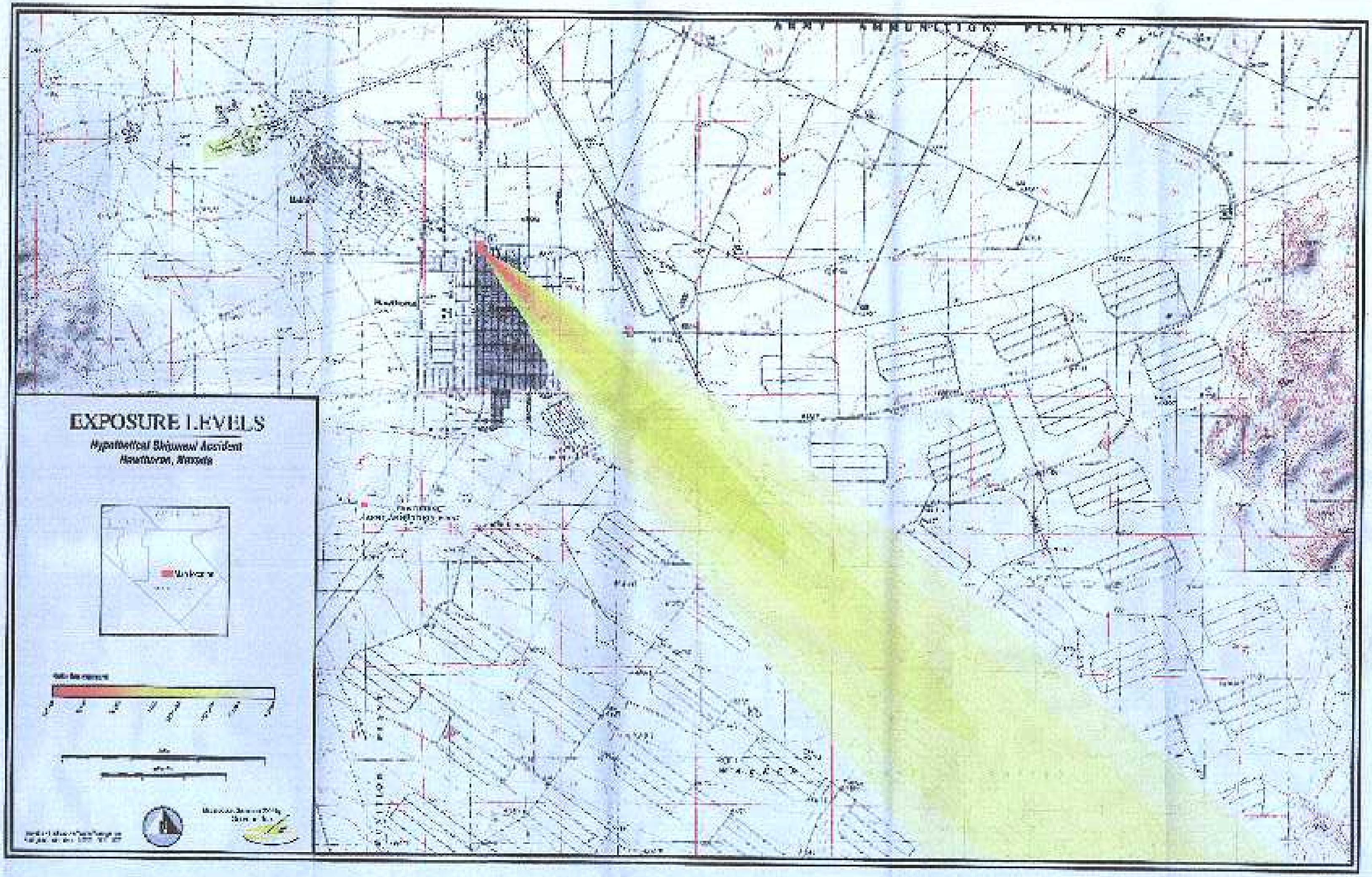
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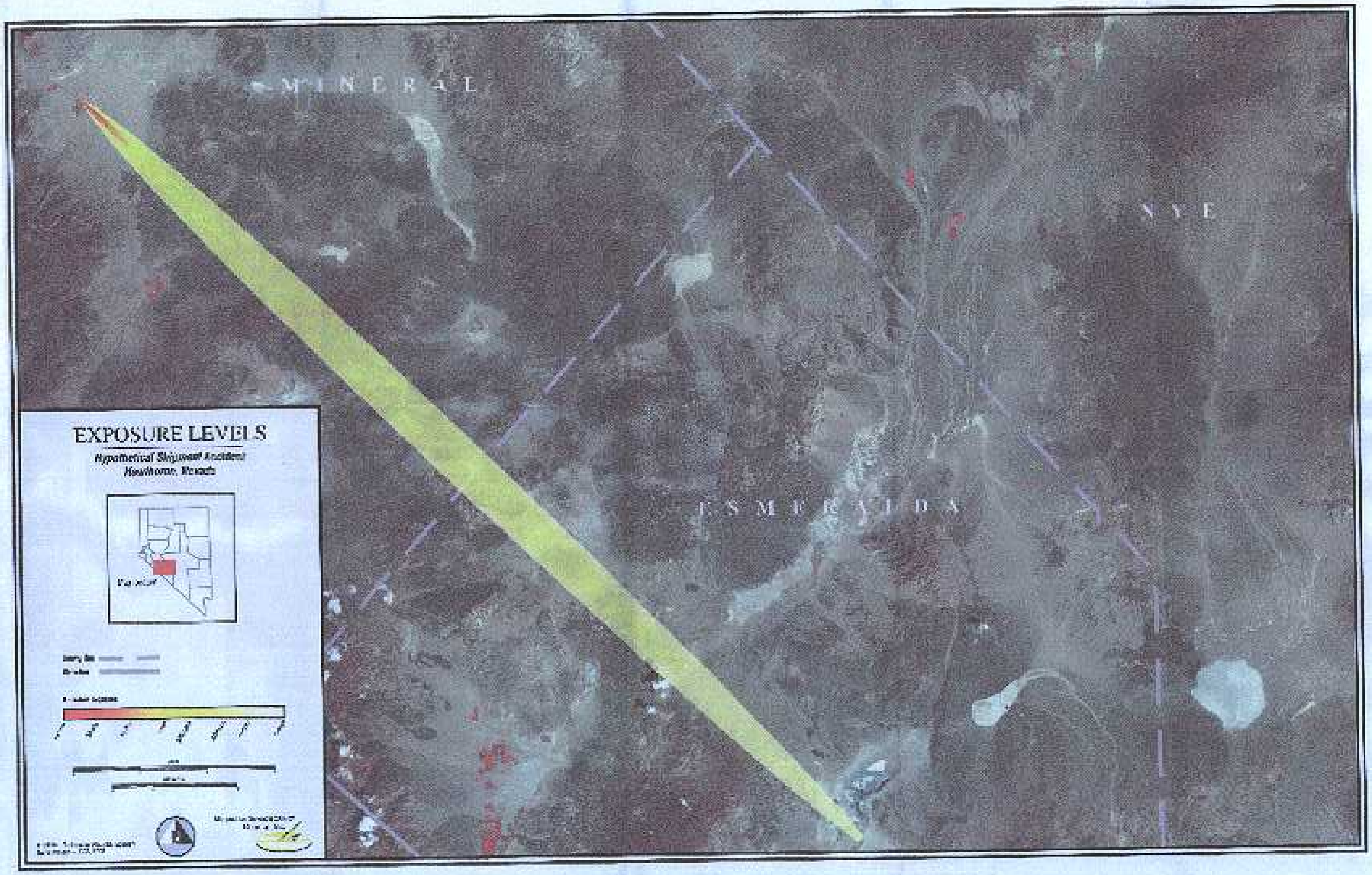
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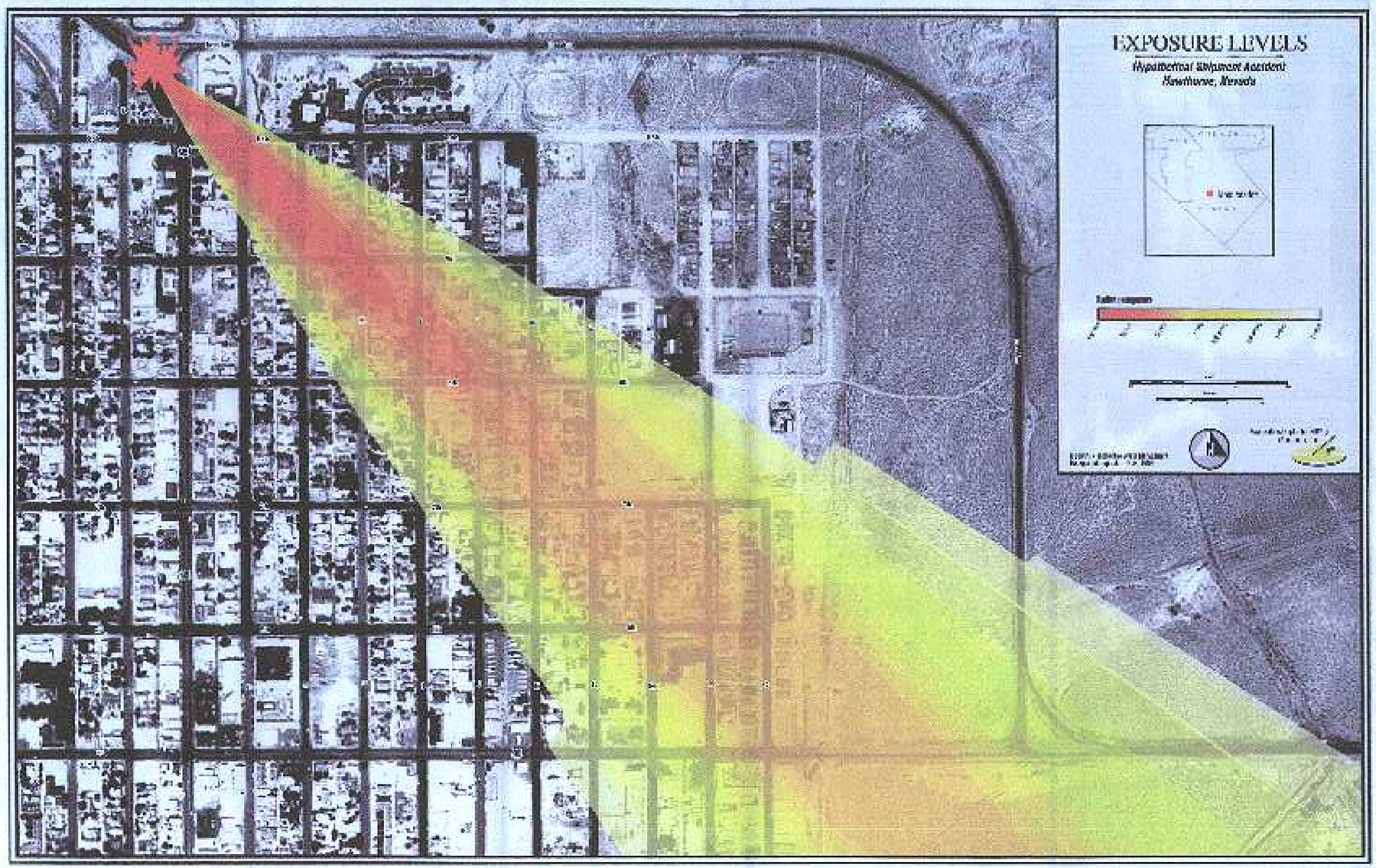
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