RADIOLOGICAL IMPACTS OF INCIDENT-FREE TRA NSPORTATION TO YUCCA MOUNTAIN; COLLECTIVE AND MAXIMALLY EXPOSED INDIVIDUAL DOSES

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ABSTRACT

According to the 2002 U.S Department of Energy (DOE) Final Environmental Impact Statement (FEIS) for a Geologic Repository at Yucca Mountain, members of the public along spent nuclear fuel (SNF) and high-level radioactive waste (HLW) transportation routes will receive routine radiation doses up to 100 mrem/year. Overall radiological impacts of incident-free shipments would be greatest under the "mostly truck" national transportation scenario. The FEIS estimates that routine exposures from 53,000 truck shipments over 24 years would result in about 2.5 latent cancer fatalities (LCFs) among members of the public and about 12 LCFs among involved workers.

The FEIS treatment of incident-free transportation impacts is deficient in five areas. The FEIS uses a non-conservative conversion factor to quantify the cancer risk per unit dose. The FEIS ignores non-cancer risks, specifically genetic and teratogenic risks. The FEIS SNF inventory projections fail to consider the possibility of reactor life extension beyond 50 years and new reactor construction. The FEIS collective dose analysis underestimates population growth in Southern Nevada and along the transportation corridors to Nevada. The FEIS ignores doses to populations located beyond 800 meters from transportation routes.

The authors estimate the increase in collective doses and resulting health impacts from including all of these issues into the FEIS analysis. For collective health effects, the true impact may be from 6.8 to 45 times higher (with a geometric mean of about 18). Risks to the highest risk individuals are similarly underestimated by a factor of 2.3 to 31(with a geometric mean of about 8.3).

Moreover, the FEIS did not assess the potential for significant routine radiation exposures due to unique local conditions at specific locations along potential highway and rail routes to Yucca Mountain. Based on calculations using the RISKIND code, the authors conclude that annual exposures at certain locations along Nevada truck routes could reach 47 mrem, and that annual exposures at certain locations along Nevada rail routes could reach 200 mrem or more. In addition to health effects, routine exposures of this magnitude may result in serious adverse socioeconomic impacts.

Finally, the FEIS dose to the maximally exposed member of the public (the service station attendant in a location where refueling options are limited) is inadequately modeled and fails to take into account doses to the attendant from his participation in refueling and minor repairs. Even DOE's flawed analysis acknowledges that mitigation by administrative controls would be required to keep this dose below 100 mrem per year.

INTRODUCTION

In 2000, M.H Chew and Associates (CAI), prepared a series of reports on the treatment of incident-free transportation radiological impacts in the U. S. Department of Energy (DOE) Draft Environmental Impact Statement (DEIS) for the proposed Yucca Mountain geologic repository (1).

CAI's work for Nevada involved two tasks. The first task was to generally review DOE's treatment of routine radiation exposure and health effects issues in the DEIS. The CAI review found that despite the sophistication of the models used to calculate impacts, many of the basic underlying assumptions and inputs into the risk calculations in the DEIS are incorrect, and are based on outdated or non-conservative forecasts (2).

CAI's second task was to prepared for NANP a series of reports estimating incident-free radiation exposures at specific locations along several potential shipping routes identified in the DEIS. CAI evaluated potential incident-free exposures from legal weight truck (LWT) shipments through northern and central Nevada,(3,4,5) heavy haul truck (HHT) transport of large rail casks through central Nevada,(6, 7) and general freight rail transport of large rail casks through the Las Vegas metropolitan area. (8).

In February, 2002 DOE issued the Final Environmental Impact Statement (9). The main purpose of this report is to show the extent to which health effects may be understated by the FEIS in the light of the changes DOE made in its assumptions and analytical methods from the 1999 DEIS to the 2002 FEIS.

CHANGES FROM THE 1999 DEIS TO THE FEIS

In the FEIS, DOE addressed several of the deficiencies noted by CAI in the DEIS. For example, DOE responded to a concern raised by CAI, as well as others, by noting that the use of the 1990 census figures for the four county area around YM did indeed underestimate the population that would be subjected to impacts from transportation of material there. In the FEIS, DOE incorporated a population growth of 40% from 1990 to 2035 (the date of closure of the repository under the baseline Scenario). DOE used the overall four-county population growth from 1990 to 2000 to arrive at this conclusion. The FEIS still uunderestinates potential population growth in Clark County, and the large stimulatory effect on local growth that the commencement of full-scale construction and repository shipments is likely to have in Nye County, where the impacts will be greatest. This will be particularly true in the case of the doses to motorists on the same highways as truck shipments or parallel to rail shipments, where traffic density is likely to increase rapidly.

In the DEIS, DOE estimated that the annual dose to the maximally exposed member of the public would be under 100 mrem. In the FEIS, DOE estimated the maximum doses to a station attendant to be as high as 130 mrem/yr, exceeding the 100 mrem annual limit for a member of the public (10CFR20 and 10CFR835). Even this higher figure, however, ignores the possibility that service station crews may be involved in rig refueling or minor repairs, tasks in which they by custom participate.

Other changes from the DEIS to the FEIS have been less substantive in terms of dealing with the concerns CAI has raised. For example, DOE has not yet revised its use of nonconservative cancer risk factors. Indeed, the estimate of **total** cancer fatalities (LCF's) in both involved workers and members of the public due to transportation of radioactive materials to Yucca Mountain have been reduced under both the mostly truck and mostly rail scenarios. For the mostly truck scenario, the LCF's have been reduced from 22.5 in the DEIS to 14.2 in the FEIS, a reduction of 35% from the DEIS. However, the estimated distribution of estimated LCF's has changed dramatically. The calculated number of LCF's among the exposed members of the public have dropped by about 86%, from 18 to 2.5, while the LCF's among involved workers have increased by a factor of 2.6. LCF's among the public dropped primarily as a result of a large reduction in the estimate of doses to other vehicle occupants on the road at the same time as the SNF or HLW shipments (the so-called on-link doses) and a reduction in the estimate of the number of stops that a team-driver truck would need to make. On the other hand, the increase in staffing levels required to supply team drivers and to make required vehicle inspections accounted for the increased number of effects among workers. For the mostly rail scenario, a similar pattern exists: the worker effects have increased by a factor of about 4, while the impacts to the public dropped by a factor of about 3.

Perhaps the most dramatic example of how the FEIS has been non-conservative in its forecasts is the issue of the estimated inventory of SNF, HLW and other waste categories. DOE's estimate of SNF inventory as of 2035, for example, continues to rely on estimates based on the premise of a) no new nuclear power plant construction and b) 10 year life extensions to currently operating plant licenses. In the former case, DOE has announced initiatives to encourage new nuclear plant construction before the issuance of the FEIS, and as of this writing, nuclear utilities have taken the first step to apply for NRC licensing for new nuclear units at four existing nuclear plant sites (9) while at least three currently operating units have obtained 20 year license extensions (FEIS, Table A-3).

FEIS IMPACT ESTIMATES

In the Yucca Mountain FEIS, DOE estimated the radiological impacts of spent nuclear fuel (SNF) and high-level radioactive waste (HLW) transportation for two inventory shipment actions and two national modal-mix scenarios. Under the Proposed Action, DOE would ship 70,000 metric tons of heavy metal (MTHM) of SNF and HLW to the repository over 24 years. Under an expanded action (Inventory Module 2) DOE would ship about 120,000 MTU over 38 years. Under a Mostly Truck national transportation scenario, more than 99 percent of SNF and HLW would be shipped by LWT. Under the Mostly Rail scenario, all HLW and about 95 percent of SNF would be shipped by rail.

For each of the 24-year shipping scenarios, DOE calculated collective doses to workers and the public, and cumulative doses to maximally exposed individuals. (Partial impact data was provided for the 38-year shipping scenarios.) For the Proposed Action (24 years), the FEIS estimates the Mostly Truck scenario would result in almost 12 latent cancer fatalities for workers and 2.5 latent cancer fatalities for members of the public..

Table I. FEIS Transportation Scenarios, Collective Doses, and Radiological Impacts

Shipments, Doses, & Health Impacts	Mostly Truck - 24 Years	Mostly Truck - 38 Years	Mostly Rail - 24 Years	Mostly Rail - 38 Years
LWT Shipments	52,706	108,544	1,079	3182
Rail Shipments	300	355	9,646	18,935
Involved Worker Collective Dose	29,000 person-rem	Not Available	7,900-8,800 person-rem	Not Available
Involved Worker LCFs	11.7	24	3.2-3.5	7
Public Collective Dose	5,000 person-rem	Not Available	1,200-1,600 person-rem	Not Available
Public LCFs	2.5	5	0.61-0.81	<2

Source: Ref. 9, p. S-69, p. S-80, Table 6-1, Table J-1

For the Proposed Action (24 years), the FEIS estimates that the maximally exposed workers, rail or truck crew members and safety inspectors, would receive a cumulative dose of 48 rem. DOE, however, assumed that administrative controls would limit occupational exposures for these workers to 2 rem per year. The maximally exposed members of the public would be a person at a service station (2.4 rem), a resident near a rail stop (290 mrem), a person next to a truck cask in a traffic jam (16 mrem, one-time occurrence), and a resident near a truck route (6 mrem).

Table II. FEIS Estimated Doses and Radiological Impacts to Maximally Exposed Individuals

Exposed Individual	Mostly Truck - 24 Years - Dose (rem)	Mostly Truck - 24 Years - Probability of LCF	Mostly Rail - 24 Years - Dose (rem)	Mostly Rail - 24 Years - Probability of LCF
Crew Member	48	0.02	48	0.02
Inspector	48	0.02	34	0.014
Railyard worker	0.13	0.000015	4.2	0.0018
Resident along route	0.006	0.000003	0.0016	0.0000008
Person in traffic jam	0.016	0.00002	0.016	0.000008

Table II, continued

Person at Service Station	2.4	0.0012	0.075	0.000038
Resident near rail stop	0.009	0.000005	0.29	0.00014

Source: Ref. 9, Table 6-9 & Table 6-12.

USE OF NON-CONSERVATIVE RISK FACTORS

The FEIS used dose to effect conversion (i.e. risk) factors taken from ICRP 60 (1991) (8) and based on BEIR V (9) and UNSCEAR 1988 (10) estimates of cancer risk. These estimates are based in part on animal studies and some human studies that suggest the same radiation dose spread out over time is significantly less effective at producing deleterious effects than a single acute dose. The magnitude of this effect, called the dose reduction effectiveness factor (DREF) is a matter of controversy and active interest.

The conversion factors recommended by ICRP and used in the FEIS have taken credit for a factor of two cancer reduction (i.e., DREF =2) when the dose is received at low, and more or less constant dose rates, as is the case at YM. The authors believe that the conversion factors used in the FEIS are not conservative for several reasons. First, EPA recommends risk factors that take dose rate credit for leukemia but not solid tumors, and result in a fifty percent higher doses and collective health risks. Second, as noted by ICRP, experimental evidence shows that for some solid tumors (e.g. thyroid) extending the dose does not appear to reduce the cancer risk (13). Third, ICRP notes that the risk from alpha radiation does not appear to be related to the dose rate, but only to the total dose. A significant fraction of the dose to workers and the public from the construction of the drifts is from Rn-222 and alpha emitting daughter products

Based on these and other considerations, the U.S. EPA recommended in 1998 that the DREF of 2 be used for leukemia but not solid tumors. (11) This has the effect of increasing the risk of LCF per rem by 50% as shown in Table III below.

Table III. Dose to Risk Conversion Factors recommended by ICRP 60 and EPA FGR-13

Exposed Group	Source and Recommended Conversion Factor	
	ICRP 60 (1991)	EPA (1998)
General Public	5×10^{-4}	7.6×10^{-4}
Adult Workers	4×10^{-4}	6×10^{-4}

OTHER HEALTH EFFECTS OF RADIATION EXPOSURE

"Cancer," DOE declares in the DEIS," is the principal potential risk to human health from exposure to low or chronic levels of radiation." The DEIS acknowledges that other health effects "such as nonfatal cancers and genetic effects can occur as a result of chronic exposure to radiation. Inclusion of the incidence of nonfatal cancers and severe genetic effects from radiation exposure increases the total change by a factor of 1.5 to 5, compared to the change for latent cancer fatalities (ICRP 1991, page 22)." DOE's only stated justification for this approach reads: "As is the general practice for any DOE EIS, estimates of the total change were not included in the Yucca Mountain EIS." [Ref 1., page F-4]. DOE continued this approach to radiation health effects in the FEIS [Ref 9, p. F-6].

In addition to latent cancer fatalities (LCFs), the FEIS should have considered at least two other risks that are part of the health effects caused by SNF and HLW transportation to YM, namely the teratogenic (risk to unborn children receiving radiation exposure *in utero*) and genetic risks (risks to future generations due to radiation exposure to the germ cells of their parents).

Teratogenic Effects

The major organ at risk from radiation exposure is the developing brain and other parts of the central nervous system (CNS); the risks of severe retardation CNS malformation are quite high during the period of peak sensitivity, between the 8th and the 15th weeks of gestation. ICRP 60 (1991) states:

> *"Within the period of maximum vulnerability the simplest statistical model consistent with the data is a linear one **without threshold**."* (page 115, emphasis added)

The risk of severe retardation is estimated to be 0.43/Gy fetal dose, or for gamma radiation, 0.0043/rem.

Multiplying this by the fraction of the general population who are women pregnant in their 8th to 15th week (~0.003), gives a risk of 1.3 x 10^{-5}/rem of collective dose. The risk to the fetus of a woman who is pregnant at a random week of gestation is (0.0043/rem x (8 weeks vulnerability)/(38 weeks gestation) or 0.0009/rem. Thus the risk to the unborn child is comparable to the lifetime risks of cancer. The collective number of expected health effects are relatively small however, because for a random group of the public, only half are women and 2-3% of those are likely to be pregnant at a particular time. Table IV below shows the magnitude of the risks to workers and members of the general public.

Genetic Effects

ICRP uses the UNSCEAR (1988) model to estimate the total number of Mendelian and chromosomal risks, plus those that are multifactorial. Since multifactorial diseases (schizophrenia, etc) appear to have more than one gene-related cause, their assessment is more difficult, but for simplicity are assumed to occur at about same rate as the Mendelian/chromosomal diseases. Genetic diseases will be expressed either in the next generation, if dominant, or in successive generations if recessive. To the extent that severe diseases reduce the likelihood of reproduction and carrying on the defect, the risk to all succeeding generations is considered to be ~5 times as great as the risk to the first two generations when they are mostly likely to be expressed first. UNSCEAR and ICRP estimate the risk to be 12,000 case/10^6 live births (double that figure to include multifactorial disease), per rad to all generations. Adjusting for the fraction of people in the general public who are in their reproductive years at any one time (~40%) the risk becomes ~1x 10^{-4}/rad.

The risk factors are summarized below in Table IV and should be added to the risk factors for the general population to obtain a total health effect risk factor. These factors, which are calculated for the general public, are somewhat conservative when applied to an adult worker population, who may tend to have a higher fraction of males (who aren't pregnant) and people who are slightly older than the general population and less likely to be reproducing.

Table IV. Non-cancer Risk Factors (effects/rem), based on ICRP (1991) (13)

Risk Component	General Public /rem	Adult Workers, /rem
Genetic Defect (all generations)	1 x 10^{-4}	1 x 10^{-4}
Risk of retardation	1.3 x 10^{-5}	1.3 x 10^{-5}
Risk (relative to FEIS risk values)	1.15	1.19

The consideration of genetic defects and retardation add about 15% to risk over the LCF, which is reflected by an effects multiplier of 1.15 in Table above. For the maximally exposed individual, the multiplier depends on the life circumstances of the individual. For a non-reproducing adult, there is no additional risk (multiplier = 1.0), while if the individual is a pregnant female in her 8th-15 week, the total risk is multiplied by 7 relative to the LCF risk alone.

EFFECTS OF INCREASE IN COMMERCIAL SNF INVENTORY

DOE assumes that the SNF/HLW inventories that will be shipped to Yucca Mountain are well known since no new nuclear plants are currently under construction and the lifetime of plants currently in operation can be accurately forecast. These assumptions are questionable, based on new interest in nuclear plant construction and life extension. (2) These results are shown in Table V below.

Table V. Effects of Existing Plant Life Extension and New Plant Construction on Health Effects

Scenario	Transportation Health Effects (collective)	Operational Health Effects (collective)	Comments
Baseline (Module 2)	100%	100%	50% of health effects during operation are due to radiation from SNF/HLW. Remainder is from release of radon and exposure to
Life Extensions to Existing Plants Only	140%	140%	
New Plants (50 year)	175%	175%	
New Plants (80 year)	230%	230%	

Life Extensions plus New Plants (50 year)	245%	245%	natural radionuclides
Life Extension and 80-year new plants	270%	270%	

Source: Ref. 2, Tables 9-12.

EFFECTS OF POPULATION INCREASES ON HEALTH IMPACTS

The DEIS used 1990 Census data to estimate the collective health effects of transportation. Population density is the one input parameter to collective health effects that varies significantly with time. The use of static population figures underestimates the level of transportation health effects for the following reasons: Clark County, the area most heavily impacted by transportation to Yucca Mountain, had the highest population growth rate (85.5%) of any major county in the United States between 1990 and 2000; the six fastest growing states between 1990 and 2000, and 14 of the 17 fastest growing states, will be primary corridor states for truck shipments to Yucca Mountain (Table VI); in western states, many of the corridor counties that will be most heavily impacted by truck shipments to Yucca Mountain have experienced high growth rates (Table VII); and even in states with average growth rates, the counties most heavily impacted by projected truck shipments to Yucca Mountain have relatively high growth rates (Table VII).

Table VI. Transportation Corridor State Population Growth, 1990 - 2000

State	1990 Pop.	2000 Pop.	% Change	Proj. Truck Shipments, 2010-2048
NV	1,201,833	1,998,257	66.3	92,851
AZ	3,665,228	5,130,632	40.0	90,111
CO	3,294,394	4,301,261	30.6	27,612
UT	1,722,850	2,233,169	29.6	80,004
ID	1,006,749	1,293,953	28.5	18,707
GA	6,478,216	8,166,453	26.4	15,150
FL	12,937,926	15,982,378	23.5	2,399
TX	16,986,510	20,851,820	22.8	7,609
NC	6,628,637	8,049,313	21.4	4,618
WA	4,866,692	5,894,121	21.1	16,240
OR	2,842,321	3,421,399	20.4	16,240
NM	1,515,069	1,819,046	20.1	7,609
DE	666,168	783,600	17.6	1,992
TN	4,877,185	5,689,283	16.7	20,566

SC	3,486,703	4,012,012	15.1	11,285
VA	6,187,358	7,078,515	14.4	1,981
AK	550,043	626,932	14.0	0
CA	29,760,021	33,871,648	13.8	12,867
AR	2,350,725	2,673,400	13.7	963
U.S. Total	248,709,873	281,421,906	13.2	92,851

Source: Ref. 12.

Table VII. Transportation Corridor County Population Growth, 1990 -2000

County/State (Route)	2000 Pop.	1990 Pop.	% Change	Proj. Truck Shipments, 2010-2048
Clark, NV (I-15, US95, I-215)	1,375,765	741,459	85.5	92,851
Mohave, AZ (I-15, I-40)	155,032	93,497	65.8	84,667
Washington, UT (I-15)	90,354	48,560	86.1	80,004
Salt Lake, UT (I-15, I-80)	898,387	725,956	23.8	52,392
Utah, UT (I-15)	368,536	263,590	39.8	52,392
Sarpy, NE (I-680)	122,595	102,583	19.5	33,685
Polk, IA (I-80, I-35)	374,601	327,140	14.5	32,869
Adams, CO (I-70)	363,857	265,038	37.3	27,612
Johnson, KS (I-435)	451,086	355,021	27.1	26,570
St. Charles, MO (I-270)	283,883	212,751	33.4	25,835
Will, IL (I-80)	502,266	357,313	40.6	21,513
Rutherford, TN (I-24)	182,023	118,570	53.5	16,329
Cobb, GA (I-75)	607,751	447,745	35.7	15,150
San Bernardino, CA (I-10, I-40, I-15)	1,709,434	1,418,380	20.5	12,867

Source: Ref. 12.

Based on historical growth rates since 1980, the population being exposed along the transportation routes, and thus the collective dose, may be underestimated by a factor between 3 and 9 over period during which SNF and HLW would be shipped to Yucca Mountain. (2) . Nonetheless, in it estimates of population increase from 1990 to 2035 to estimate the effects of Yucca Mountain operation, DOE used to lower population growth estimates from Nye and Lincoln County to arrive at a population increase of only 40%.

EFFECTS OF DOSES OVER 800 METERS FROM THE CASK

The FEIS used the RADTRAN code developed by Sandia National Laboratory to model the collective doses to members of the public along transportation routes. The code explicitly assumes that the dose from a transportation container is small enough to ignore the collective dose at distances over 800 m, at which point the population density may also decrease, especially in rural areas. However, the collective dose includes layover of legal weight trucks and rail shipping casks in urban areas where the population density over 800 m from the transportation route may be higher than it is within 800 m. Future population increases will affect population density at distances greater than 1/2 mile from route. Neglecting this dose leads to a small error, on the order of 10 percent, that should be added to the dose estimated in the FEIS. (2)

HEALTH EFFECTS BASELINE MULTIPLIERS

The CAI overview report produced two tables of multipliers (Tables VII and IX, below) which are meant to be applied to the DOE health effects tables in Chapter 6 and Appendix J of the FEIS. For collective health effects, the true impact may be from 7.6 to 50 times higher (with a geometric mean of about 20). Risks to the highest risk individuals are similarly underestimated by a factor of 2.3 to 31, with a geometric mean of about 8.3.

Table VIII. Individual And Total Effect Of Factors Identified (as a Multiplier Of Baseline Effects) On The Collective Health Effects To The Public

Factor	Transportation health effects on public (multiplier of baseline)
Doses Outside 800 m	x1.1
Cancer Risk Factor	x1.5
Non-cancer Effects	X 1.15
Commercial SNF Inventory (life extension/new plants[1,2]	x (1.5-2.94)
Population Increase [1, 2]	x (2.4-8.1)
Overall Effect [3]	x (6.8-45.1)
Geometric Mean of Range of Multiplier[3]	x 17.6

[1] These effects are not independent, because the assumption of greater fuel inventory lengthens YM operation time, which also increases the local population to be exposed.
[2] A range of values indicates a range of values from different scenarios considered
[3] The overall effect is the product of these factors; the geometric mean represents the value if all factors are in the middle of their range
Source: Ref. 2.

TableIX. Individual And Total Effects Of Factors Identified (As A Multiplier Of Baseline Effects) On The Most Exposed Individual (MEI) Member Of The Public

Factor	Health Effects from Transportation (multiplier of baseline)

Doses Outside 800 m	X 1.0
Dose to LCF Conversion	x1.5
Non-cancer [1] (based on Ref. 2, Table 13, relative to generic member of public	X 1.0-7.0
Commercial SNF Inventory (life extension/new plants)[2, 3]	X (1.5-2.91)
Population Increase [2, 3]	x 1
Overall Effect [4]	X (2.3-30.6)
Geometric Mean of Range of Multiplier [4]	X 8.3

[1] Technically, these affect the unborn fetus and future generations, not the individual exposed. The upper range value, however, includes these. See Table 13 and accompanying discussion

[2] These effects are not independent for collective effects, but are for MEI effects. See Note 2 to Table 1 above.

[3] A range of values indicates a range of values from different scenarios considered

[4] The overall effect is the product of these factors; the geometric mean represents the value if all factors are in the middle of their range

Source: Ref. 2.

However, the Nevada and national health effects due to transportation (presented in Chapter 6, Tables 6.3 through 6.6, among others) are listed for the Proposed Action Inventory, which contains approximately 62 percent of the expected SNF and HLW inventory from existing sources. To a reasonable approximation, the collective transportation health effects from 38 year operation (Module 2) will be 1.6 times greater than those from the Proposed Action, all other things being equal.

RADIATION EXPOSURES FROM LWT TRANSPORT

CAI estimated potential annual radiation doses at maximum exposure locations along certain Nevada highway routes that could be used for legal-weight truck (LWT) transportation of SNF and HLW to Yucca Mountain. From the DEIS, NANP selected LWT shipping scenarios and routes that would maximize opportunities for routine exposures. NANP further selected locations where exposures would be maximized by proximity to casks during required transport vehicle stops and/or travel at slow speeds. The selected locations include residential and commercial buildings, parking lots, sidewalks, and pedestrian crosswalks. While members of the public are frequently present at these locations, the CAI analyses estimated the maximum annual dose at a particular location without regard to the actual presence of an exposed individual or individuals at that location.

Under the mostly truck transportation scenario in the DEIS, DOE identified the potential for up to 95,957 LWT shipments of SNF, HLW, and miscellaneous radioactive wastes over 38 years. DOE's base case routing analysis assumed that these truck shipments would use interstate highway routes through the Las Vegas metropolitan area. DOE also identified, and partially evaluated, six alternative routes that would avoid Las Vegas. [DEIS, pp. J-92 to J-95]

NANP selected one of the alternative routes identified in the FEIS, referred to as NDOT Route B, for these analyses. NDOT Route B, so-called by reference to its designation in a 1989 report prepared for the Nevada Department of Transportation [Ardila-Coulson, 1989], enters Nevada from Utah on I-80, travels South on U.S. 93A and U.S. 93, West on U.S. 6, and South again on U.S. 95. The route is travels through the cities of West Wendover, McGill, Ely, Tonopah, Goldfield, and Beatty. The distance from the Nevada state line to Yucca Mountain by this route is about 430 miles.

The DEIS assumed that this route could be used by all LWT shipments, an average of 2,525 per year for 38 years. NANP believes that NDOT Route B could reasonably be used for shipments from all sites identified in the DEIS except five reactor sites in Arizona and California. For this analysis, NANP assumed that about 87,600 LWT shipments of SNF and HLW, 94% of total LWT shipments to the repository, would use this route. This would result in an average of 2,305 SNF and HLW shipments per year, or 6.3 shipments per day. There would also be about 80 LWT shipments per year of miscellaneous radioactive wastes. The FEIS states that there could be 108,544 shipments over 38 years, so the analyses prepared by CAI actually understates doses by about 15 percent.

In West Wendover, NANP selected two sidewalk locations used by pedestrians walking from parking lots to a major casino. The sidewalks are adjacent to intersections where SNF trucks are required to stop. In Ely, NANP selected three sidewalk locations and a retail establishment near intersections where traffic signals require SNF trucks to slow down and/or stop prior to turning. In Goldfield, NANP selected two sidewalk locations and a road shoulder near a residential property where SNF trucks would be required to stop at a pedestrian crosswalk and slow down to negotiate an extremely sharp curve. NANP estimated transit speeds (including truck deceleration and acceleration) and stop times based on field observations.

CAI calculated cumulative annual doses at the locations selected by NANP using the code RISKIND 1.11, supplemented with analytical modeling. Some scenarios called for situations not addressed in RISKIND, such as trucks decelerating to a stop at crosswalks. An analytical model was thus calculated with an inverse power-law representation of the dose curve. The fitted curve exaggerates the dose rate at larger distances, so the results should be conservative. The calculation was broken into two parts: the approach, and the deceleration to a stop. The model was tested by setting the deceleration to zero and adding the doses from the two parts. This was compared with the results for a half-passing calculation from RISKIND. In other situations, similar approaches were used, for example, to estimate the exposure as the truck moves along a curved path. The exposure from the truck negotiating a sharp turn can't be described by either the *Passing* calculation or the *Stop* calculation in the code. As a result, an approximate analytic calculation was made to estimate an equivalent *Stop* calculation.

For the DEIS mostly truck scenario, CAI found that annual exposures at certain locations near intersections ranged from 46 mrem (at 10 meters) to 4 mrem (at 21 meters). A location near a pedestrian crosswalk requiring brief stops (15 seconds) received an annual dose of 47 mrem (at 4 meters). Near-route locations where trucks slowed down, but did not stop, received annual exposures ranging from 28 mrem (at 4 meters) to 6 mrem (at 4 meters).The estimated annual doses for each location are shown in Table X.

Table X. Est. Annual Doses at Locations Along LWT Routes to Yucca Mtn.

Location	Distance from Cask (meters)	Stop Time (seconds)	Travel Speed (miles/hour)	Annual Dose (millirem)
W. Wendover #1	10	38 - 52	15 - 25	22 - 30
Ely #1	10	24 - 72	20 - 35	18 - 43
Ely #2	10	24 - 72	20 - 35	20 - 46
Ely #3	21	24 - 72	20 - 35	4 - 11
Ely #4	4	0	3	28
Goldfield #1	4	0	20	6
Goldfield #2	4	15	20	47
Goldfield #3	4	0	11	11

Source: Reference 3, table 1; Reference 4, pg. 10; Reference 5, table 4.

RADIATION EXPOSURES FROM HHT TRANSPORT

CAI estimated potential annual radiation doses at maximum exposure locations along one of the Nevada highway routes that could be used for heavy haul truck (HHT) transportation of SNF and HLW to Yucca Mountain. From the DEIS, NANP selected a HHT shipping scenario and route that would maximize opportunities for routine exposures. NANP further selected locations where exposures would be maximized by proximity to casks during required transport vehicle stops and/or travel at slow speeds. The selected locations include sidewalks and road shoulders near residential and commercial buildings, and pedestrian crosswalks. While members of the public are frequently present at these locations, the CAI analysis estimated the maximum annual dose at a particular location without regard to the actual presence of an exposed individual or individuals at that location.

Under one version of DOE's mostly rail transportation scenario, heavy haul trucks HHTs could be used to transport large (125 to 180 tons) rail casks from an intermodal transfer facility (ITF) to a repository at Yucca Mountain. NANP selected for analysis a segment of US 95 through Goldfield that could be used for shipments from an ITF in Caliente to Yucca Mountain.

The HHTs proposed by DOE would be about 220 feet (67 meters) long, using trailers supported by 16 or more axles and powered by push and pull diesel tractors. DOE expects these HHTS to travel an average speed of 20-30 mph. These rigs would require special State of Nevada permits restricting operations to daylight hours, Monday through Friday (holidays excluded). Other operational details, such as driver work rules, the need for way stations, and escort requirements, are unclear.

Under DOE's mostly rail scenario, over 38 years, an average of 521 HHTs and 96 LWTs per year could traverse Goldfield on US 95. The number of shipments would thus be much lower than under the LWT scenario. HHTs would likely operate at substantially slower speeds than LWTs, about 10-15 mph in towns. The restricted hours of operation could \ increase the number of shipments required to stop for pedestrians in cross walks. The size and weight of the HHT would increase stop and restart times. The reference rail cask, the large (21 PWR) MPC, has a side-to-side diameter of 85 inches (about 2.2 meters), compared to the reference truck cask diameter of 37 inches (about 1 meter), reducing distance between MEI locations and the cask side by about 0.6 meter compared to LWT shipments.

CAI calculated cumulative annual doses at the HHT route locations selected by NANP using the code RISKIND 1.11, supplemented with analytical modeling similar to that employed for the LWT dose calculation. Total doses for the HHT scenario represent the sum of the doses for 521 HHT shipment and 96 LWT shipments per year. In the FEIS, DOE reduced the projected number of shipments to 498, and reduced LWT shipments to 82 per year. Therefore the CAI results should be reduced by about 4 percent.

For the DEIS mostly rail scenario, assuming all rail casks were transported to Yucca Mountain by HHT, CAI found that a location near a pedestrian crosswalk requiring brief stops (30 seconds) received an annual dose of 30 mrem (at 3.4 meters). Near-route locations (at 3.4 meters from the cask) where trucks slowed down, but did not stop, received annual exposures ranging from 3.4 mrem to 5.8 mrem. The estimated annual doses for each location are shown in Table XI.

Table XI. Estimated Annual Doses at Locations Along HHT Route to Yucca Mountain

Location	Distance from Cask (meters)	Stop Time (seconds)	Travel Speed (miles/hour)	Annual Dose (millirem)
Goldfield #1	3.4	0	10 - 15	3.4
Goldfield #2	3.4	30	10 - 15	30.0
Goldfield #3	3.4	0	5.6	5.8

Source: Ref. 6, table 4.

RADIATION EXPOSURES FROM GENERAL FREIGHT RAIL TRANSPORT

CAI estimated potential annual radiation doses at maximum exposure locations along one of the existing Nevada rail routes that could be used for transportation of SNF and HLW to Yucca Mountain. From the DEIS, NANP selected a rail shipping scenario and route that would maximize opportunities for routine exposures. NANP further selected locations where exposures would be maximized by proximity to casks during planned and unplanned stoppages. The selected locations include parking lots and entrances to major commercial buildings. While members of the public are frequently present at these locations, the CAI analysis estimated the maximum annual dose at a particular location without regard to the actual presence of an exposed individual or individuals at that location.

Under the mostly rail transportation scenario in the DEIS, DOE evaluated the impacts of 19,800 rail cask-shipments to four potential rail spur originations and three potential intermodal transfer stations. The heaviest routine rail transportation impacts on downtown Las Vegas would likely result from the Jean rail spur or Sloan/Jean intermodal transfer options. DOE's rail routing analysis for Jean indicates that about 87% of all rail shipments to Yucca Mountain would use the Union Pacific mainline through downtown Las Vegas. There would be 17,364 rail cask-shipments through Las Vegas over 38 years, an average of 457 cask-shipments per year.

The DEIS and FEIS both assume that SNF rail casks will be shipped in general freight service, although the railroads and many stakeholders believe that all SNF shipments should be made by dedicated train. Indeed, many experts believe DOE will be forced to use dedicated trains. However, for purposes of evaluating a credible maximum incident-free scenario, NANP assumed each rail cask would be shipped through Las Vegas separately by general service in a different train. Thus there are 457 rail cask-shipments per year through Las Vegas over 38 years.

There are a number of locations in downtown Las Vegas along the Union Pacific where entire trains and groups of freight cars are routinely stopped for varying periods of time. For this analysis, NANP selected two such locations near large casino hotels and one location near a major government building.

The DEIS and FEIS provide few details about expected rail operations, other than the decision that dedicated trains will not be required. Train stops occur for many reasons. Stops for carrier interchange or train assembly could require from 2 to 24 hours. Stops for crew changes, car changes, engine refueling, train maintenance, regulatory inspections, and traffic control, could range from 15 minutes to more than 2 hours. In planning for receipt of casks shipped by general freight service, DOE has indicated its intention to take advantage of USDOT regulations that allow stoppage of SNF cars in transit for periods of up to 48 hours (DEIS, p. 2-50).

NANP directed CAI to evaluate exposures under two rail-stop scenarios: (1) a one time cask-car stoppage at the designated location for 48 hours, the regulatory maximum; and (2) the cumulative annual exposure assuming that each cask-shipment stops at the designated location one time for one-hour only (a total of 457 hours per year). Since the FEIS reduced the estimated number of annual rail shipments through Las Vegas from 457 to 434, the CAI estimated doses may overstate the cumulative annual doses by about five percent.

CAI calculated routine doses at the rail route locations selected by NANP using the code RISKIND 1.11. The cases of 48 hr and 457 hr stops were examined. Since RISKIND does not allow calculations for stop times greater than 100 hr, the 48 hr doses were multiplied by (457/48) to give the doses for the longer time. Since the doses are only reported to two significant figures, this may slightly degrade the accuracy of the results for 457 hr due to round-off problems. Because the stop doses would be considerably larger than passing doses, the latter were not examined. The cask was assumed to be the large (21 PWR) MPC. Table G.4 in the RISKIND users manual gives a length of 5.29 meters and a radius of 1.086 meters. No gamma fraction was listed, so the value of 0.83 was taken. The loading is assumed to give 10 mrem/hr at a distance of 2 meters from the cask surface.

Table XII reports the results obtained by CAI. The cumulative annual doses (457 hours) in the hotel parking lots ranged from 200 mrem (at 15 meters) to 36 mrem (at 35 meters). The cumulative annual doses (457 hours) at hotel-casino entrances ranged from about 28 mrem (at 40 meters) to about 1 mrem (at 160 meters). At the Government Center, the cumulative annual dose (457 hours) is 114 mrem in the parking lot (at 20 meters), about 50 mrem at the nearest entrance (at 30 meters), and about 3 mrem at another entrance (at 100 meters). The 48-hour doses ranged from 21 mrem (at 15 meters) to 0.1 mrem (at 160 meters).

Table XII. Estimated Doses at Locations Along Las Vegas Rail Route

Location	Distance from Cask (meters)	48 hr dose (mrem)	457 hr dose (mrem)
Casino A, Loc #1	40	2.9	27.6
Casino A, Loc #2	15	21	200
Casino B, Loc #1	35	3.8	36.2
Casino B, Loc #2	160	0.11	1.05
Govt. Center, Loc #1	20	12	114
Govt. Center, Loc #2	30	5.2	49.5
Govt. Center, Loc #3	100	0.36	3.43

Source: Ref. 7, table 1.

DOSES TO MAXIMALLY EXPOSED MEMBERS OF THE PUBLIC—THE STATION ATTENDANT SCENARIO

DOE identified the service station attendant as the maximally exposed member of the public in the DEIS (1), especially in locations where refueling options are limited; i.e. most trucks passing by would be forced to refuel because of the limited truck range and the distance to the next refueling stop. The DEIS estimated this annual dose as 81 mrem/yr, but time and motion observations by Griego et al. (17) led DOE to raise the estimate in the FEIS to 130 mrem, or 30% over the annual limit for members of the public and a 50% increase over the DEIS estimate.

Both DOE estimates of annual dose to these individuals are predicated on the attendants receiving only causal dose; that is, they are collecting payment for fuel and other amenities but not assisting in the refueling or other servicing of trucks.

It is not in the interests of either DOE or the public to burn out" drivers by having their occupational dose reach or exceed the administrative limit of 2 rem per year; in fact, that likelihood might increase the tendency for attendants to be drawn into refueling and serving process by the drivers to decrease their own doses.

The observations of truck stop times by did not include the replacement of tires or other minor repairs, estimated by et al to occur about 1 service stop in every 20. If all servicing is done by the driver, the service time will increase significantly and the driver exposure will skyrocket, requiring experienced drivers to be furloughed or receive radiation work restrictions (RWR's) and assigned to duties not involving radiation exposure.

Ironically, restricting the involvement of station attendants in refueling and repairs significantly increases collective radiation dose to the public. This is because as Reference 17 shows, an SNF truck parked at a refueling bay not only irradiates the attendants present, but also uninvolved members of the public, such as other rig drivers and others, such as local residents, who may be using the service station amenities. Conversely, getting the attendant involved in refueling—especially when multiple nozzles as used, as is frequently the case—and in minor repairs would actually reduce collective public exposure, albeit at the cost of some additional exposure to the attendant.

As discussed above, when a radiation worker's radiation dose approaches the annual limit, he can be assigned to other duties in order to prevent additional exposure during that year. No such protection or controls exist for members of the public, including the service station attendant, who becomes an indentured recipient of unnecessary radiation exposure. Nonetheless, the DOE response to the FEIS estimate of 130 mrem/yr is to simply assume, without justification or elaboration, that appropriate steps will be taken to prevent annual dose over 100 mrem [Table 6.1 of Reference 1].

Although it is not within the scope of this report to suggest how this might be accomplished, it occurs to the authors that several substantive administrative steps might be taken to give reasonable assurance that service station attendants are not overexposed:

- Have NRC and the nuclear industry commit to shipping oldest fuel first, at least for the first few years of Yucca Mountain operation. This will tend to minimize radiation fields around the shipping casks (probably to below 50% or less of the regulatory limit of 10 mrem/hr at 2 meters distance.

- At least for service station locations identified as being in areas with limited refueling options, designate attendants as "Radiation Worker I", a category of radiation worker involving only modest exposures to external radiation and requiring minimal training. Then attendants can freely participate in refueling and servicing. Furthermore, the designation as a Radiation Worker I is likely to increase the pay and benefits to the workers involved, a real boon to workers in what is otherwise an occupation with low pay and status. Since such workers can then freely participate in refueling and servicing of shipments to Yucca Mountain, both driver doses and those to other members of the public are reduced by minimizing stop times. This would tend to minimize overall collective dose as well.

- In location where refueling options are limited, establish a separate refueling bay dedicated for Yucca Mountain shipments, located farther from the station office and other refueling bays, and possibly shielded. Such facilities would probably have to be subsidized by DOE, as would the radiation worker training of attendants described above.

Based on the assumption of 2200-2300 shipments per year, and a baseline work year of 1800 hrs/yr, the authors have arrived at higher estimates of annual attendant doses based on time and motion studies done by Rogers and Associates (17) in 1985, assuming attendant participation in refueling and servicing. These estimates are conservative, however, because the number of shipments could be as high as 2,800 to 2,900 per year over 38 years if the total projected inventory of SNF and HLW (designated in Appendix A as Module 1 inventory) is shipped to Yucca Mountain (Reference 5, p. A-1).

Table XIII. Service Station Attendant Annual Doses if Overtime Hours and 8 AM-12AM Refueling are Assumed. Time and Motion Data from Sandquist et al, 1985 (16).

Scenario	Total Annual Dose
Baseline (no overtime and 24 hour refueling)	555
25% Overtime, and 24 hour refueling	694
Normal (1800 hours/yr), 8 AM-12 AM refueling [a]	832
25% Overtime and 8 AM-12 AM refueling [a]	1041

[a] 8AM-12AM refueling assumes that most trucks are at rest stops or otherwise parked for part of the night and that refueling is therefore preferentially done from 8AM through 12AM. An 1800 hour normal work year is also assumed except as noted.

Thus, even removing some of the conservatism built into the equation above (e.g. assume that there are always at least two attendants available to refuel trucks on every shift and only 50% of the cask trucks stop at any one station), it is still very likely that the annual dose will significantly exceed the 100 mrem limit if service station attendants are drawn into vehicle refueling or servicing.

CONCLUSIONS

CAI's work for Nevada involved two tasks. The first task was to generally review DOE's treatment of routine radiation exposure and health effects issues in the DEIS. The CAI review found that despite the sophistication of the models used to calculate impacts, many of the basic underlying assumptions and inputs into the risk calculations in the DEIS are incorrect, and are based on outdated or non-conservative forecasts. The effects of these inconsistencies and errors on the estimated time integrated exposures to workers and members of the public along proposed transportation routes are substantial. For collective health effects, the true impact may be from 7.6 to 50 times higher (with a geometric mean of about 20). Risks to the highest risk individuals are similarly underestimated by a factor of 2.3 to 31, with a geometric mean of about 8.3. These deficiencies have not been corrected in the FEIS.

CAI's second task was to prepared for NANP a series of reports estimating incident-free radiation exposures at specific locations along several potential shipping routes identified in the DEIS. CAI evaluated potential incident-free exposures from legal weight truck (LWT) shipments through northern and central Nevada, heavy haul truck (HHT) transport of large rail casks through central Nevada, and general freight rail transport of large rail casks through the Las Vegas metropolitan area. CAI found that annual exposures at certain locations along truck routes could reach 47 mrem, and that annual exposures at certain locations along rail routes could reach 200 mrem. When the revised shipments numbers in the FEIS are considered, the CAI results appear to understate LWT doses by about 15 percent and overstate rail and HHT doses by about 5 percent.

Finally, the authors have determined that radiation doses to service station workers will be likely to exceed the100 mrem annual limit for members of the public, in locations where refueling options are limited. When attendants are assumed to participate in refueling and servicing of SNF shipments bound for Yucca Mountain, their annual doses may exceed the limit by a large factor.

REFERENCES

1. "Draft 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," DOE/EIS-0250D, U.S. Department of Energy, Washington, D.C. (July 1999).

2. H. E. Collins, "Review of Radiological Assessment Issues and Draft Environmental Impact Statement for The Yucca Mountain Project" , Report for the Nuclear Waste Projects Office, State of Nevada, M.H. Chew and Associates, Livermore, CA (2001)

3. G.R. Gathers, "Calculations with RISKIND for Truck Transport of Spent Nuclear Fuel Casks Via West Wendover," Report for the Nuclear Waste Projects Office, State of Nevada, M.H. Chew and Associates, Livermore, CA (2001)

4. G.R. Gathers, "Calculations with RISKIND for Truck Transport of Spent Nuclear Fuel Casks Via Ely, Nevada," Report for the Nuclear Waste Projects Office, State of Nevada, M.H. Chew and Associates, Livermore, CA (2001)

5. "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," DOE/EIS-0250D, U.S. Department of Energy, Washington, D.C. (July 1999).

6. G.R. Gathers, "Calculations with RISKIND for Legal-Weight Truck (LWT)Transport of Spent Nuclear Fuel Casks Via Goldfield, Nevada," Report for the Nuclear Waste Projects Office, State of Nevada, M.H. Chew and Associates, Livermore, CA (2001)

7. G.R. Gathers, "Calculations with RISKIND for Heavy Haul Truck (HHT) Transport of Spent Nuclear Fuel Casks Via Goldfield, Nevada," Report for the Nuclear Waste Projects Office, State of Nevada, M.H. Chew and Associates, Livermore, CA (2001)

8. G.R. Gathers, "Calculations with RISKIND for Rail Transport of Spent Nuclear Fuel Casks Via Las Vegas, Nevada" Report for the Nuclear Waste Projects Office, State of Nevada, M.H. Chew and Associates, Livermore, CA (2001)

9. "Exelon Picks Clinton for Possible New Construction", Nuclear News Vol. 22, No 1: 23-24 (June, 2002)

10. "1990 Recommendations of the International Commission on Radiation Protection," Publication 60 (1991)

11. "Biological Effects of Ionizing Radiation Committee, Report V"**.** National Academy of Science***s*.** National Academy Press (1991).

12. United Nations Subcommittee on the Effects of Atomic Radiation (UNSCEAR),

"Sources, Effects and Risks of Ionizing Radiation". Report to the General Assembly, with Annexes, United Nations, New York 1988.

13. Environmental Protection Agency Federal Guidance Report No.13 -Part 1, Interim Version: "Health Risks From Low-Level Environmental Exposure To Radionuclides", EPA 402-R-97-014, U.S. Environmental Protection Agency, Washington, DC, January 1998.

14. Nevada Agency for Nuclear Projects, "State of Nevada Yucca Mountain Impact Report," February 2002.

15. Annals of the International Commission for Radiation Protection, "Risks Associated with Ionising Radiations", International Council on Radiation Protection, Vol. 22, No 1, Pergamon Press, Oxford (1991)

16. G. M. Sandquist, V.C. Rogers, A.A. Sutherland, G.B. Merrell. "Exposures and Health Effects from Spent Fuel Transportation", Rogers and Associates Engineering Corporation, Salt Lake City. Report prepared for the U.S. Department Energy Office of Civilian Radioactive Waste Management (1985).

17. N.R. Griego, J.D. Smith and K.S. Neuhauser." Investigation of RADTRAN Stop Model Input Parameters for Truck Stops", Sandia National Laboratory, unpublished report, 1996