Diablo Canyon Decommissioning Engagement Panel
Review/Summary of the Transportation Risk Analysis
by the B. John Garrick Institute for the Risk Sciences at UCLA
(June 2020)

Background

The Diablo Canyon Power Plant (Diablo Plant) is set to close by 2025. After that time, the plant will be decommissioned by the plant owner, PG&E, subject to oversight by the Nuclear Regulatory Commission, the California Energy Commission, the California Coastal Commission, the County of San Luis Obispo, and several other regulatory entities.

Among other things, the decommissioning will involve the shutting down and demolition of multiple structures and facilities on the Diablo Plant site. It is expected that most of the materials from the decommissioning will have to be transported away from the site and disposed of in compliance with federal and state law (although some non-irradiated materials could theoretically be left on site). Some materials will begin to be removed immediately after plant shut-down, including clean waste (no detectable radiation), concrete, metals, and low-level radioactive wastes[1]. Other materials -- specifically highly radioactive spent nuclear fuel and Greater Than Class C waste -- will likely be stored on site for years or decades to come, with possible eventual transfer to consolidated interim or permanent storage facilities (which have yet to be constructed).

The removal and transportation of demolished structures and other debris away from the Diablo Plant site (even without the removal of highly radioactive materials that will be left onsite indefinitely) is a massive task. Completing this task will require the removal of millions of pounds of waste, take several years to complete, and will need a large workforce of both PG&E personnel and outside contractors. Many thousands of truckloads of materials over multiple decades could result in a degradation of air quality as well as substantially increased traffic[2] and noise to neighboring communities.

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[1] Low-level radioactive waste includes items that have become contaminated with radioactive material or have become radioactive through exposure to neutron radiation. It is designated as Classes A, B, or C waste based on the concentration of isotopes present in the waste measured in curies per cubic meter. This waste typically consists of contaminated protective shoe covers and clothing, wiping rags, mops, filters, reactor water treatment residues, equipment and tools, and luminous dials. Low-level radioactive waste is typically stored on-site by licensees, either until it has decayed away and can be disposed of as ordinary trash, or until amounts are large enough for shipment to a low-level radioactive waste disposal site in containers approved by the U.S. Department of Transportation.

[2] Traffic impacts may be mitigated in part by a smaller Diablo Plant workforce during decommissioning.

Because of the concern over the impacts to local communities, members of the Diablo Canyon Decommissioning Engagement Panel (Panel) requested that PG&E consider alternative transportation routes and methods (including truck, barge, and rail) for removal of the demolition materials from the Diablo Plant site. Specifically, the Panel asked whether barging the materials from the Diablo Plant site could be considered. (This is a critical question because removing decommissioning materials by truck alone could result in 35,000 truckloads (70,000 round trips) leaving the Diablo Plant and then driven through neighboring communities, whereas barging those materials could result in a significant reduction in the number of truckloads.) In response, PG&E collaborated with the B. John Garrick Institute for the Risk Sciences of UCLA to conduct an analysis of risks associated with, among other things, trucking the demolition materials versus rail or barging.

The Garrick Institute completed its analysis and issued the report, "Transportation Risks Associated with the Decommissioning of Nuclear Power Plants: Methodology and Application to Diablo Canyon Power Plant" (UCLA Transportation Risk Analysis) in May of 2020. The UCLA Transportation Risk Analysis did not consider in significant detail the issues associated with the management and eventual removal of spent nuclear fuel or Greater Than Class C waste, which may be the subject of future analyses.

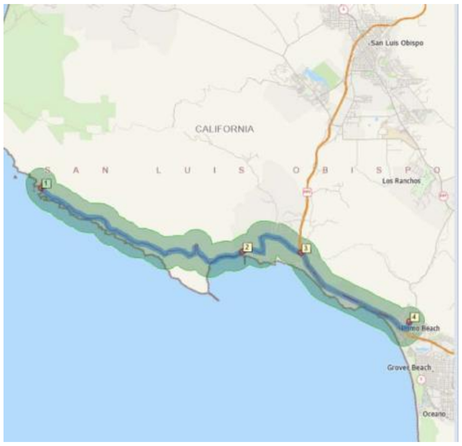
The full UCLA Transportation Risk Analysis can be found here: www.diablocanyonpanel.org

The Panel has reviewed the UCLA Transportation Risk Analysis and provides this summary of it to help facilitate a public discussion of the critical issues surrounding the transportation of demolition materials and low-level radioactive materials resulting from the decommissioning of the Diablo Plant.

<u>Focus of UCLA Transportation Risk Analysis</u>

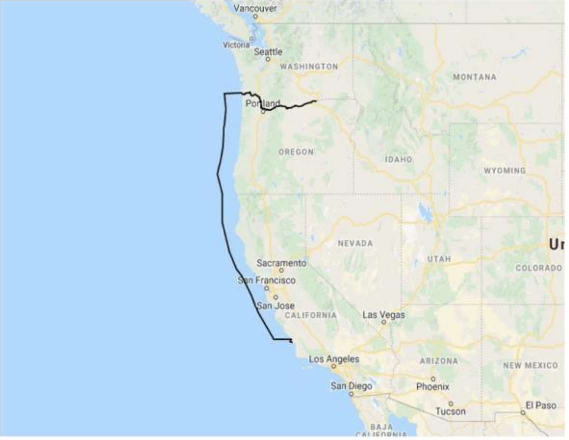
<u>Transportation Alternatives</u>**:** The UCLA Transportation Risk Analysis considered three alternative methods to remove the demolition materials from the Diablo Plant.

(1) *<u>Southern Truck Route</u>*. This route would truck materials to the south through Avila Beach to the Pismo Beach Rail Yard for further transportation by rail or truck to the final destination.

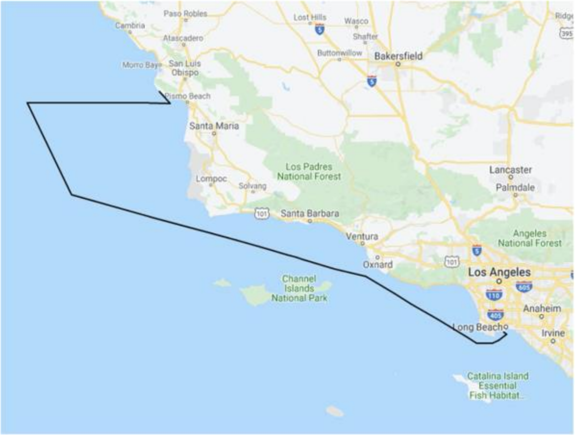


(2) *Northern Truck Route*. This route would truck materials to the north through the North Ranch of the Diablo Canyon Lands, Montana de Oro State Park, and Los Osos to the Pismo Beach Rail Yard for further transportation by rail or truck to the final destination.

(3) *Barge Route*. This route would barge materials from the coast adjacent to the Diablo Plant site to either Long Beach, California or Boardman, Oregon before using rail or truck to the final destination.



Barge Route to Boardman, OR



Barge Route to Long Beach, CA

The "final destination" referenced above will depend upon the nature of the materials being removed. Final destinations include disposal/management sites in Arizona, Utah, Nevada, Idaho, and/or Texas.

<u>Breakwater Alternatives</u>**:** The UCLA Transportation Risk Analysis also considered the risks associated with the removal of the Breakwater (i.e., the barriers of cement surrounding the Diablo Plant seawater intake cove) versus leaving it in place to be repurposed for other public uses.

<u>Risks Considered</u>**:** In comparing the alterative transportation routes as well as considering the Breakwater alternatives, the UCLA Transportation Analysis considered "conventional transportation risks," which are accidents, injuries, and fatalities using the TRAGIS software developed by the U.S. Department of Energy. The analysis also considered non-incident/accident related risks from potential radiological releases using the RADTRAN software developed by Sandia National Laboratories.

Conclusions

Key findings of the UCLA Transportation Risk Analysis include the following:

1. On the basis of conventional transportation risks (i.e., accidents, injuries, fatalities), barging has the lowest risk compared to trucking and rail transport (Figure ES-1);

2. On the basis of conventional transportation risks, including travel distance, the Southern Truck Route has lower risk than the Northern Truck Route, although the difference is small (See Figure ES-1);

3. On the basis of conventional transportation risks, rail transport is less risky than trucking (on a per-mile basis, rail transport fatality risks are higher, but a train can carry 150 to 180 times the material of a truck so there are fewer miles traveled);

4. On the basis of the human health and safety risks from potential radioactive releases[3], transportation on land and in coastal waters was deemed to be so low as to be inconsequential in the selection of one transportation option over another;

5. Leaving the Diablo Plant Breakwater in place (and thereby reducing the amount of waste leaving the Diablo Plant during decommissioning by about half) results in a significant decrease in risk (by almost 50 percent) (See Figure ES-2); and

6. The combination of using barge transport for the first leg of the route and keeping the Breakwater in place lowers the fatality risks by more than 40 percent. The corresponding reduction in injury risk is approximately 32 percent lower and the accident risk is over 9 percent lower.

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[3] The U.S. Nuclear Regulatory Commission (NRC) is responsible for protecting the health and safety of the public and the environment by licensing and regulating the civilian uses of radioactive materials.

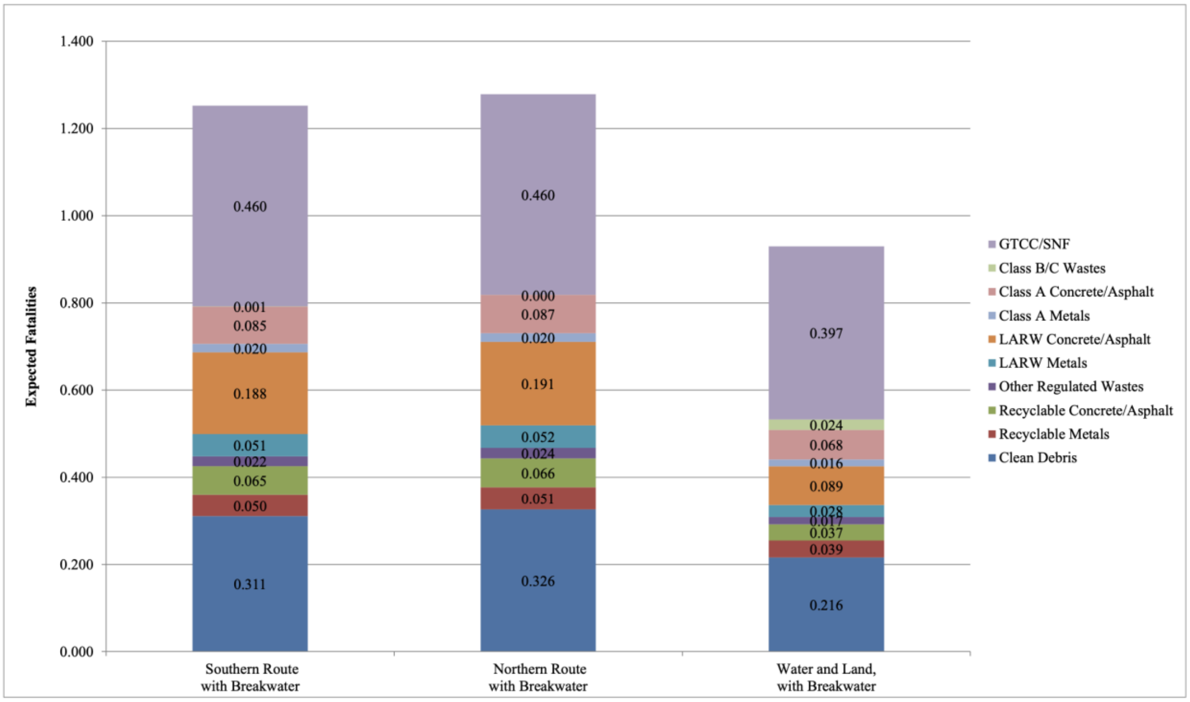

Figure ES- 1. Conventional Risks of Transportation for Base Case (Includes Breakwater Removal)

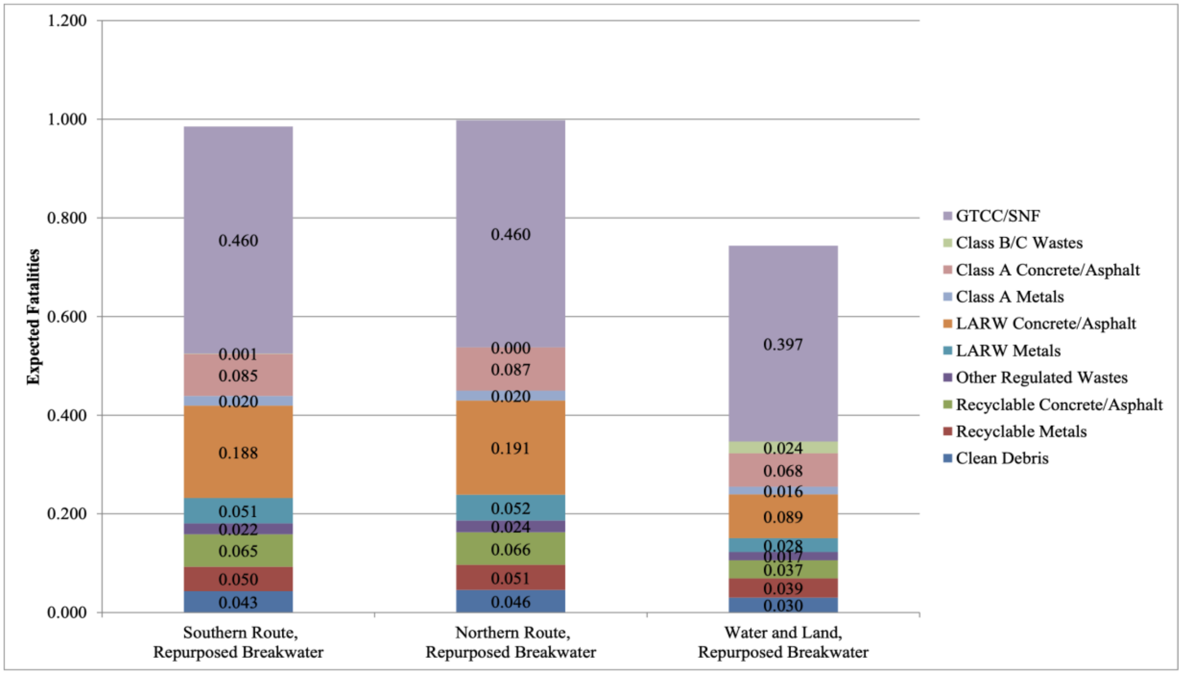

Figure ES- 2. Conventional Risks of Transportation for "Breakwater Repurposed" Case

Limitations

The UCLA Transportation Risk Analysis provides useful information about the risks associated with various transportation options for decommissioning materials and low-level radioactive wastes. The conclusions, however, are subject to the following limitations:

1. The analysis did not address risks associated with the following;

   a. Loading, transfer, staging, intermediate storage, and unloading of materials;
   b. Security risks or terrorism;
   c. Environmental risks at land and sea;
   d. Risks of other impacts such as noise, dust, and traffic constraints as thousands of truckloads of debris pass through neighboring communities; and
   e. Financial impacts, including depreciation of home values near transportation routes.

2. The final decisions will be heavily influenced by the costs to ratepayers, taxpayers, and possibly shareholders, as well as policies and information/environmental reports prepared by governmental entities charged with examining the potential impacts of decommissioning.

3. The solutions for short- and long-term management and storage of spent nuclear fuel and other high-level radioactive waste are beyond the reach of this analysis.

4. The analysis did not consider the merits or risks associated with disposal of decommissioning materials on the Diablo site.

5. The fatality and incident rates contained in the UCLA Transportation Risk Analysis are based on national averages that do not differentiate between weather conditions or potential mitigation that could be imposed such as night-time or off-peak trucking restrictions.

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The B. John Garrick Institute for the Risk Sciences
UCLA ENGINEERING

Transportation Risks Associated with the Decommissioning of Nuclear Power Plants: Methodology and Application to Diablo Canyon Power Plant

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ACRONYMS AND ABBREVIATIONS

CISF	Consolidated Interim Storage Facility
DCPP	Diablo Canyon Power Plant
DCPP-N	Northern truck route out of Diablo Canyon Power Plant to Pismo Beach Rail Yard, via Montana de Oro State Park
DCPP-S	Southern truck route out of Diablo Canyon Power Plant to Pismo Beach Rail Yard, via Avila Beach
EPRI	Electric Power Research Institute
ESSM	Emergency Ship Salvage Material
FOSC	Federal On-Scene Coordinator
GEIS	NRC's Decommissioning Generic Environmental Impact Statement (GEIS, NUREG-0586)
GTCC	Greater than Class C Waste
HAC	Hypothetical Accident Conditions
IAEA	International Atomic Energy Agency
IMC	Intermodal Container
LARW	Low-Activity Radioactive Waste
LCF	Latent Cancer Fatalities
MEI	Maximally Exposed Individual
MREM	Milli REM or One Thousandth of a REM, also mrem
NCP	National Oil and Hazardous Substance Pollution Contingency Plan
NDCTP	Nuclear Decommissioning Cost Triennial Proceeding
NRC	U.S. Nuclear Regulatory Commission
ORNL	Oak Ridge National Laboratory
PBRY	Pismo Beach Rail Yard
PDO	Property Damage Only
PG&E	Pacific Gas and Electric
PTWC	Pacific Tsunami Warning Center
RAM	Radioactive Material
RAMP	The Radiation Protection Computer Code Analysis and Maintenance Program of the U.S. Nuclear Regulatory Commission
REM	Roentgen Equivalent Man, unit of equivalent dose, also rem
SNF	Spent Nuclear Fuel or Spent Fuel
SNL	Sandia National Laboratories
USDOE	U.S. Department of Energy
USDOT	U.S. Department of Transportation
WCS	Waste Control Specialists LLC

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Executive Summary

The purpose of this study to develop a methodology for the assessment of risk associated with the transport of radioactive and non-detect wastes from the decommissioning of nuclear power plants, and to demonstrate the method in comparing such risks from the decommissioning of the Diablo Canyon Power Plant (DCPP). Pacific Gas & Electric Company (PG&E) is planning the transportation of all wastes generated during the decommissioning of DCPP. The plan includes the removal of millions of pounds of wastes from the site (see Table 1). Some of the wastes will be recycled (in Las Vegas, NV and Salt Lake City, UT). Clean materials will be sent to La Paz, AZ for disposal. Some regulated non-radioactive wastes will be sent to Beatty, NV for disposal. Low activity radioactive waste (LARW 20.2002) will be transported to a location in Idaho. Class A wastes will be transported to Clive, UT. Class B/C wastes, greater than Class C wastes and spent nuclear fuel (SNF) will be transported to Texas.

The non-radioactive materials will be transported in standard 20-foot dry containers in batches of 40,000 lbs or in industrial bags that can hold the same quantity. LARW and Class A wastes will also be transported in the same industrial packaging. The Class B/C wastes will be transported in robust, certified casks that are designed to withstand most traffic accidents. The greater than Class C wastes and SNF will be transported in highly engineered certified casks that have been shown by analysis and field testing to withstand impacts and fires that are beyond the events expected in traffic accidents.

The application of the method to DCPP would assist PG&E in selecting between:

1. Using the southern route out of DCPP that passes through Avila Beach to truck materials out of DCPP either to the Pismo Beach Rail Yard (PBRY) for further transportation by rail or for direct trucking to the final destination
2. Using the northern route out of DCPP that passes through the Montana de Oro State Park to PBRY or the final destination as in (1) above
3. Barging the materials either to Long Beach Port or to Boardman, OR, before using rail or truck to the final destination

The transportation of non-radioactive wastes will result in conventional transportation risks. These will be accidents, injuries and property damage accidents. Traditionally, the risks of such accidents have been assessed in terms of the number of expected fatalities. The same is done in this study. To perform these calculations, appropriate routes were defined between DCPP and the destination to get the number of miles (return trip) by each type of transportation for that route segment. The rates of fatalities per truck mile, train mile or barge mile were obtained from data sources maintained by the Federal Government. Additionally in this study, estimates have been provided for injuries and accidents.

When radioactive materials are transported, regulations require that the radiation dose at a distance of 2 meters from the package is below a certain limit to guard the health of persons who have to approach the package. Nevertheless, there is a low level of radiation that people are exposed to when they share the road with the vehicle or if they reside close by. The radiation dose of such exposure has been assessed using a computer program called RADTRAN. RADTRAN was developed at Sandia National Laboratories and is now maintained and distributed by the US Nuclear Regulatory Commission (NRC). The current major version of RADTRAN is “6”, i.e., it is a mature computer code.

The radiation dose discussed in the preceding paragraph is given at short distances from the truck, train, or barge carrying the material. But in case of a traffic accident there is the additional possibility that the package will sustain damage and spill its contents. If the accident is on land some of the spilled material may become airborne and disperse, thereby exposing people to radiation as they breathe or come in contact with radioactive material particles that are small enough to be dispersed. An assessment of these accidental release risks was also made using RADTRAN. This assessment provides both the consequences to an exposed individual who may be near the stricken vehicle as well as the collective radiation dose to the population in the vicinity of the accident site weighted by the probability of the accident.

For the case of transportation by barge, the material that is released from its package during the accident does not become airborne but is dispersed by the water. The dispersed particles will then cause radiation exposure through inhalation of spray, exposure to sediments, ingestion of sediments, fish, crops, milk, and meat. The International Atomic Energy Agency (IAEA) has developed methods to assess and sum the risks from all of these exposure pathways. A spreadsheet implementation of these methods was used to assess the risks of accidents during barge transportation.

The conventional risks of transportation are presented graphically in Figures ES-1 and ES-2 for the cases including and excluding breakwater removal, respectively. Land transport using the northern route results in higher risks than if using the southern route, but the difference is small. Repurposing of the breakwater results in a significant decrease in risk and should be considered, if feasible.

The lowest risks for conventional transportation are for barging. The fatality rates for barging per mile are of the same order of magnitude as for trucking, but a barge carries approximately 200 times the material that a truck carries. Second to barging for conventional risks is rail transport. On a per mile basis rail transport fatality rates are much higher than those for trucking, but the fact that a train will carry 150 or 180 times the material as a truck tips the balance in favor of rail over trucking.

The large contribution of the SNF casks is an artifact of the assessment method, whereby all of the fatality risks of rail transport for a train with many cars are assigned to the SNF cask. The same error is embedded in the calculated risks for the Class B/C wastes, but the number of shipments is only 9 vs. 148 for SNF.

The combination of using barge transport for the first leg of the route and repurposing the breakwater lowers the fatality risks by more than 40%. The corresponding reduction in injury risk is approximately 32%. The overall accident/incident risk is reduced by more than 9%.

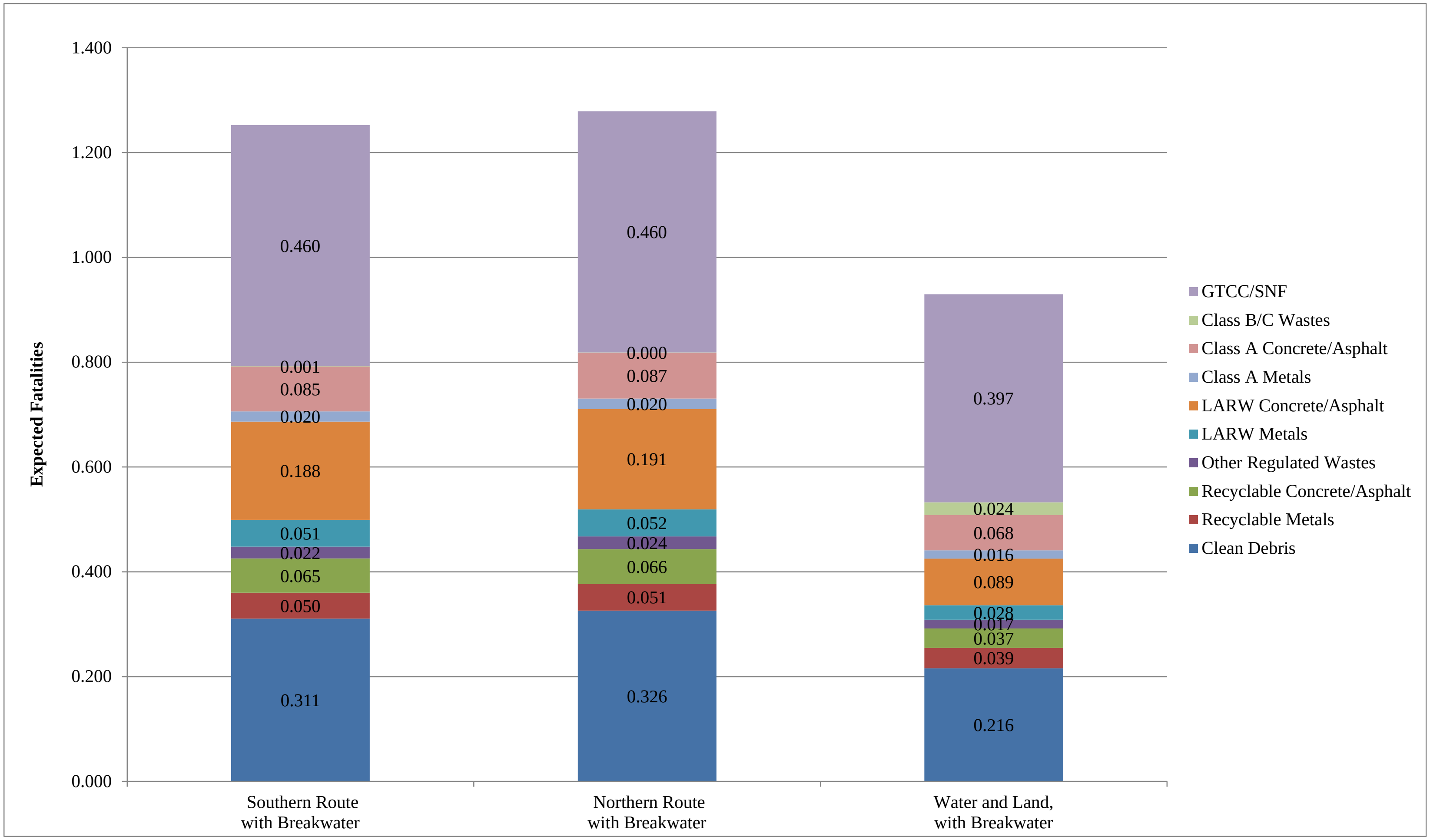

Figure ES- 1. Conventional Risks of Transportation for Base Case (Includes Breakwater Removal)

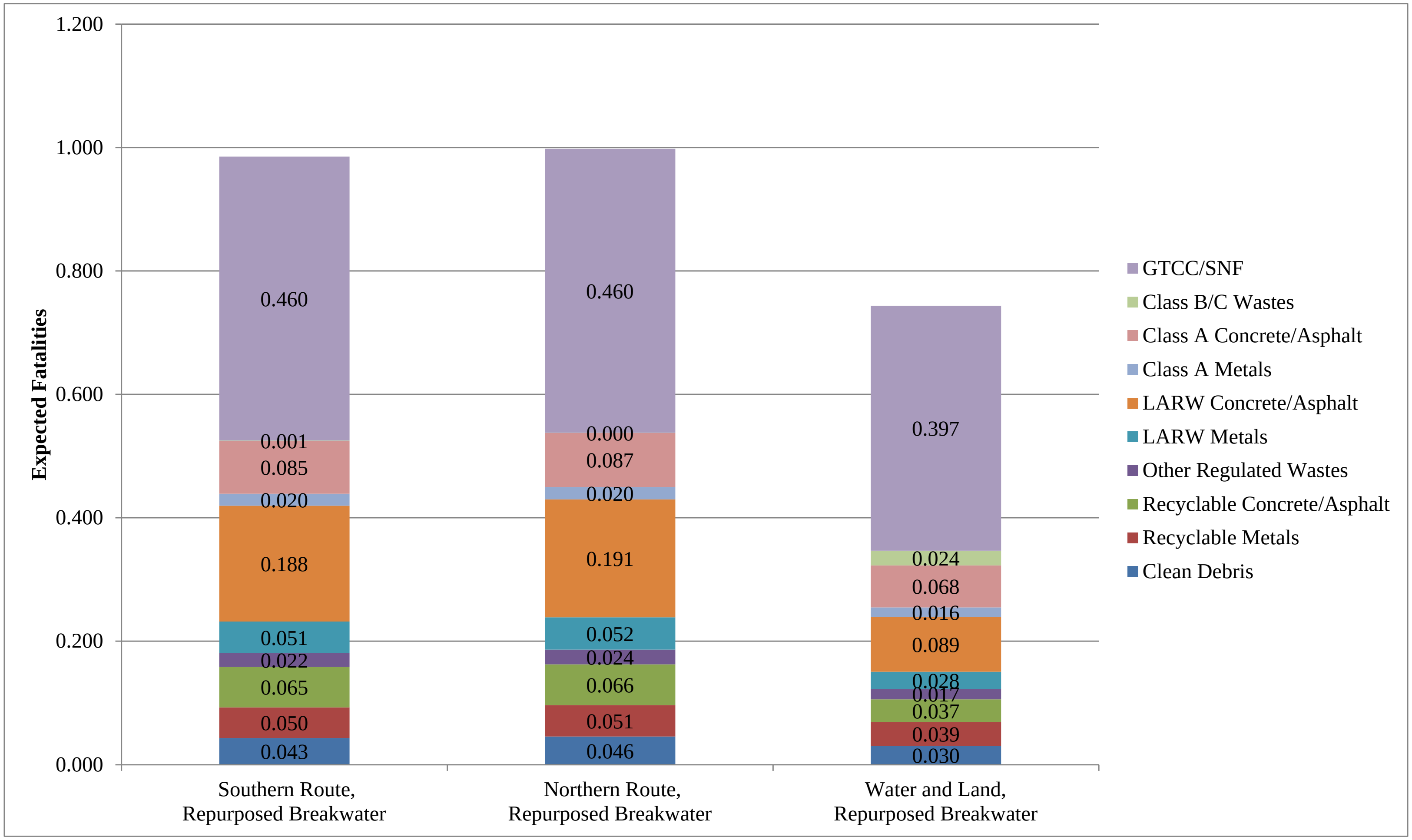

Figure ES- 2. Conventional Risks of Transportation for "Breakwater Repurposed" Case

A comparison of the conventional transportation risks of only the first leg out of DCPP (to PBRY) by truck is presented below in Table ES-1. The risks for the southern route through Avila Beach are almost half the risks for the northern route, in proportion to the length of the route. In the context of the entire campaign these differences are small. The repurposing of the breakwater also halves the risks.

Table ES- 1. Conventional Transportation Risks for First Leg from DCPP by Truck

Item	**Expected Fatalities**	**Expected Injuries**	**Expected Accidents**
Southern Route (to PBRY) Including Breakwater Removal	0.032	0.820	2.801
Southern Route (to PBRY) with Breakwater Repurposed	0.016	0.407	1.389
Northern Route (to PBRY) Including Breakwater Removal	0.058	1.510	5.158
Northern Route (to PBRY) with Breakwater Repurposed	0.029	0.747	2.550

A good way to look at the expected values of traffic fatalities in Table ES-1, which are presented in terms of fractional numbers and have small values, is in terms of probabilities. For most purposes, traffic fatalities can be interpreted using the Poisson distribution. When the expected fatalities are 0.016 there is a 98.4% probability that there will be zero fatalities, a 1.6% probability that there will be one fatality, with significantly lower (but non-zero) probability of two or more fatalities during the entire multi-year campaign. In case the breakwater has to be removed, the expected fatalities on the local roads is 0.032. This implies a 96.9% probability that there are no fatalities, a 3.1% probability that there is one fatality and significantly lower (but non-zero) probability of two or more fatalities. It should be noted that this analysis is based on the totality of large truck and bus accident data. Since drivers of vehicles carrying hazardous materials have additional testing and licensing requirements, there is an expectation that the accident rates are lower than for general commercial trucking. An additional factor that is relevant is that the traffic on the local roads during decommissioning waste transportation will be lower since DCPP will be operating with a lower employee count.

The conventional risks of transportation are calculated using national average fatality rates per mile for truck, rail and barge transportation. The comparison of risks on the northern and southern routes out of DCPP is therefore based on the assumption that the expected fatality rates are similar, which in turn implies that the driving conditions are not very different. During the site visit (on September 18, 2019) by one of the authors of this report, it was observed that the northern route will require significant roadwork to make it truck worthy.

The incident free radiological risks are presented in Figures ES-3 and ES-4 for workers and for members of the public, respectively. For workers the radiologic risks are virtually identical on the northern and southern land routes. The radiological risk for the barge option is lower for workers due to the greater distance between the crew and the radioactive materials. For members of the public the incident free radiological risks are about 8% higher for the northern land route option than for the southern route. The slow speed of the barge when it is close to land results in higher incident free radiological risks, but the difference is small in the context of the overall incident free radiological risks.

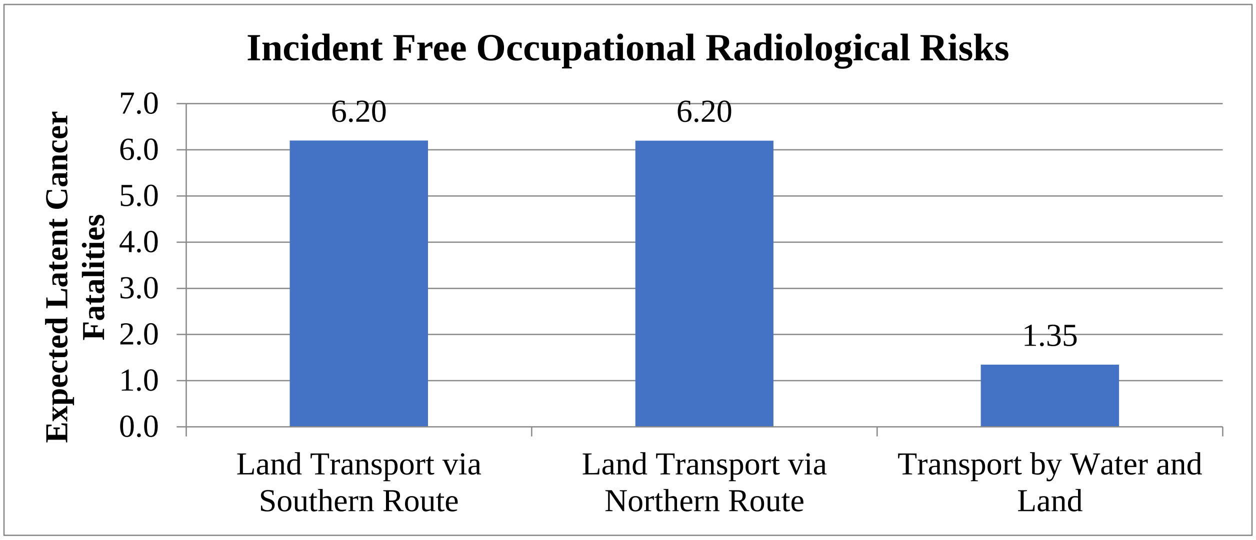

Figure ES- 3. Incident Free Occupational Radiological Risks

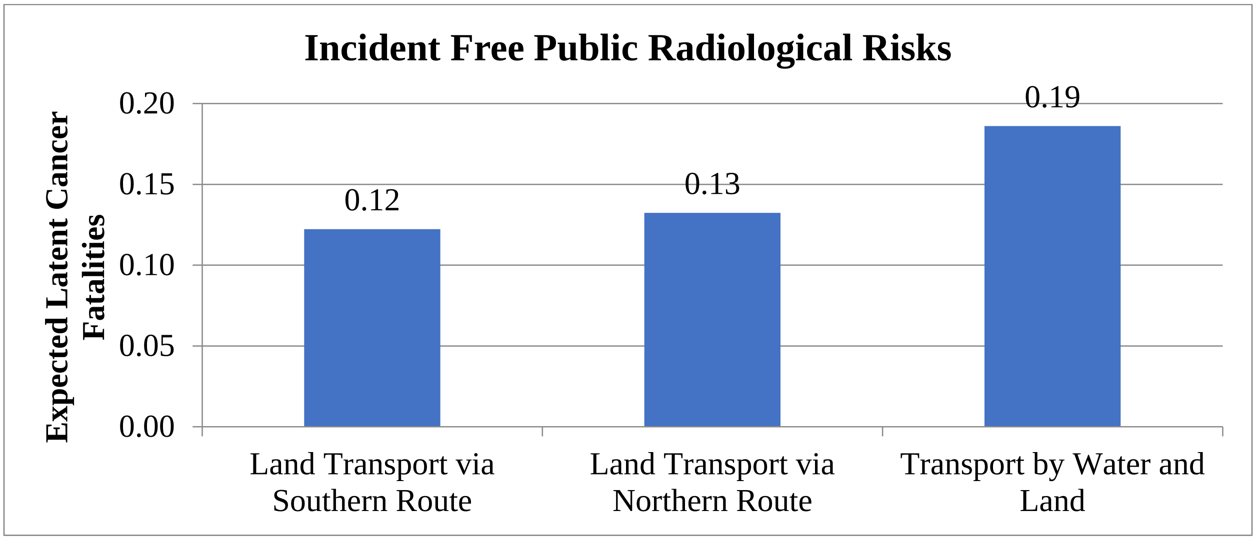

Figure ES- 4. Incident Free Public Radiological Risks

A comparison of the incident free radiological risks of transport for the first leg by truck out of DCPP to PBRY is presented in Table ES-2.

Table ES- 2. Incident Free Radiological Risks for First Leg from DCPP to PBRY

Item	Dose to the MEI (per trip, mrem)	Collective Dose (person-rem)	Expected Latent Cancer Fatalities
Southern Route to PBRY	6.9E-04	11.2	6.2E-03
Northern Route to PBRY	6.9E-04	29.3	1.6E-02

The risk to the maximally exposed individual (MEI) is identical on both routes. The collective risk is lower for the southern route than for the northern route. The collective dose is presented in this study since it is customary. It is important to note that this risk is shared over the entire campaign duration of several years by the entire exposed population. For this reason, it is important to focus on the dose to the MEI. The MEI dose is calculated for a person standing approximately 100 ft from the truck as it passes by slowly (at a speed of 15 mph). If the speeds are higher, or the distances greater, the dose is lower. It is extremely unlikely that the same person will be exposed to multiple trucks a night in this fashion. However, if it were to happen, then that person's exposure would come out to approximately 12 mrem over the entire multi-year campaign. This number is smaller than the background dose in a single year by a factor of about 50. The collective dose is the sum of the dose to all exposed persons, along the route, including those in vehicles sharing the road. With regard to the collective dose, it should be noted that the use of average traffic densities in the calculations results in conservative estimates, since the transportation will be undertaken at night when the traffic on the roads is expected to be lower than average.

The human health and safety risks from releases following a transportation accident on land and in coastal waters are so low as to be inconsequential to the selection of one transportation option over another.

There is significant uncertainty in the characterization of the composition and activity levels of the LARW and Class A wastes. The radiological risks associated with accidental releases of the materials are proportional to assumed activity levels. However, these risks are very low both in terms of consequence to the MEI and in terms of the collective dose risk to the population. The incident free radiological risks have been assessed assuming that the dose at 2 meters from the package and the vehicle meets the regulatory limits for transporting radioactive materials. It is possible that for the loads with really low activity this results in overestimation of the risks. However, this overestimation applies to all modes of transportation and hence a comparison still yields valuable insight. The study should be revisited after site characterization work has been completed and the radioactive payloads being transported can be properly defined.

Storage, handling, loading and unloading risks have not been included in this study and should be evaluated after the most likely transportation option has been selected and detailed procedures are available.

Security risks have not been included in this study, but it is considered that such risks are best addressed by the regulators and security apparatus at the state and national levels.

The assessment of accidental release risks uses average weather inputs and relatively simple dispersion models included in the RADTRAN software. Since the accidental release risks thus calculated are very small, it is considered that such modeling is adequate.

The configuration of the trains used for transportation is important for the risk estimation. If the assumption of the number of rail cars and number of packages per car turns out to be different than that assumed in this study, the study should be revisited.

Transportation routes have been defined using the software webTRAGIS from the US Department of Energy (DOE). It is possible that the actual routes selected are different, based on input from local authorities. If the routing is substantially different from that assumed in this study, the study should be revisited.

The study finds that the transportation option involving the use of a barge for the first leg of the trip is the one that comes with the lowest conventional transportation risks and overall incident free radiological risks. This difference is significant. This finding is subject to three caveats.

1. This study has not been able to quantify the collective dose risks of barging LARW up the Columbia River and has come to the conclusion, based on a non-quantitative assessment, that river barging, particularly for the concrete/asphalt in IP-1 bags should be reconsidered.
2. Accidental release dose risks to humans for barging in coastal waters are very low. However, the probability of loss of radioactive material into the water followed by failure of salvage efforts is low but not zero. This represents a risk transfer of human health and safety risk to environmental risk.
3. For the materials for which the base case is one of direct trucking from DCPP to the final disposal site, the alternate case of barge plus land transport involves an intermediate port stop with transfer to land transportation for which the risks have not been evaluated and included in this study. The comparison of risks for barge and rail with truck and rail is a valid one (only subject to the assumption that unloading, staging, storage and loading risks at PBRY will be similar to those at the barge port).

1 Study Objective

The purpose of this study to develop a methodology for the assessment of risk associated with the transport of radioactive and non-detect wastes from the decommissioning of nuclear power plants, and to demonstrate the method in comparing such risks from the decommissioning of the Diablo Canyon Power Plant (DCPP). Alternate routes and transport modes are considered for moving the wastes to out of state disposal and storage facilities. Transport modes considered include truck, rail, and barge, and their combinations. The risk measures are those specified by the U.S. Nuclear Regulatory Commission (NRC) in a Generic Environmental Impact Statement (NUREG-0586). They include cumulative radiation dose for the transport workers and public. For non-radioactive waste the impacts are expressed in terms of accident fatalities. In addition to fatalities, the study also documents expected numbers of injuries and all accidents. The assessment output will be used to determine which transport mode further ensures the health and safety of the workers and the public.

In applying the methodology, the following specific risks were assessed.

i. Comparative risks of trucking wastes from DCPP to the Pismo Beach Rail Yard (PBRY) by a northern route through the Montana de Oro State Park and a southern route through Avila Beach.
ii. Risks for transporting the wastes defined in the Nuclear Decommissioning Cost Triennial Proceeding (NDCTP).
iii. Transportation risks for greater than Class C waste (GTCC) and spent nuclear fuel (SNF).
iv. Transportation risks for an alternate plan in which the first leg of the shipping route is by barge rather than by truck.

In addition, an evaluation was made of the retrievability of radioactive wastes involved in an accident. While tsunami and seismic risks were not individually assessed, their impact on transportation risk was accounted for in the database. Risk insights were developed for the case that the breakwater can be repurposed.

2 Scope of the Assessment

The Pacific Gas & Electric (PG&E) decommissioning cost estimate outlines the expected waste types to be dispositioned during or after DCPP decommissioning. The following waste types are currently planned to be transported from DCPP and disposed of at an offsite location using a combination of truck and rail transport.

- Non-detect/clean
- Concretes for recycling
- Metals for recycling
- LARW (10 CFR 20.2002)
- Class A
- Class B/C
- GTCC and spent fuel

Briefly, non-detect/clean waste is waste that has not been contaminated and involves such materials as metal, concrete, and asphalt, some of which is recyclable. Low-activity radioactive waste (LARW) is material that exhibits minimal detectable activity. Class A waste is easily detectable but does not exceed 0.1 times the value in Table 1 of 10 CFR 61.55. Class A waste accounts for 96 percent of all low-level waste generated. Class B waste is more radioactive than Class A but is limited by 10 CFR 61.55. The physical form and characteristics of Class B waste must meet all requirements set forth in 10 CFR 61.56(a) and also meet the stability requirements of 10 CFR 61.56(b) to ensure stability after disposal. Class C waste typically has higher concentrations of much longer lived isotopes. The radioactive content limits of 10 CFR 61.55 must be met along with all physical form and characteristics and stability requirements of 10 CFR 61.56.

GTCC is radioactive waste not acceptable for near-surface disposal as the radionuclide content exceeds the limits set forth in 10 CFR 61.55 for Class C waste. Spent or used fuel while not considered a waste explicitly is being treated as such. SNF is highly radioactive and represents the greatest challenge in terms of its disposal. Deep geological disposal is the internationally preferred method of disposal, but until such facilities are available spent fuel and GTCC are to be stored on the DCPP site.

Table 1 provides the items to be compared. As shown, all waste types are assumed to go to the same disposal site as proposed in the NDCTP except for GTCC/SNF. For this assessment, GTCC/SNF is assumed to go to a consolidated interim storage facility (CISF).

Table 1. Disposition by Waste Types

Waste Type	**Proposed Disposal Site**	**Transport Mode in 2018 NDCTP**	**Risk Assessment Transport Mode**
Clean Debris	La Paz, AZ	Truck to Rail[1]	Barge to Rail[2]
LARW	US Ecology, ID	Truck to Rail[1]	Barge to Truck[3]
Class A	Clive, UT	Truck to Rail[1]	Barge to Rail[2]
Class B, C	WCS, TX	Truck to Rail[1]	Barge to Rail[2]
Concretes for Recycling	Las Vegas, NV	Direct Truck	Barge to Truck[2]
Metals for Recycling	Salt Lake City, UT	Truck to Rail[1]	Barge to Rail[2]
Other Regulated Wastes[4]	Beatty, NV	Direct Truck	Barge to Truck[2]
GTCC and SNF	NDCTP: Federal Repository UCLA: CISF[5] (NM and TX)	Up to DOE; see Plan 23 UCLA: Truck to Rail[1]	Barge to Truck[2]
NDCTP: Nuclear Decommissioning Cost Triennial Proceeding			

The risk measures adopted are as outlined in the NRC's Decommissioning Generic Environmental Impact Statement (GEIS, NUREG-0586), updated to current NRC practices and requirements. The NRC uses a two-pronged approach that considers both radiological and non-radiological impacts from waste transport since decommissioning involves both radiological and non-radiological wastes.

- For radiological impacts, the NRC evaluated incident-free shipments and those that involve an accident with subsequent radiological release (NUREG-0586, page 4-79). The impact was expressed in cumulative dose for the transport workers and public.
- For non-radiological impacts, the NRC evaluated transportation accidents. Consistent with available data, the impact was expressed in terms of fatalities. Because this facet does not consider radiological consequences, the NRC merely used distance and transport mode accident rates.

For non-radiological impacts, this study presents expected injuries and accidents in addition to fatalities. Also, in addition to guidance given by the NRC above, consequences of a lost load as a result of an accident are analyzed in terms of impact and retrievability.

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[1] Transfer at Pismo Beach Rail Yard
[2] Transfer at Long Beach Port
[3] Transfer at Boardman, OR
[4] Wastes containing regulated materials such as asbestos, lead paint, etc.
[5] CISF is an interim storage facility. Further transportation to the permanent repository is not considered in this study.

Specific waste/haul route information by transport mode and waste type is analyzed. DCPP-PMP-005 (Transportation Project Management Plan) Section 5 contains a discussion on route options. Waste handling, staging, storage, transfer and terrorism risk are not included in the scope of the risk assessment.

3 Overall Methodology and Assessment Boundaries

3.1 Risks Assessed

The process followed in the risk assessment is presented in Figure 1. Five types of risks were assessed.

1. Non-radiological risks expressed as total number of expected fatalities from transportation accidents, as well as in terms of expected injuries and accidents. These risks apply to all materials and all modes of transport.
2. Non-incident radiological risks posed by the movement of radioactive waste materials by truck, rail, and barge in areas where persons may be exposed to the external radiation emitted by any package containing radioactive materials. The radiation dose from external radiation to any member of the public or crew during routine transportation, including stops, is evaluated.
3. Increased radiological risks due to degradation of shielding caused by a traffic accident. The accidents of interest for the evaluation of these risks are those that are not severe enough to cause a loss of containment of the radioactive materials themselves but are severe enough to degrade the shielding. These risks only apply to Class B/C wastes which are transported in lead shielded Type 8-120B casks. LARW and Class A wastes are transported in packages that do not incorporate shielding; hence loss of shielding is not a relevant failure mode. GTCC and SNF are transported in steel casks that have been demonstrated to not lose shielding from a severe accident.
4. Increased radiation exposure risks due to the airborne dispersion of radioactive materials following a severe accident. Pathways for exposure included are inhalation, groundshine, cloudshine, and resuspension. These risks apply to all of the radiological wastes with the exception of SNF and GTCC, since it is assumed that the HI-STAR 100 cask will not lose containment in the worst-case traffic accident due to either impact or fire.
5. Increased radiation exposure risks due to an accident during barge transport that results in loss of containment. Pathways for exposure include external exposure to radionuclides deposited on the shore, ingestion of seafood caught in the area of the accident, inadvertent ingestion of beach sediments, inhalation of particles resuspended from beach sediments and inhalation of sea spray. These risks have been evaluated for all of the radioactive materials included in this study.

3.2 Risk Assessment Boundaries

This study focused on the risks of transportation of decommissioning wastes. Loading, transfer, staging, intermediate storage, and unloading related risks are excluded. The reasons are (1) the evaluation of these risks is only possible after detailed procedures have been prepared and (2) the risks are primarily occupational in nature, i.e., members of the public are unlikely to be affected.

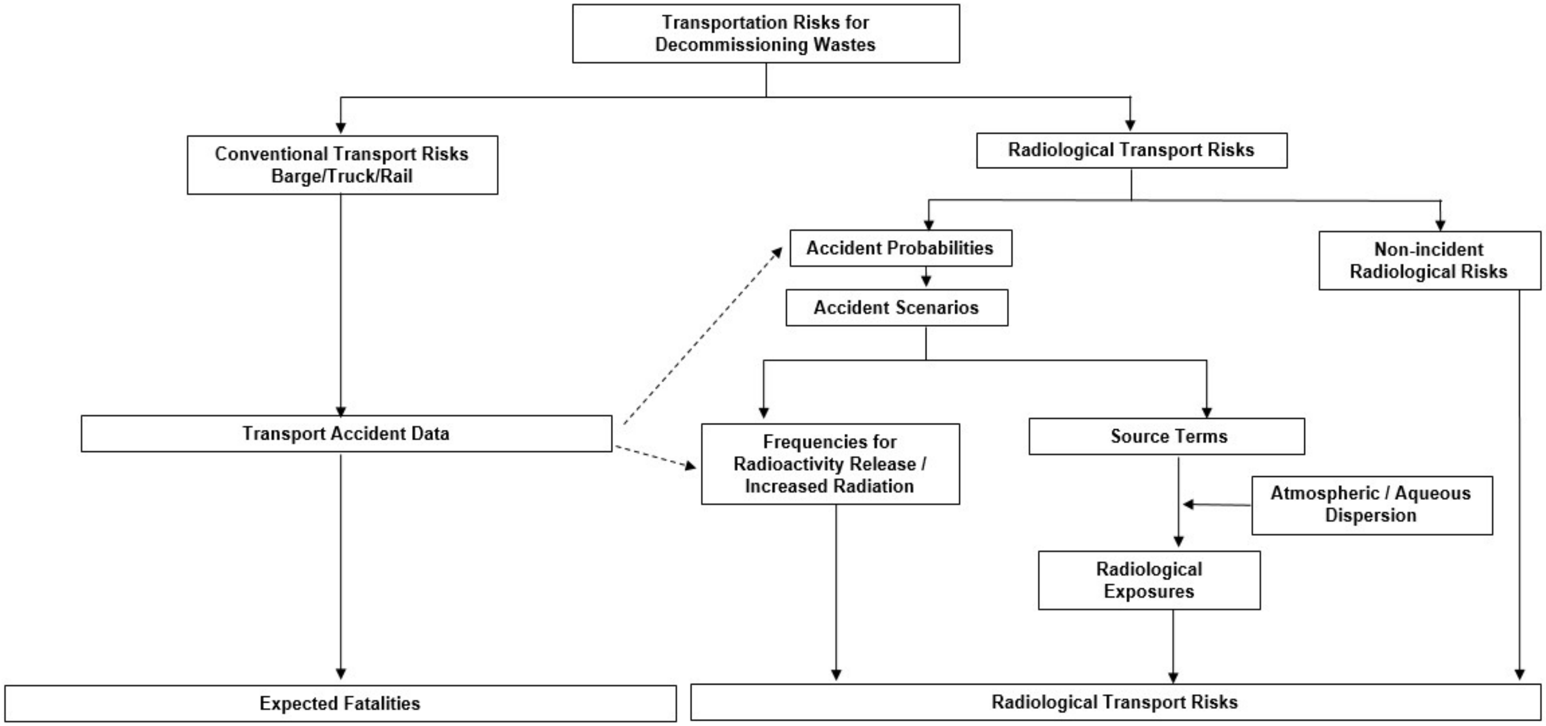

Figure 1. Risk Assessment Workflow.

3.2.1 Terrorism

The risks of a terrorist act during the transportation of radioactive materials are not included in this study. Terrorism risk assessments require fresh threat information since the threat is adaptive and the risks cannot be assessed based on historical information. Additionally, some information regarding the performance of the SNF casks upon aircraft impact is public. For example, much relevant information such as the performance in case of a car bomb attack is classified. The following is excerpted from NUREG-0586 and best describes the appropriate handling of the terrorism component of the risks of transportation of decommissioning wastes.

> *Malevolent acts affecting the physical security of nuclear power plants is an important issue for all reactors, both operating and permanently shut down, and is not unique to reactors in the decommissioning process. Shortly after the events of September 11, 2001, the NRC initiated a comprehensive review of its security requirements at nuclear power plants to ensure that the appropriate level of protection is in place for both operating and decommissioning reactors. The safety review will transcend the entire NRC licensing framework (operating reactor licensing, license renewal, decommissioning etc.) to fulfill NRC's responsibilities under the Atomic Energy Act. The findings resulting from the NRC's comprehensive review of its security requirements and whatever actions the Commission determines to be appropriate will be required of decommissioning reactors.*

3.2.2 Tsunami Risk

According to the Pacific Tsunami Warning Center (PTWC) of the National Weather Service tsunamis are imperceptible in the open ocean (https://ptwc.weather.gov/ptwc/faq.php). The PTWC recommends moving to water depths greater than 400 m in case there is ample warning time.

Lynett, et al., 2014[6] state that “Depths greater than 30 fathoms (~55 m) will in general be safe, particularly for dispersed or larger vessels. This number may become a valuable, consistent future policy recommendation for vessel evacuation along California's coast."

It can be concluded that tsunami risk to the barge movement considered in the study is limited to short periods of time when the barge is moving out to sea or coming into port. Large tsunamis that may result in barge grounding or sinking are low frequency events, occurring once every

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[6] Lynett, P. J., Borrero, J., Son, S., Wilson, R., & Miller, K. (2014). Assessment of the tsunami-induced current hazard. *Geophysical Research Letters, 41*(6), 2048–2055. https://doi.org/10.1002/2013gl058680

several years. On the other hand, grounding and sinking events due to other causes occur several hundred times a year along the coastal waters of the USA. It is therefore concluded that the frequency contribution of tsunamis to the overall frequency of barge accidents is negligible.

3.2.3 Seismic Risk

Analogous to the discussion of tsunami risk, it is noted that accident rates for truck and rail transportation are derived from thousands of events per year, while those for barge transportation are derived from hundreds of events per year. It is therefore concluded that the contribution of seismic events to transportation accident rates is negligible.

3.3 Conventional Transportation Risks

The evaluation of conventional transportation risks is based on historical transportation accident data. Three modes of transportation are considered in this study – truck, rail, and barge. The data used to evaluate the conventional transportation risks for these modes of transportation are presented below.

3.3.1 Truck Accident, Injury and Fatality Rates

The required accident, injury and fatality rate data for transportation by truck can be found in a single report produced by the U. S. Department of Transportation (USDOT), "Large Truck and Bus Crash Facts 2017". The report provides data for the years 2008 through 2017. The data are tabulated in Table 2.

Table 2. Truck Accident, Injury and Fatality Rates

Item (for Period 2008~2017)	Value
Total Fatalities in Large Truck Crashes	40,149
Total Injuries in Large Truck Crashes	1,040,000
Million Vehicle Miles Traveled by Large Trucks	2,841,795
Fatal Crashes Involving Large Trucks	35,597
Injury Crashes Involving Large Trucks	737,000
Property Damage Only (PDO) Crashes Involving Large Trucks	2,772,000
Crashes per Truck-Mile	1.25E-06
Injuries per Truck-Mile	3.66E-07
Fatalities Per Truck-mile	1.41E-08

The data in Table 2 is derived from close to 3 trillion driven truck miles. It should be noted that the fatality rate per truck mile in Table 2 is higher than the value used in NUREG-0586, which is 8.8E-09/mile. This must be attributed to the availability of quality data, since the USDOT 2017 document cited above shows a significant decrease in the fatality rates for truck transport since 1999, which is the vintage of the source quoted in NUREG-0586.

3.3.2 Rail Accident, Injury and Fatality Rates

The accident, injury and fatality rates for rail transport used in this study to characterize the conventional risks of transportation are derived from the Federal Railroad Administration's Accident/Incident Database, Table 1.12, Ten Year Accident/Incident Overview Table, available at http://safetydata.fra.dot.gov/OfficeofSafety/. The data for the period 2008~2017 were used for this assessment and are presented in Table 3.

Table 3. Rail Accident, Injury and Fatality Rates for Conventional Transportation Risks

Item (for Period 2008~2017)	Value
Total Fatalities	7,380
Total Injuries (non-fatal conditions)	86,634
Total Accidents/Incidents	117,665
Total Main Line Miles	6,359,154,971
Accidents/Incidents per Train Mile	1.85E-05
Injuries per Train Mile	1.36E-05
Fatalities Per Train-Mile	1.16E-06

The probabilities of different accident scenarios for rail transport used in the modeling of the radiological risks are sourced from the USDOT John A. Volpe National Transportation Systems Center report "Comparative Safety of the Transport of High-Level Radioactive Materials on Dedicated, Key, and Regular Trains", 2006. The relevant accident rate for train transport for that analysis is 2.03E-06/mile.

3.3.3 Barge Accident, Injury, and Fatality Rates

The accident, injury and fatality rates for conventional risks of barge transport are derived from three sources. The first is the article "Barge Accidents and the Shipment of Spent Nuclear Fuel" (Reardon, et al., 2003), the second is the report "U.S. Coast Guard - American Waterways Operators Annual Safety Report," National Quality Steering Committee Meeting, July 31, 2018 and the third is a database query provided by the US Army Corps of Engineers. The data used are for the period 2006 through 2017. For the radiological risks of accidental releases the probabilities are derived from the data for the period 1994 through 2000. The accident rate relevant to that analysis is 3.02E-06. The barge mile data used in this study is presented in Appendix F and supersedes the barge mile data contained in Reardon, et al., 2003.

Table 4. Barge Accident, Injury and Fatality Rates for Conventional Transportation Risks

Item (for Period 1994~2000)	Value
Total Fatalities	92
Total Injuries	1,601
Total Incidents	20,161
Total Barge Miles	2,889,502,220
Incidents per Barge Mile	6.98E-06
Injuries per Barge Mile	5.54E-07
Fatality Rate per Barge Mile	3.18E-08

3.3.4 Route Definition

The routes for the various decommissioning wastes, using the relevant transportation were defined using the routing software webTRAGIS. webTRAGIS is maintained by Oak Ridge National Laboratory (ORNL). The following description is provided.

> *The Web Transportation Routing Analysis Geographic Information System (webTRAGIS) model is a browser-based geographic information system tool for modeling transportation routing. webTRAGIS offers numerous options for route calculation utilizing uniquely value-added network databases for highway, rail, and waterway infrastructures in the continental United States. The model also provides population data for all transportation segments using the LandScan USA population distribution data model. The TRAGIS model is deployed as a browser application, where the map display and user interface are accessed through a web browser and the routing engine is located on an external ORNL server.*[7]

The use of webTRAGIS greatly facilitates the application of the software RADTRAN for assessing the radiological transportation risks. However, webTRAGIS has some limitations, whereby the origin and destination are not exactly respected. For the calculation of conventional transportation risks, the route length provided by webTRAGIS was corrected to reflect the real distance between DCPP and the destination.

webTRAGIS could not be used to generate the northern route from DCPP to the PBRY. Instead the commercial software Maptitude was used to generate the northern route. To ensure that the comparison of the risks of using the northern vs. southern route used the same database, Maptitude was also used to define the southern route from DCPP to PBRY. All of the routes generated with webTRAGIS and Maptitude are presented in Appendix B.3.4.

3.4 Radiological Transport Risks

3.4.1 Non-Incident Radiological Risks

Non-incident radiological risks, i.e., the risks to crew and members of the public solely due to proximity to the package containing the waste materials, have been assessed using the software program RADTRAN. RADTRAN is made available by the NRC via its RAMP website. The following is a description of RADTRAN from the NRC RAMP website.

> *The Radioactive Material Transport (RADTRAN) computer code is used for risk and consequence analysis of radioactive material (RAM) transportation. A variety of RAM is transported annually within this country and internationally. The shipments are carried out by overland modes (mainly truck and rail), marine vessels, and aircraft. Transportation workers and persons residing near or sharing transportation links with*

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[7] "This research was done utilizing the webTRAGIS routing analysis system developed by UT-Battelle, LLC, operator of Oak Ridge National Laboratory under Contract No. DE-AC05-00OR22725 with the United States Department of Energy. The United States Government has certain rights in any generated routing data. Neither UT-BATTELLE, LLC NOR THE UNITED STATES DEPARTMENT OF ENERGY, NOR ANY OF THEIR EMPLOYEES, MAKES ANY WARRANTY, EXPRESS OR IMPLIED, OR ASSUMES ANY LEGAL LIABILITY OR RESPONSIBILITY FOR THE ACCURACY, COMPLETENESS, OR USEFULNESS OF THE DATA GENERATED."

> *these shipments may be exposed to radiation from RAM packages during routine transport operations; exposures may also occur as a result of accidents. Risks and consequences associated with such exposures are the focus of the RADTRAN code.*
>
> *Under U.S. Nuclear Regulatory Commission and U.S. Department of Energy funding, Sandia National Laboratories (SNL) in Albuquerque, New Mexico, developed the RADTRAN code. It was first released as RADTRAD I in 1977 in conjunction with the preparation of NUREG-0170 (ML12192A282 and ML022590370). The analytical capabilities of the code have been expanded and refined in subsequent releases. RADTRAN II was released in 1983, and RADTRAN III was released in 1986. RADTRAN 4 represented a major new direction for RADTRAN development. The analyst now could carry out route-specific analyses by assigning route-segment-specific values for a number of parameters (population density, vehicle speed, traffic count, etc.) to up to 60 route segments per run. These route-specific capabilities were improved and expanded in RADTRAN 5, and a number of features were added, including the ability to evaluate radiological consequences of routine, accident-free transportation of RAM, as well as radiological and non-radiological consequences and risks from accidents that might occur during transportation of such materials. Additionally, RADTRAN 5 produces estimates of incident-free population dose, accident dose-risk, non-radiological traffic mortality, and a suite of individual dose estimates.*
>
> *The current NRC version of the RADTRAN computer code is version 6.02.1. This version is a Fortran95 compiled version that can be executed in batch mode only from a command prompt. The NRC is evaluating the development of an upgraded user-friendly GUI to support the ease of use for input development, execute RADTRAN 6.02.1, and re-branding this version of the code as NRCRADTRAN.*

The details of the mathematical models implemented in RADTRAN can be found in Weiner, et al., 2014, “RADTRAN 6 Technical Manual” and are not presented in this report. A RADTRAN 6/RadCat 6 User Guide is also available.

NUREG-2125 presents a detailed assessment of spent fuel transportation risks and used RADTRAN. NUREG-2125 included the Holtec HI-STAR 100 casks that will be used at DCPP. NUREG-2125 also includes discussion of many of the inputs required to use RADTRAN for the analysis of risks due to transportation of radioactive materials. This study has made significant use of the work contained in NUREG-2125.

For incident free risks, RADTRAN assesses the following.

(i) Risks to the crew (assuming regulatory limits)
(ii) Risks to members of the public in vehicles adjacent to the package
(iii) Risks to members of the public in communities the package passes through
(iv) Risks to inspectors and yard workers
(v) Risks associated with first response in the event of an accident that does not entail loss of shielding or loss of containment

The main inputs to RADTRAN are the following.

1. Type of transportation (highway/rail/barge)
2. Route segment length. This information is generated by webTRAGIS.
3. Speed on route segment. This is derived from the time taken to travel the segment, generated by webTRAGIS
4. Route segment type (rural/suburban/urban). This information is generated by webTRAGIS and is based on population density
5. Population density in an area 800 m wide on both sides of the route. This information is generated by webTRAGIS.
6. Traffic density. Number of vehicles/hr. For highway the values used in this study were 1155 for rural highways, 2414 for suburban highways, and 5490 for urban highways. The source for these inputs is the RADTRAN Technical Manual. The values for non-Interstate roads recommended in the RADTRAN Technical Manual are lower at 287, 618, 1711 respectively. In this study, only the values for Interstates were used, irrespective of the type of road traversed. For rail the values used were 1, 5 and 5 for rural, suburban and urban sections. These values come from the RADTRAN User Guide. For barge traffic density, estimates of 1, 1 and 1 were used based on visual observation of shipping density on marine traffic.com. For the first leg of truck transportation from DCPP to PBRY the traffic densities were sourced from the DCPP report “Environmental Report Post-Shutdown Decommissioning Activities Report” dated April 2019.
7. Crew size. One for short haul truck, two for long haul truck, three for rail and ten for barge. The values for trucks are based on analyst judgment. Crew size for rail and barge is sourced from the RADTRAN User Guide.
8. Distance from crew to the package. 3 m for truck, 150 for rail and 30 m for barge. The values for truck and rail are sourced from the RADTRAN User Guide. The value for barges is estimated for towing alongside as depicted in Figure 2.

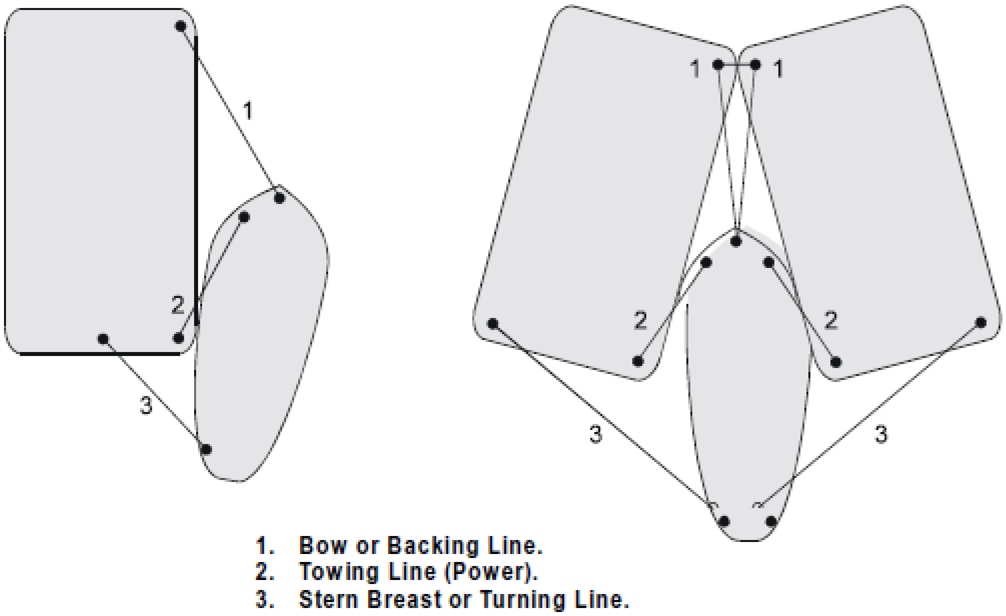


Figure 2. Schematic for "Towing Alongside" (courtesy of U.S. NAVY TOWING MANUAL, Rev. 3)

9. Inspection. No inspection was modeled for trucks. One inspection was modeled for each train trip at 2 m distance for a period of 4 hours. No inspection modeled for barge trips.
10. Two classification stops have been modeled at 200 m – 800 m distance with a duration of 27 hours (one at origin and one at destination).
11. Percentage of gamma and neutron emissions. 100% for LARW, Class A and Class B/C. 90% gamma for SNF sourced from NUREG-2125 for rail steel cask.
12. For SNF only, a 27-hour stop is modeled for accident conditions. This is the only consequence of a transportation accident for SNF since neither loss of shielding nor loss of containment is modeled.
13. The largest dose from a moving vehicle to an individual member of the public is sustained when that individual is 30 meters (a conservative estimate of the Interstate right-of-way) from the moving vehicle and the vehicle is moving at the slowest speed it would be likely to maintain. This speed is 24 kilometers per hour (kph) (16 miles per hour (mph)) for both rail and truck. Source NUREG-2125.

3.5 Accident Probabilities and Accident Scenarios

3.5.1 Truck Transport

The event tree for truck accidents used in this study is due to Mills, et al. This is the same event tree that is used in NUREG-2125. The event tree is presented in Figure 3.

LARW/Class A

The IMC and IP-1 bags used for packaging the LARW and Class A wastes do not have any special integrity or structural requirements. It is therefore assumed that they can lose containment in any truck accident. Thus, a conditional probability of 1 is used for loss of containment scenarios.

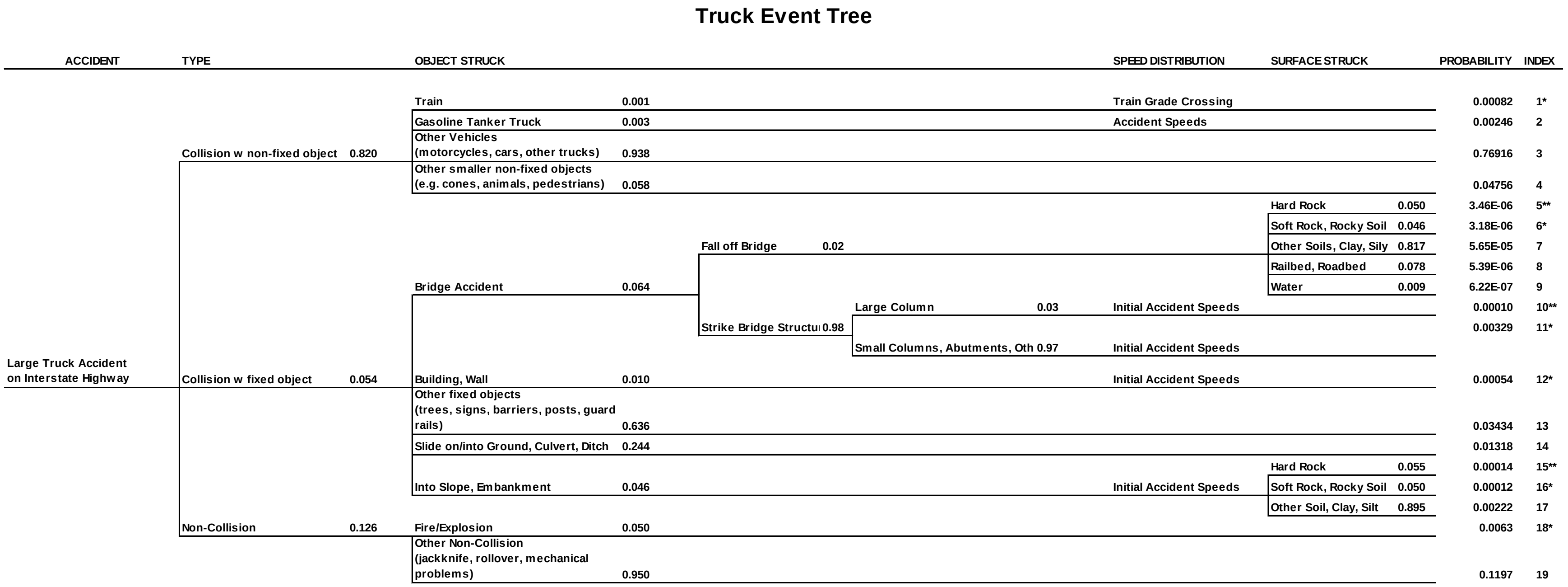
Class B/C

The conditional probability of release given a truck accident for an 8-120B cask is 0.0113 from the scenarios in Figure 3 that are marked with an asterisk.

Loss of shielding events have been modeled using lead slump fractions and conditional probabilities from NUREG-2125.

GTCC/SNF

No loss of shielding or loss of containment scenarios have been modeled for SNF This decision is based on information presented in NUREG-2125 that shows that the Holtec HI-STAR 100 casks have been tested and analyzed against “Beyond Design Basis” events and will not lose shielding or containment even for the worst case transportation impact or fire scenarios.



*Accident scenarios that might lead to cask failure (loss of containment)
**Collision accidents judged to pose significant threats

Figure 3. Event Tree for Truck Accidents (Mills, et al., 2006)

3.5.2 Rail Transport

The event tree used in this study is from the report "Comparative Safety of the Transport of High-Level Radioactive Materials on Dedicated, Key, and Regular Trains" and is presented in Figure 4. An alternate version of this event tree is presented in NUREG-2125 and is reproduced in Figure 5. These event trees were simplified for this study as follows.

LARW/Class A Metals

It was assumed that the IMCs would slide off the rail car and lose containment. The conditional probability used for loss of containment events is 1.0.

LARW/Class A Concrete/Asphalt

It was assumed that in the event of a derailment the IP-1 bag would suffer loss of containment since the gondola would disgorge its contents. The conditional probability from the NUREG-2125 version of the event tree is 0.736.

Class B/C

The conditional probability of release given a train accident is 0.0132 and is derived from the rail event tree.

Loss of shielding events have been modeled using lead slump fractions and conditional probabilities from NUREG-2125.

GTCC/SNF

No loss of shielding or loss of containment events have been modeled for GTCC/SNF.

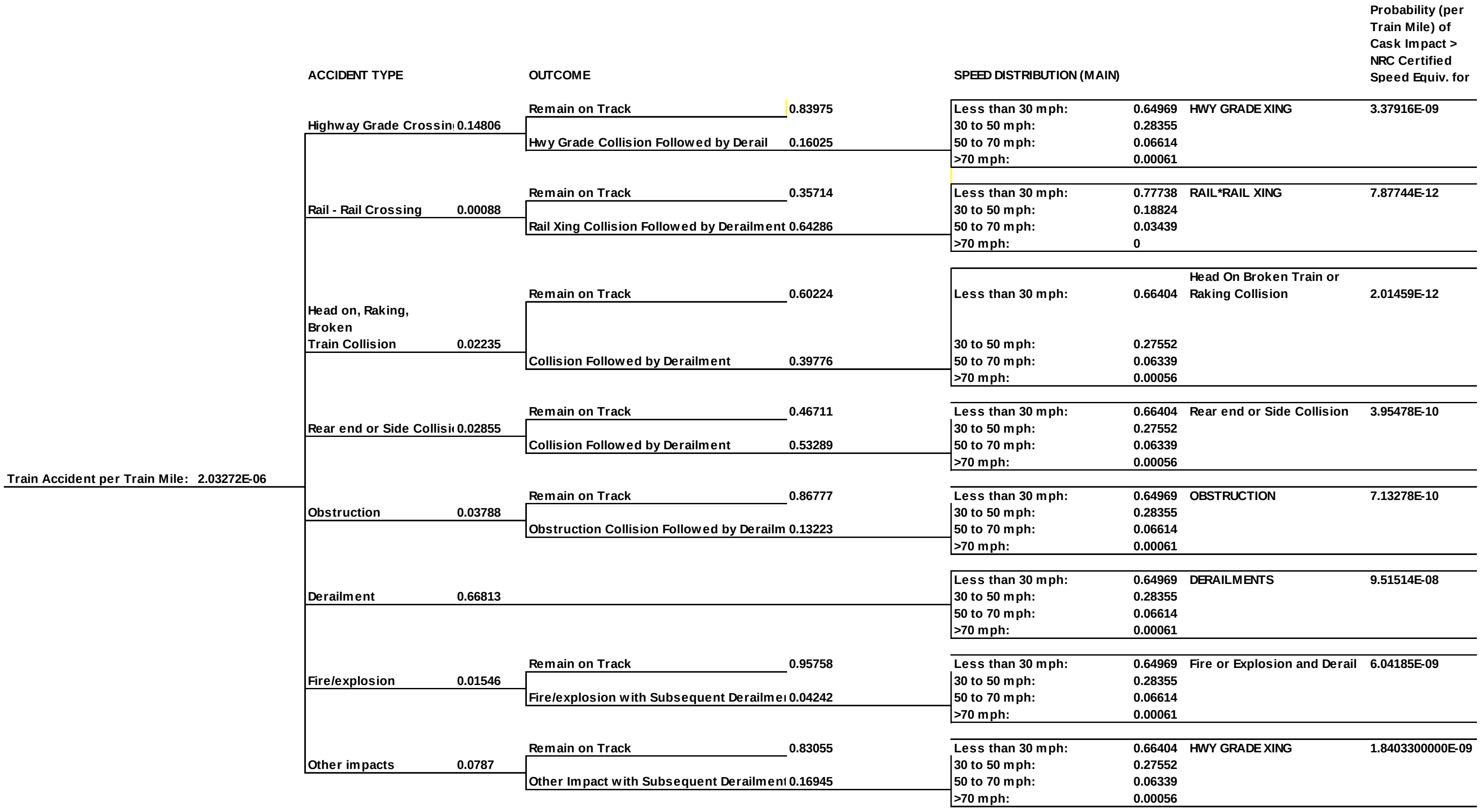


Figure 4. Rail Accident Event Tree (Volpe Institute Report)

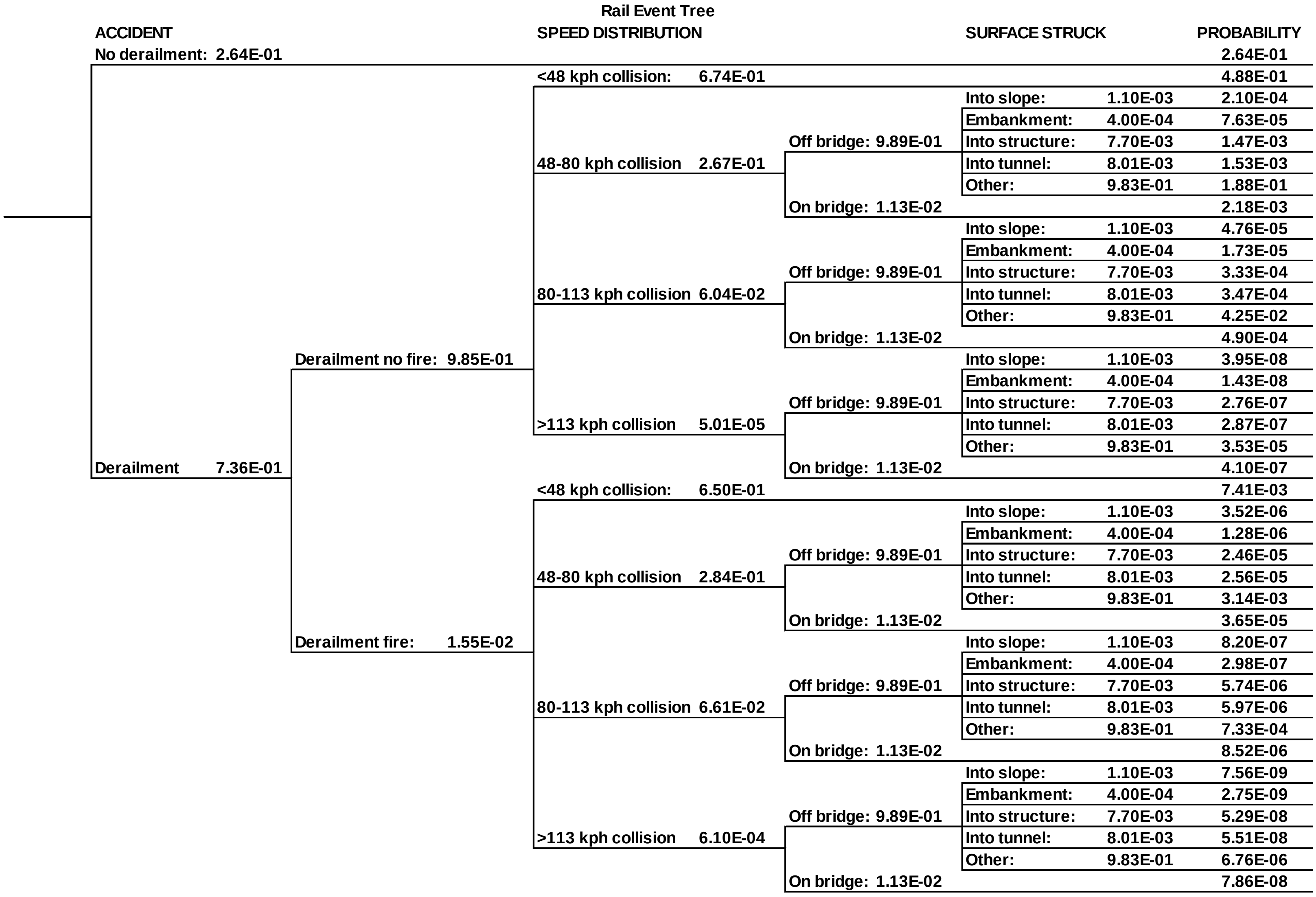


Figure 5. Alternate Form Rail Accident Event Tree (NUREG-2125)

3.5.3 Barge Transport

Retrievability

Prior to constructing the event trees for barge accidents, it is necessary to evaluate the possibility of recovery of cargoes lost at sea. The success of salvage operations depends on the robustness of the package being salvaged and the depth of water at the site of the loss. The literature on what salvage operations are currently feasible is sparse and anecdotal in nature. The US Naval Sea Systems Command, which maintains spill response assets at Port Hueneme, states the following[8]:

> *The Salvage Operations Division maintains standing worldwide commercial contracts for salvage, emergency towing, deep ocean search and recovery operations, and oil pollution abatement. Additionally, we own, maintain and operate the worldwide Emergency Ship Salvage Material (ESSM) system, which incorporates the world's largest inventory of salvage and pollution abatement equipment. We also own, maintain, and operate a large number of deep ocean search and recovery systems, with depth capabilities up to 20,000 feet. We also routinely provide salvage technical assistance to fleet salvors, as well as to other federal agencies.*
>
> *Within the National Oil and Hazardous Substance Pollution Contingency Plan (NCP), SUPSALV has been assigned as 1 of 7 "Special Teams" available to the Federal On-Scene Coordinator (FOSC). Thus, we provide assistance (personnel and/or equipment) for commercial oil or hazardous substance spills, or potential spills (i.e. salvage operations), as requested by any FOSC. Assistance ranges from salvage technical or operational assistance to mobilization of SUPSALV and other Navy resources to support a partial or full federal response to a marine casualty.*
>
> *Deep ocean search operations require the use of highly specialized equipment and personnel. We maintain several deep ocean search and salvage systems designed to work as deep as 20,000 feet. Our search systems range from simple towed pinger locators to sophisticated survey systems. With these systems, we have successfully located items as small as airplane propellers and as large as sunken ships. Once the target is located, we bring in one of our sophisticated remotely operated vehicles to inspect and, if necessary, salvage the item. These services are commonly utilized to support USAF, NASA, USCG and other federal agencies, in addition to USN requirements.*
>
> *All of these systems are designed to be operated off ships of opportunity and, if the situation requires, flown to the site. By containerizing these systems, we are assured that they arrive at the remote site with all required components and spare parts to support the mission.*

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[8] https://www.navsea.navy.mil/Home/SUPSALV/00C2-Salvage/

SMIT Salvage, of The Netherlands, is one of the premier suppliers of deep ocean and salvage services and serves as the exclusive marine salvage and engineering support contractor for the US Naval Sea Systems Command. To acquire probabilities of success for the types of salvage operations relevant to this study, Mr. Doug Martin, General Manager, SMIT Salvage Americas LLC was contacted and interviewed (on January 10, 2020). Significant information gleaned is presented below:

1. Operations in water depths to 2,000 m are currently considered routine. With special equipment it is possible to mount operations in depths to 4,000 m.
2. It takes several weeks to deploy the appropriate equipment to the salvage site. It is therefore important that the package is able to maintain integrity for several weeks.
3. Weights up to 150 tons do not pose any particular challenge for salvage operations.
4. Intermodal containers are usually able to maintain integrity since they are not water tight and the pressure equalizes.
5. Equipment such as grabbers would need to be used as part of salvage operations.
6. Likelihood of success for salvage of robust containers such as the Type B packages would be in excess of 90% in depths to 2000 m.
7. Likelihood of success for salvage of IMC in shallow waters, to 200 m, is also in the range of 90%.
8. The MSC Zoe lost up to 342 containers in the North Sea in January, 2019 in a storm. Reported water depth was in the range of 30 m. Over 85% of the lost cargo was recovered over a period of 5 months.
9. IP-1 bags may not retain integrity or have the structural strength to be salvaged using available equipment.

Mr. Jim Greene, Operations Manager at Global Diving & Salvage, Inc., was also interviewed (on January 13, 2020) with regard to salvage on the Columbia river. The information provided by him is similar to what has been documented above, except that he believes that the probability of successful salvage of IMC is greater than 95% and also that the probability of successful salvage of plastic bags may not be zero. However, he was unable to provide any anecdotal experience of salvaging bags.

The roots of the barge event trees are sourced from Reardon, et al., 2003. Barge accidents are broken down into seven types of events. For the Type B casks, only a barge sinking was considered to result in loss of cargo. For the IMC and IP-1 bags sinking was assumed to result in a loss of 100% of the cargo. Additionally, collisions and explosions were assumed to result in a loss of 20% of the cargo. By combining the work of Reardon, et al., 2003, with the salvage related information presented above, nine event trees have been proposed and are presented in Figures 6 through 14. It should be noted that the term “allision” in Figures 6-14 is defined as contact with an affixed or stationary object under or above the water line in contrast with the term “collision,” which is contact between two or more moving vessels/objects.

It should be noted that the probability of location of the lost cargo is included in the probability of salvage success. It is suggested that for the Type B packages, which are small in number and shipped infrequently, suitable beacons be used to obtain their location in case of loss in deep water. Such beacons (or “pingers”) are readily available, the only decision being what battery life to select[9].

Location of lost IP-1 bags is more difficult than location of IMC since active sonar devices are less effective when density differences are small.

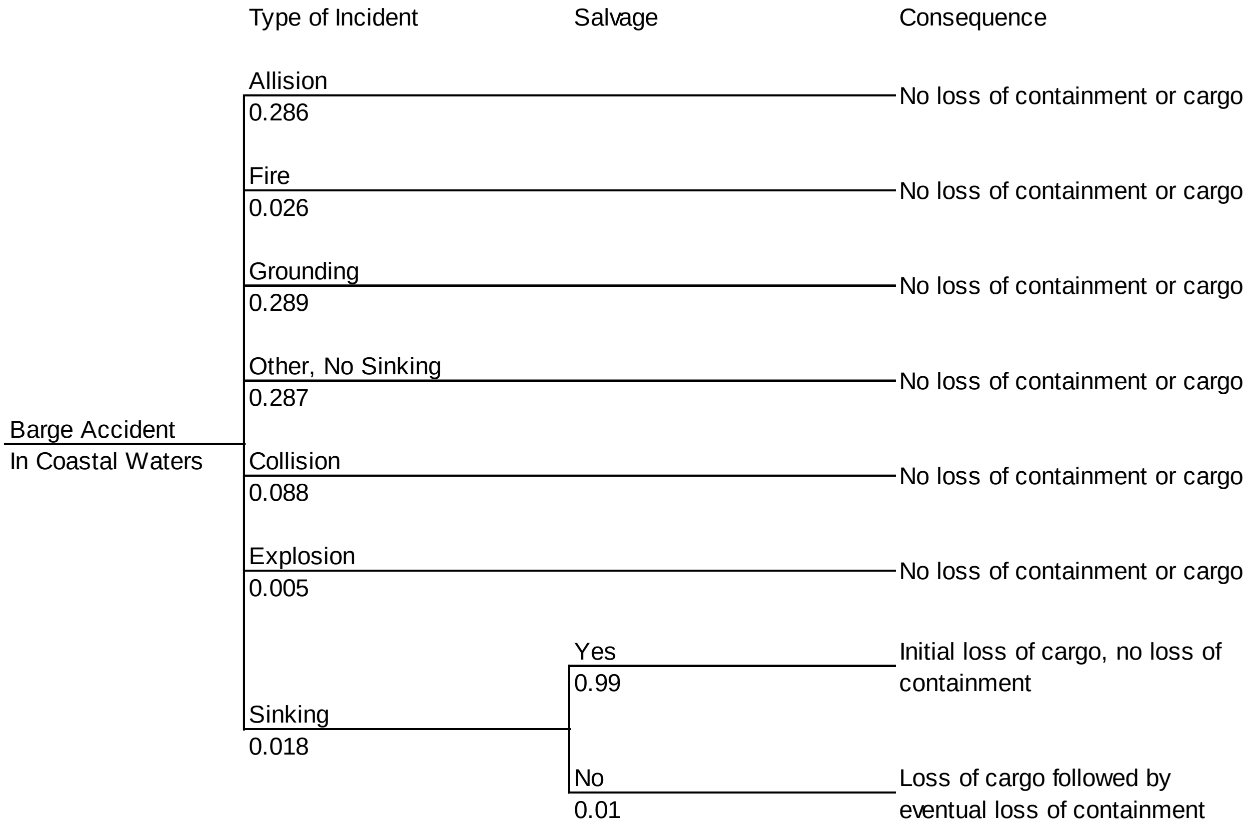

Figure 6. Event Tree for Accidents in Less Than 50 m of Water for Barging of GTCC/SNF and Class B/C

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[9] 30 days is standard.

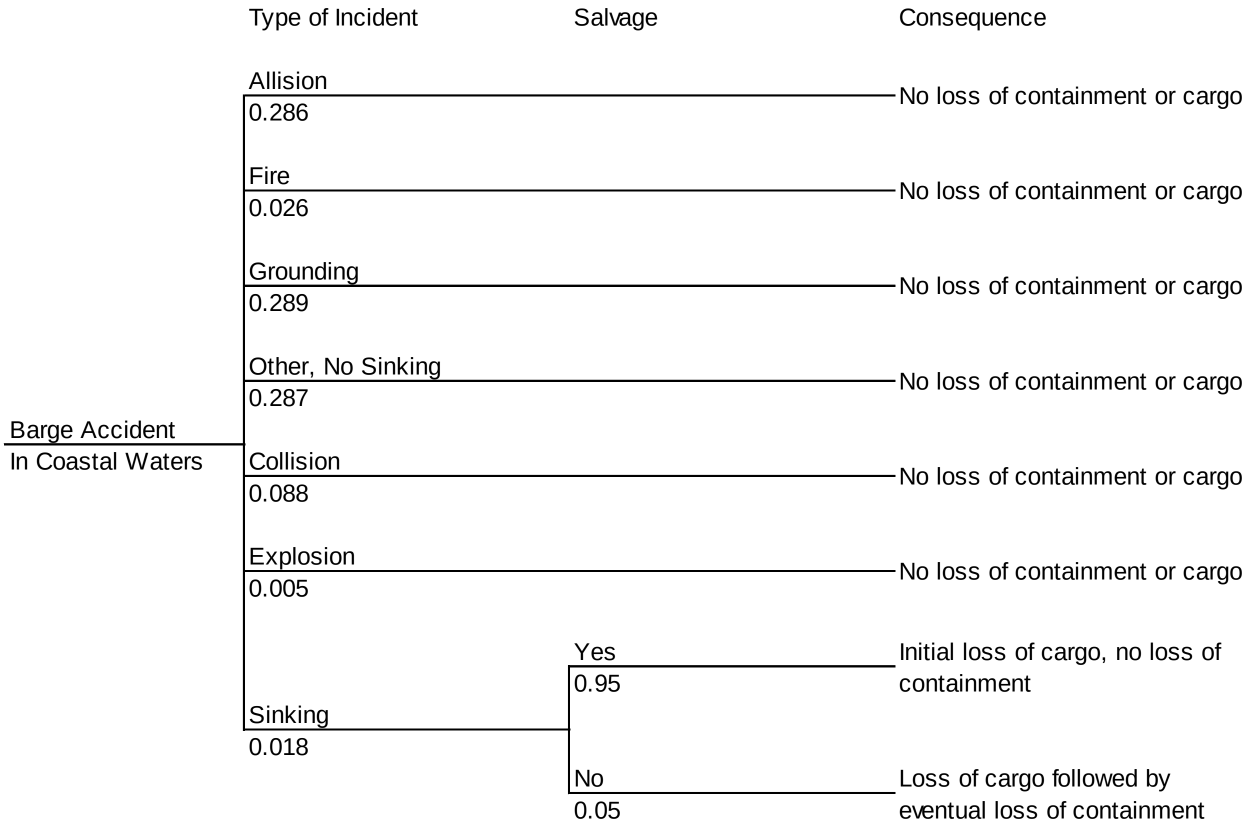

Figure 7. Event Tree for Accidents in 50~200 m of Water for Barging of GTCC/SNF and Class B/C

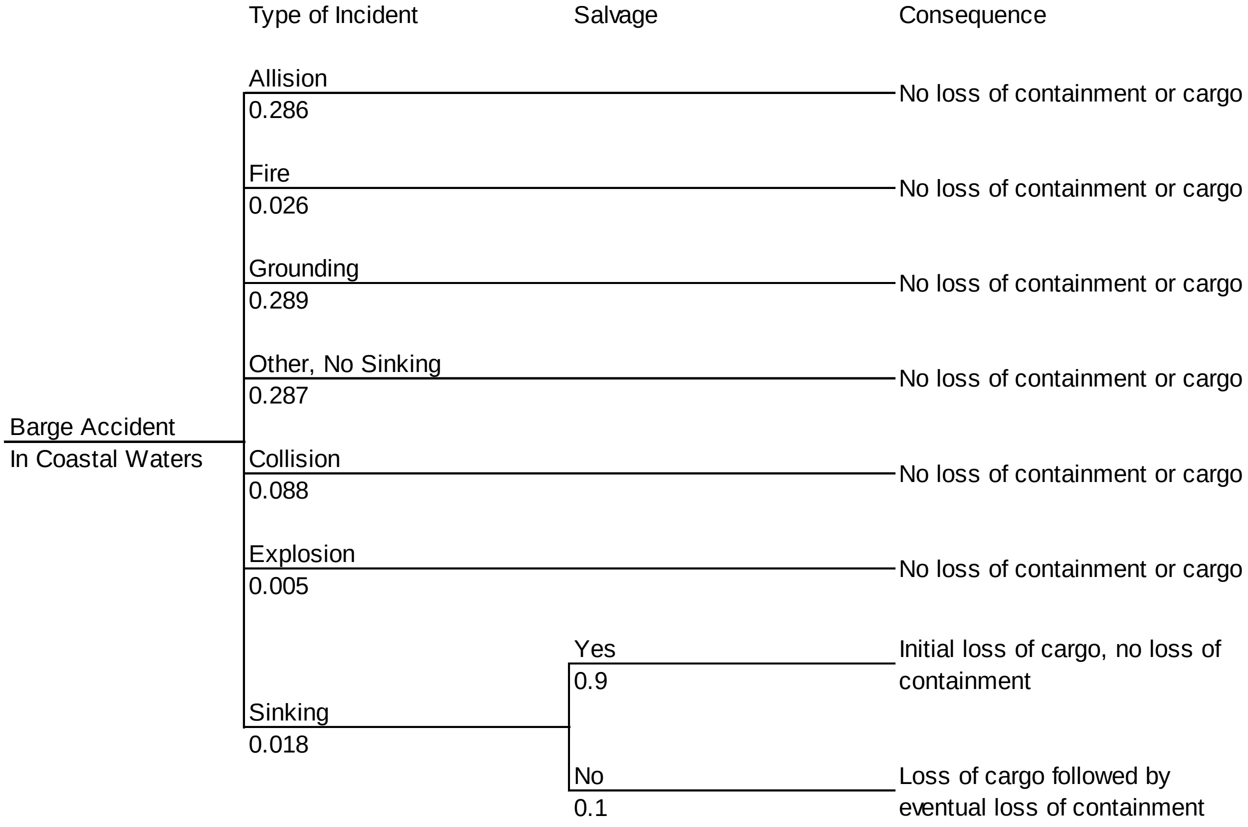

Figure 8. Event Tree for Accidents in Over 200 m of Water for Barging of GTCC/SNF and Class B/C

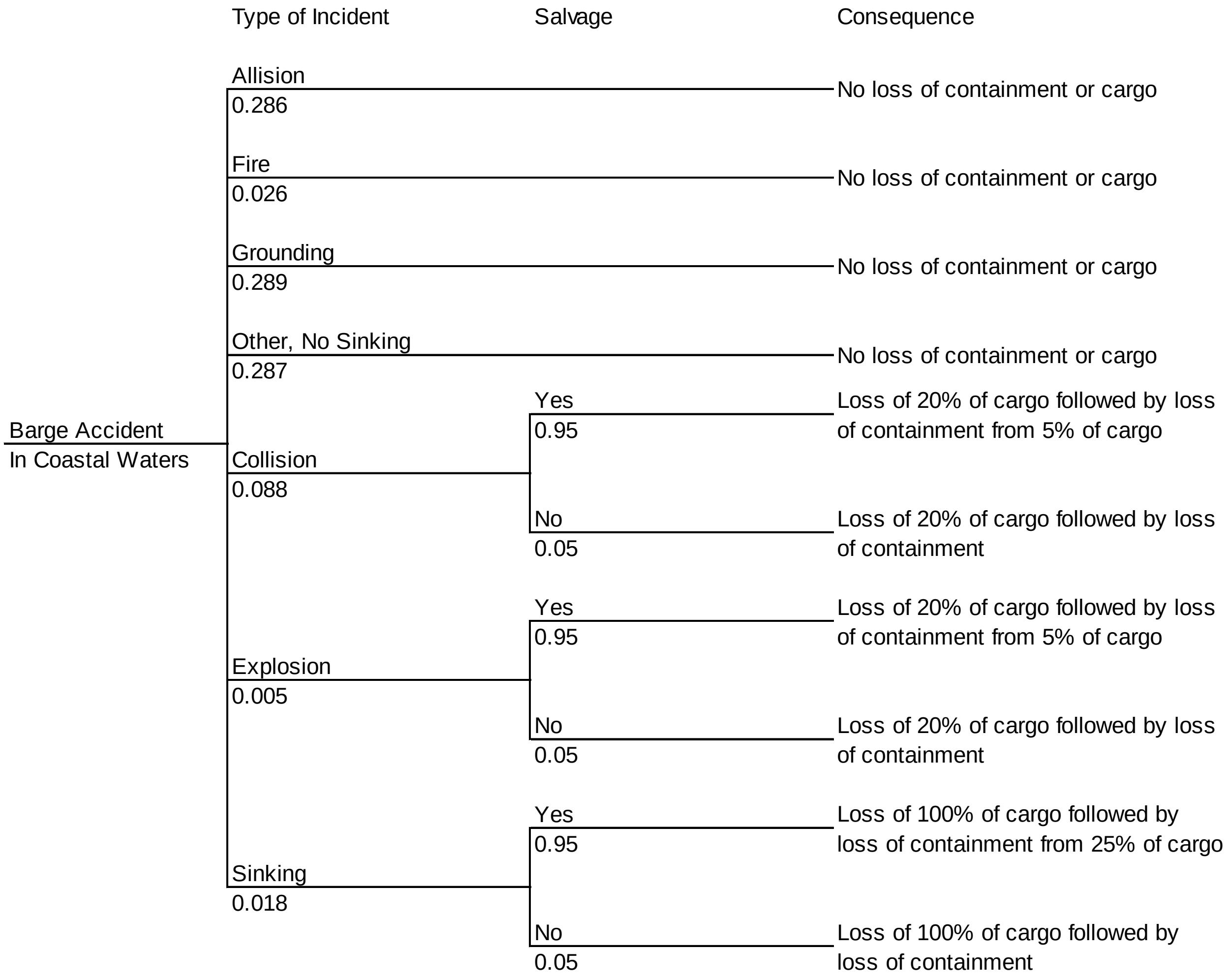

Figure 9. Event Tree for Accidents in Less Than 50 m of Water for Barging of LARW and Class A Metals in IMC in Coastal Waters

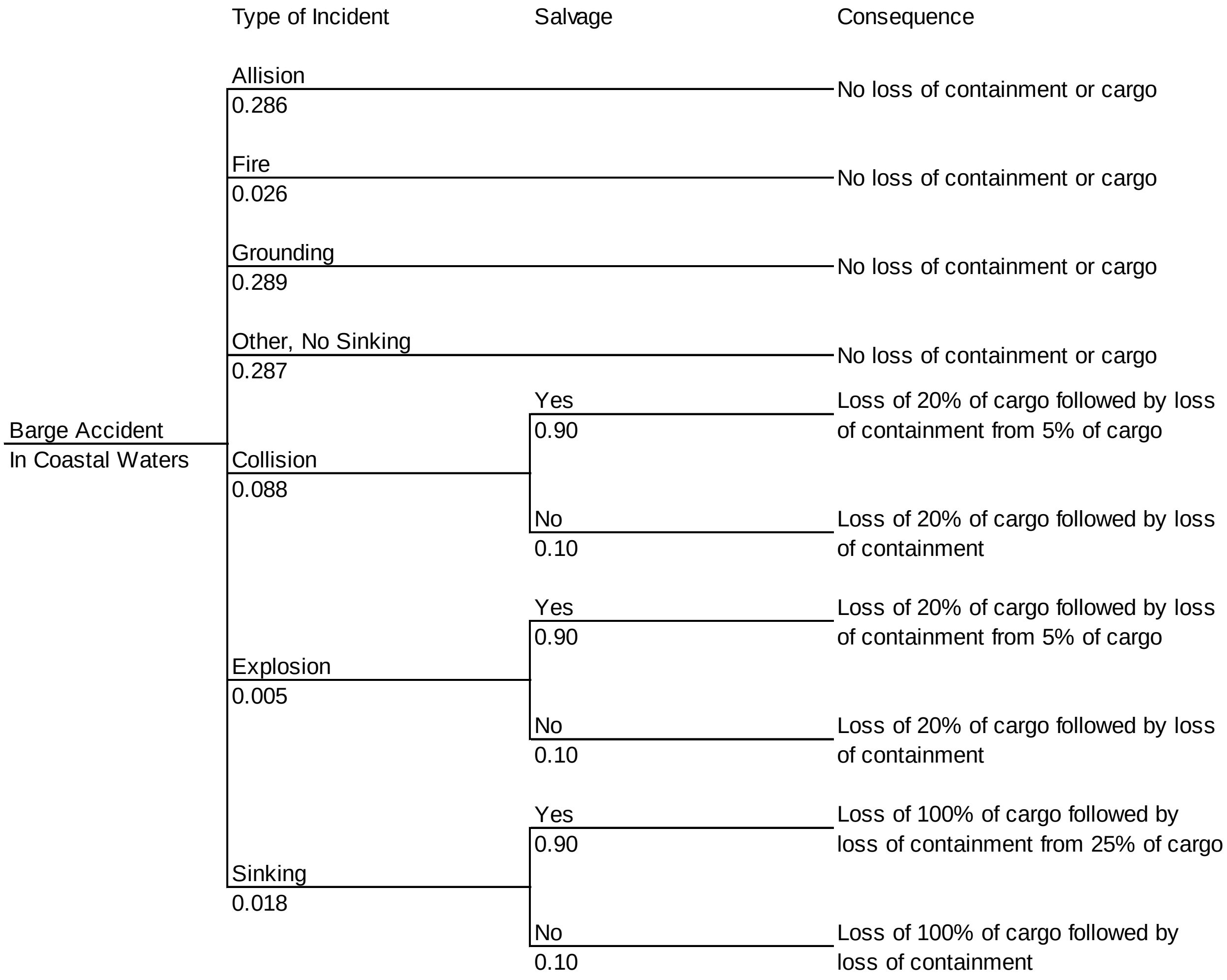

Figure 10. Event Tree for Accidents in 50~200 m of Water for Barging of LARW and Class A Metals in IMC in Coastal Waters

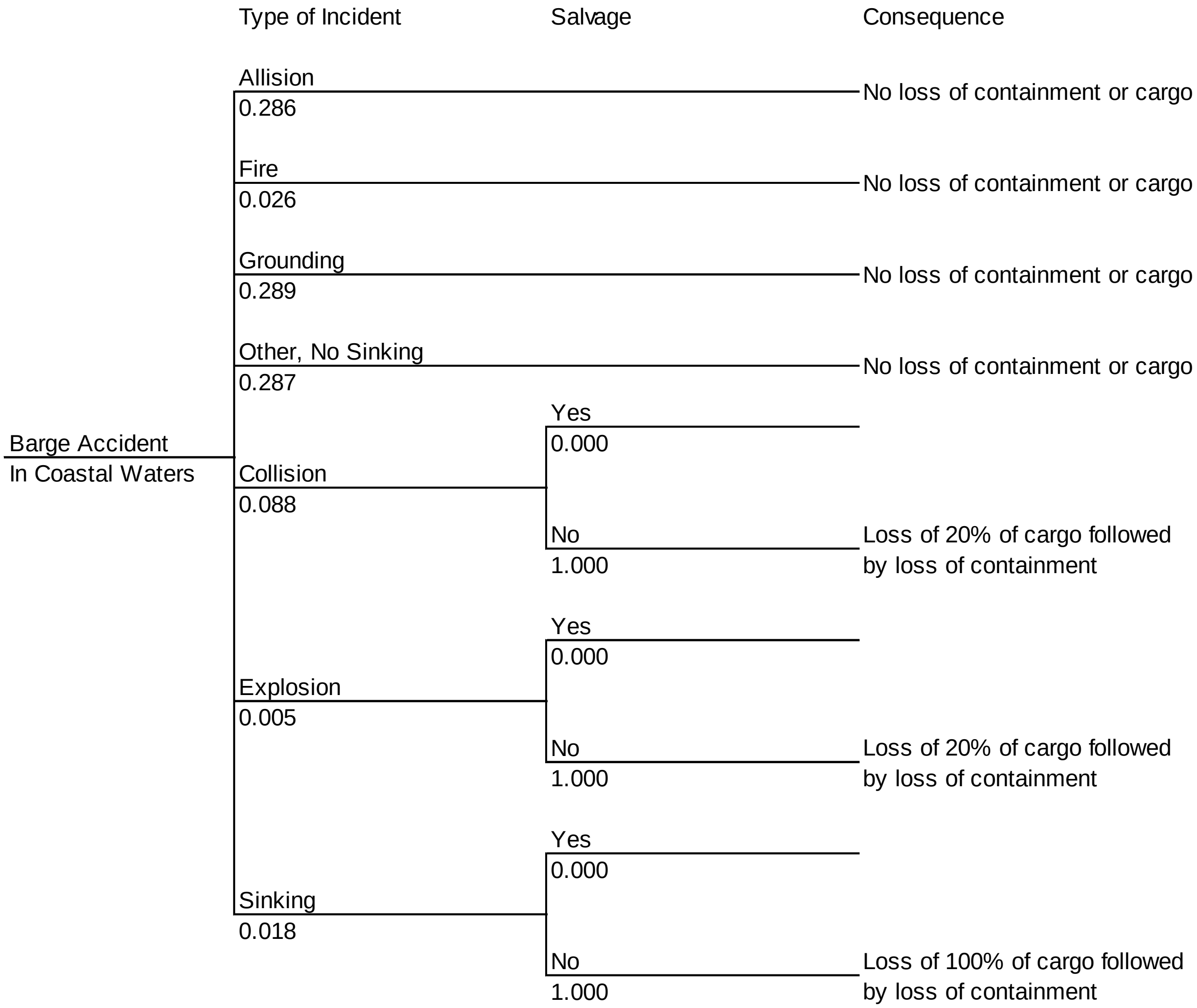

Figure 11. Event Tree for Accidents in Over 200 m of Water for Barging of LARW and Class A Metals in IMC in Coastal Waters

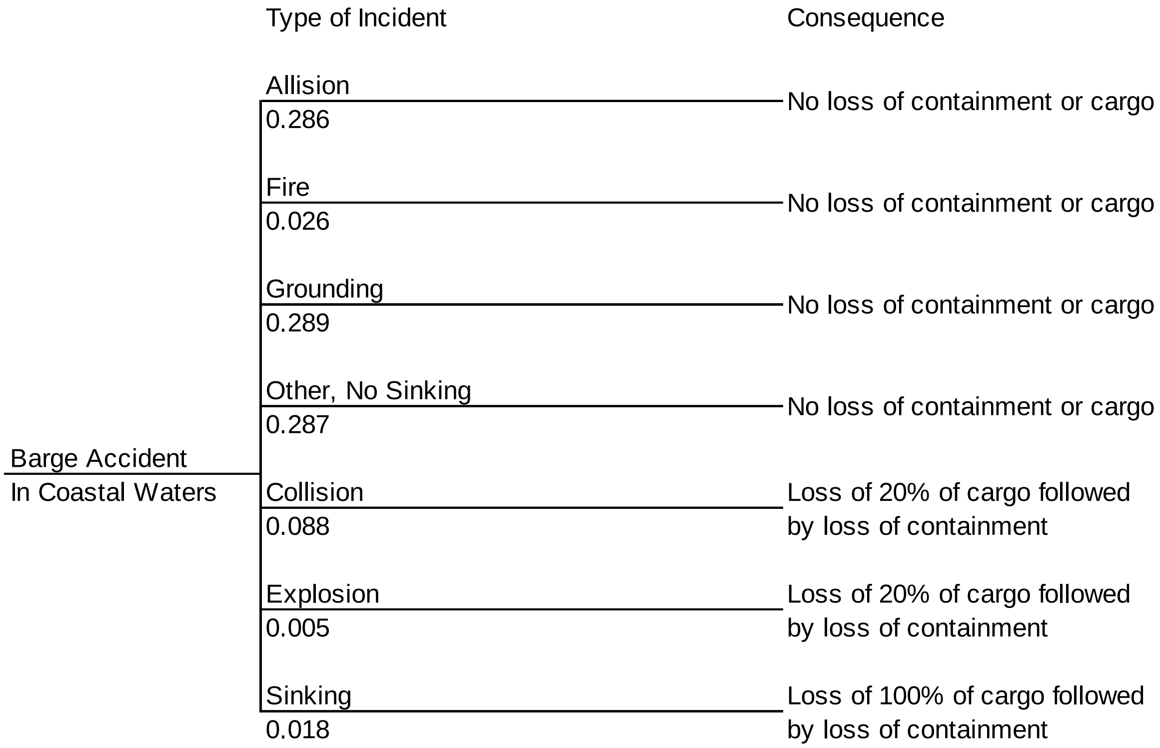

Figure 12. Event Tree for Accidents for Barging of Class A Concrete/Asphalt in IP-1 Bags

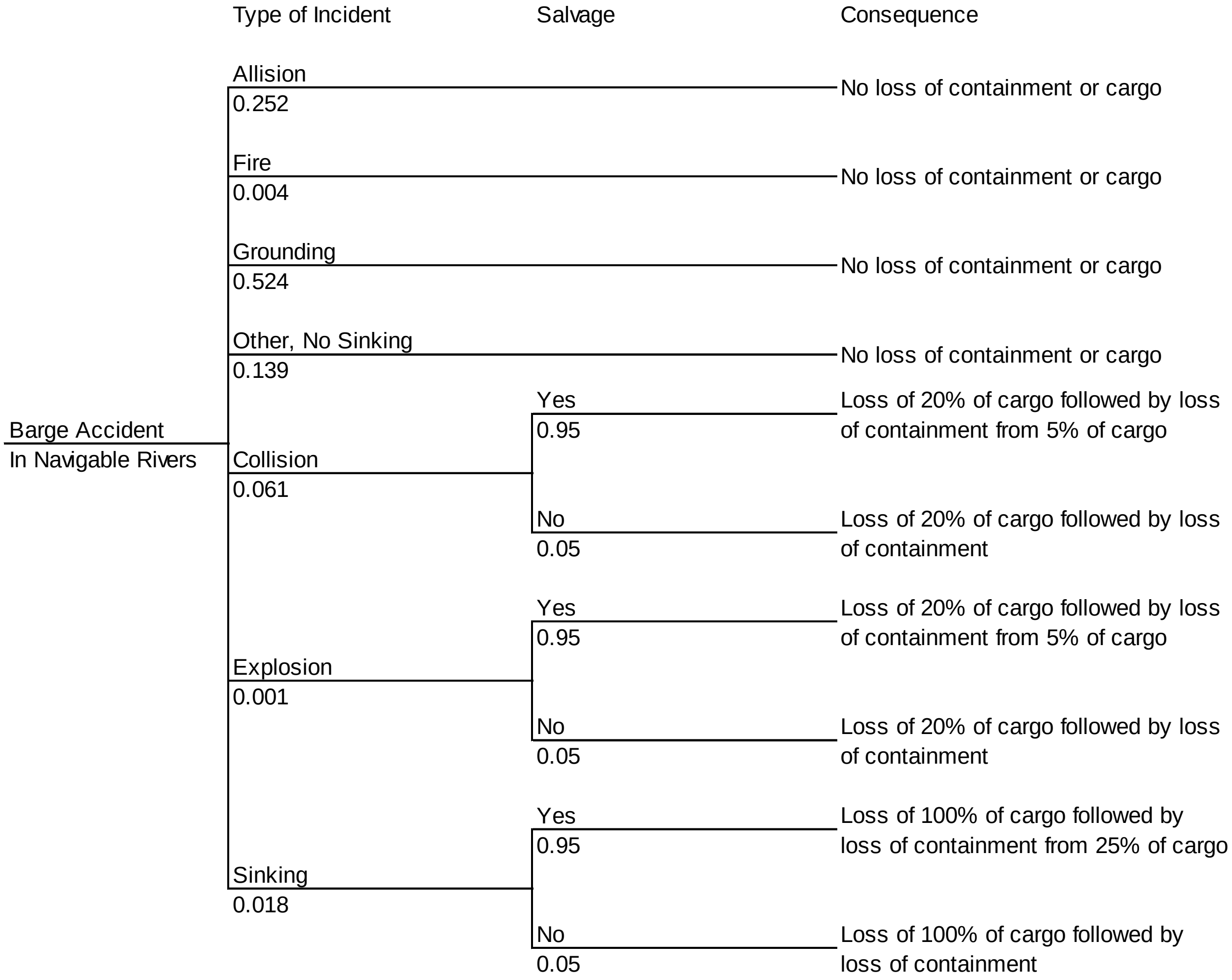

Figure 13. Event Tree for Accidents for Barging of LARW Metals in IMC on the Columbia River

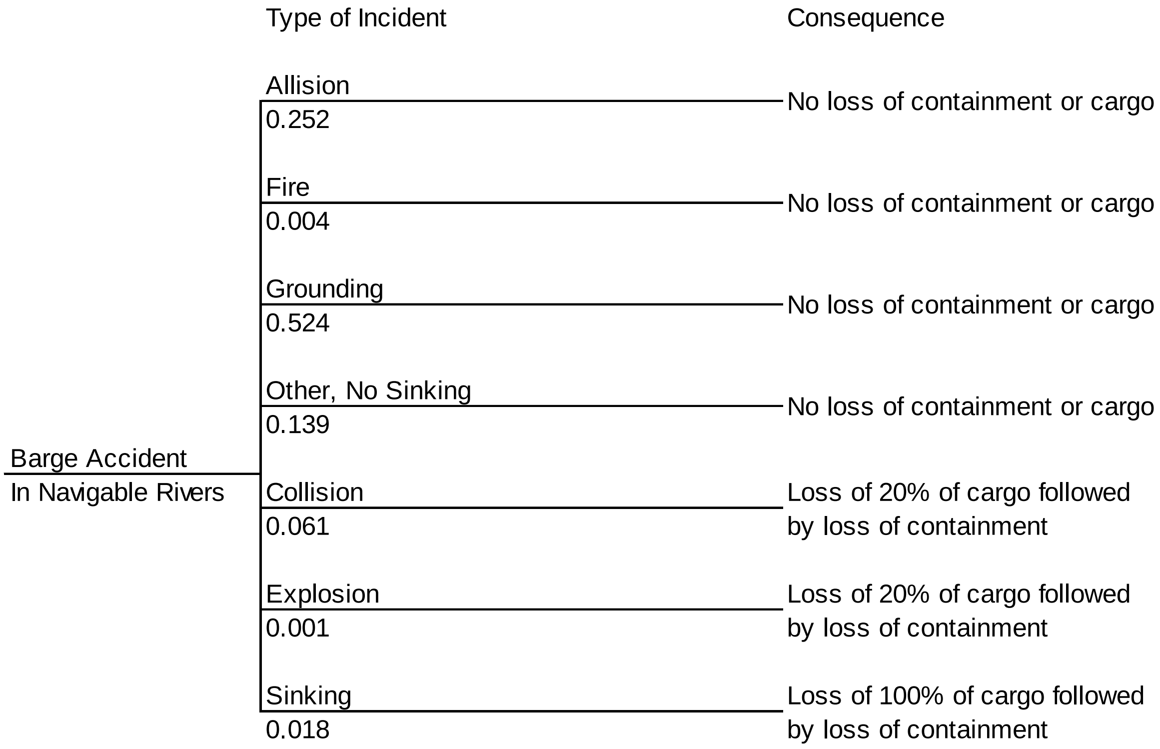

Figure 14. Event Tree for Accidents for Barging of LARW Concrete/Asphalt in IP-1 Bags on the Columbia River

3.6 Source Terms

3.6.1 GTCC/SNF

The contents of the Holtec HI-STAR 100 MPC-32 cask are sourced from Rev. 20 of the Safety Analysis Report and presented in Table 5. For transport by truck and rail, no loss of containment scenarios are modeled; hence this information is not used. For the barge transport accident scenarios, it is assumed that the release rate is equal to one times A_2[10] in a week. This is the permitted leakage rate for hypothetical accident conditions (HAC). The rationale for the selection of this source term is that the barge accident scenarios do not result in impact loads on the casks that are greater than design. Hence no loss of containment is considered. In the event that the cask is lost at sea and cannot be retrieved, corrosion may eventually result in some minor leakage. Such leakage would not be expected to exceed the HAC permitted rate. The time it would take for corrosion to result in leakage was not analyzed, given the robustness of the cask design.

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[10] The A_2 value, the amount of the radionuclide that could be transported in a Type A container, is an indication of the radiotoxicity; the larger the A_2 value, the smaller the radiotoxicity of that nuclide.

Table 5. Inventory of MPC-32

Radionuclide	**Activity in 32 Assemblies (Ci)**
Gases	
3_{H}	8.83E+03
129_{I}	6.94E-01
85_{Kr}	1.50E+05
81_{Kr}	2.55E-06
127_{Xe}	1.90E-09
Crud	
60_{Co}	6.98E+02
Volatiles	
90_{Sr}	1.45E+06
106_{Ru}	1.59E+06
134_{Cs}	1.42E+06
137_{Cs}	2.16E+06
89_{Sr}	4.00E+00
103_{Ru}	1.17E-01
135_{Cs}	8.93E+00
Fines	
$225_{\mathrm{Ac*}}$	9.76E-07
$227_{\mathrm{Ac*}}$	7.55E-05
$110m_{\mathrm{Ag}}$	5.54E+03
$241\ _{\mathrm{Am*}}$	1.52E+04
$242M_{\mathrm{Am*}}$	1.79E+02
$243_{\mathrm{Am*}}$	7.14E+02
$210M\ _{\mathrm{Bi*}}$	0.00E+00
$247_{\mathrm{Bk*}}$	0.00E+00
144_{Ce}	1.53E+06
$248_{\mathrm{Cf*}}$	0.00E+00

Radionuclide	**Activity in 32 Assemblies (Ci)**
$249_{\text{Cf*}}$	2.56E-03
$250_{\text{Cf*}}$	9.34E-03
$251_{\text{Cf*}}$	1.09E-04
$252_{\text{Cf*}}$	1.32E-02
$254_{\text{Cf*}}$	3.81E-12
$240_{\text{Cm*}}$	0.00E+00
$242_{\text{Cm*}}$	1.03E+04
$243_{\text{Cm*}}$	5.15E+02
$244_{\text{Cm*}}$	1.04E+05
$245_{\text{Cm*}}$	1.04E+01
$246_{\text{Cm*}}$	3.39E+00
$247_{\text{Cm*}}$	2.26E-05
$248_{\text{Cm*}}$	1.34E-04
154_{Eu}	1.29E+05
155_{Eu}	4.29E+04
55_{Fe}	2.23E+03
$148_{\text{Gd*}}$	0.00E+00
$236_{\text{Np*}}$	3.13E-04
$237_{\text{Np*}}$	7.46E+00
239_{Np}	7.14E+02
$231_{\text{Pa*}}$	5.82E-04
147_{Pm}	1.37E+06
$210_{\text{Po*}}$	1.25E-07
$236_{\text{Pu*}}$	6.53E+00
$238_{\text{Pu*}}$	8.19E+04
$239_{\text{Pu*}}$	6.11E+03

Radionuclide	Activity in 32 Assemblies (Ci)
240_{Pu*}	1.05E+04
241_{Pu}	2.42E+06
$242\ _{Pu*}$	5.28E+01
244_{Pu*}	3.55E-12
223_{Ra*}	7.58E-05
224_{Ra*}	2.74E-01
225_{Ra*}	9.76E-07
226_{Ra*}	9.02E-07
228_{Ra*}	3.16E-10
222_{Rn*}	9.02E-07
125_{Sb}	9.18E+04
151_{Sm}	8.32E+03
$119m_{Sn}$	1.75E+04
$125m_{Te}$	2.24E+04
227_{Th*}	7.46E-05
228_{Th*}	2.74E-01
229_{Th*}	9.76E-07
230_{Th*}	6.91E-04
231_{Th*}	2.28E-01
230_{U*}	4.26E-22
232_{U*}	4.83E-01
233_{U*}	4.51E-04
234_{U*}	1.59E+01
236_{U*}	5.12E+00
90_{Y}	1.45E+06

3.6.2 Class B/C

It has been assumed that the Class B and C wastes will have the composition of the wet operational wastes generated at DCPP and an activity level equivalent to the maximum permissible by the 8-120B cask. An evaluation of the maximum permissible inventory for the cask by the procedures presented in the Safety Analysis Report (Rev. 14) revealed that the applicable limit would be the 3000 A_2 limit specified in Section 1.2.2.2. The inventory corresponding to this limiting value is presented in Table 6.

Table 6. Inventory of Class B/C Radionuclides in Type 8-120B Casks

Radionuclide	**Composition**	**A_2 (Ci)**	**3000 A_2 for Mixture (Ci)**
Co-60	46.1%	1.1E+01	3.21E+04
Mn-54	1.6%	2.7E+01	1.11E+03
Ni-63	24.4%	8.1E+02	1.70E+04
Fe-55	24.7%	1.1E+03	1.72E+04
C-14	0.5%	8.1E+01	3.48E+02
Mixture	97.3%	2.3E+01	6.77E+04

For accidental releases during transportation by truck and rail a worst case release of 8.4 times the A_2 quantity for the material, in a week, has been modeled and was selected by analogy with the NUREG-2125 accidental release scenario for the rail lead cask. This is a release rate that is greater than the HAC permitted rate.

For the barge transport accident scenarios modeled, it is assumed that the release rate is equal to one times A_2 in a week. This is the permitted leakage rate for HAC. The rationale for the selection of this source term is that the barge accident scenarios do not result in impact loads on the cask that are greater than design. Hence no loss of containment is considered. In the event that the cask is lost at sea and cannot be retrieved, eventually corrosion may result in minor leakage. Such leakage would not be expected to exceed the HAC permitted rate. Given the robustness of the design, this study did not include estimation of the time it would take for corrosion to result in a leak.

3.6.3 Class A

Class A wastes have been assumed to have the same composition as the dry operational wastes generated at DCPP. Further, for the base case, it is assumed that the Class A wastes are at the limit of what can be classified as Class A. The resulting inventory is presented in Table 7.

Table 7. Inventory in IMC/IP-1 Bag for Class A Waste

Radionuclide	**Composition**	**Ci/m^3**	**Base Case Activity (Ci/IMC)**	**Sensitivity Case Activity (Ci/IMC)**
Co-60	26.8%	4.69	153.4	15.3
Cr-51	21.2%	3.71	121.3	12.1
Ni-63	19.6%	3.43	112.2	11.2
Fe-55	11.6%	2.03	66.4	6.6
Co-58	6.0%	1.05	34.3	3.4
Nb-95	6.0%	1.05	34.3	3.4
Zr-95	3.9%	0.68	22.3	2.2
Mn-54	1.8%	0.32	10.3	1.0
Sb-125	1.1%	0.19	6.3	0.6

It is expected that the assumption of maximum Class A activity for all of the Class A wastes will prove to be excessively conservative. For comparison the Electric Power Research Institute (EPRI) report "Characterization and Remediation of Contaminated Concrete", 2015 provides an estimate of an average activity of 1800 Bq/g (4.86E-08 Ci/g). This average activity represents a level of activity that is less than one six hundredths of the base case activity in Table 7. Hence a sensitivity case assuming one tenth of the activity levels of the base case is also considered in this study.

It is expected that the actual radionuclide composition of the decommissioning waste will be different from that listed in Table 7. In particular, some presence of Cs-137 and Eu isotopes would be expected. It is expected that the high activity levels selected above will ensure that the risks estimated in this study are conservative with respect to the risks of transporting the actual Class A decommissioning wastes.

In the event of an accident on land, it is assumed that the IMC or IP-1 bag loses integrity and all of the materials are spilled. The release fraction is assumed to be 0.001. Further, the aerosol fraction is assumed to be 0.001. These factors are derived from the International Atomic Energy Agency (IAEA) Safety Standard "Advisory Material for the IAEA Regulations for the Safe Transport of Radioactive Material (2012 Edition)" and are consistent with the rationale for the selection of the A_2 values for the radionuclides.

For barging related accidents, based on the guidance used for the consequence modeling, it is assumed that all of the lost radionuclides are released into the water over a period of one year. The quantity of radionuclides lost is 5%, 20%, 25% or 100% of the cargo, depending on the branch of the event tree (Figures 9-12) being modeled.

3.6.4 LARW

Three levels of activity have been modeled for the LARW. These are 10%, 1% and 0.1% of the base case Class A activity presented in Table 7.

The accident event modeling for LARW is analogous to that for Class A.

3.7 Atmospheric Dispersion and Dose Estimation

Radionuclides released into the environment are dispersed by wind. The dispersion is modeled using the accident model in RADTRAN, which is a Gaussian dispersion model. The dispersion was modeled using neutral weather conditions (Pasquill: stability D) similar to NUREG-2125. The wind speed in RADTRAN, in case Pasquill Stability D is selected, is 4 m/s. For Pasquill Stability D, the maximally exposed individual (MEI) is considered in RADTRAN to be located directly downwind from the accident—36 meters from the package. The dose from a release depends on dispersion of the released material, which either remains suspended in the air, producing cloudshine, or is deposited on the ground producing groundshine, or is inhaled.

RADTRAN models five exposure pathways associated with dispersal of material from damaged package(s). These pathways are inhalation, cloudshine, resuspension, groundshine, and ingestion.

Minor and/or uncommon pathways such as absorption through skin or through open wounds are not included. External doses calculated in RADTRAN, including incident-free doses, groundshine and cloudshine doses, and doses from loss-of-shielding accidents are expressed as effective dose equivalents.

The exposure duration is set by default in RADTRAN to 24 hours. This is the same as the exposure duration used in NUREG-2125 and is based on the expectation of evacuation of the exposed population. The exposure for the land transportation modes is short term. This is different from the modeling, presented below for aquatic dispersion where exposures are modeled over a period of a year.

The following is excerpted from the RADTRAN Technical Manual.

> *The term "dose risk" is a RADTRAN artifact, constructed to demonstrate the relationship between radiation dose and the probability of that dose occurring. The units of dose risk are radiation dose units, Sv or rem. In analyzing routine, incident-free transportation, it is recognized that the probability of such transportation is indistinguishable from unity, and the impact is referred to as "dose." However, the probability of an accident and the probability of a particular accident is not unity, and is usually much, much less than unity. "Dose risk" is essentially the product of overall accident probability, scenario specific conditional probability, and radiation dose.*

3.8 Aquatic Dispersion and Dose Estimation

3.8.1 Coastal Waters

The aquatic dispersion of radionuclides released into surface waters is modeled using guidance provided in the IAEA Report “Generic Models for Use in Assessing the Impact of Discharges of Radioactive Substances to the Environment”, 2001. Methods for the calculation of individual doses due to inhalation and ingestion of seafood are also included.

The IAEA document “Determining the Suitability of Materials for Disposal at Sea under the London Convention 1972 and London Protocol 1996: A Radiological Assessment Procedure”, 2015 provides methodology for calculating individual doses from additional pathways – (i) inadvertent ingestion of beach sediments, (ii) inhalation of resuspended beach sediments and (iii) inhalation of sea spray. This document provides guidance on the estimation of collective doses to the public.

The conservative assumptions for regional conditions incorporated in the approach described include:

- The entire radionuclide inventory of the material disposed is released into the marine environment in a readily available form. Under normal circumstances substantial proportions of the inventory would be retained in the material.
- The release of radionuclides from the material disposed occurs within a single year. Such releases from some materials occur over significantly longer time intervals.
- Disposal operations take place continuously throughout a year thereby resulting in temporally uniform conditions being established. In practice, radionuclide concentrations in the water decrease rapidly, within a period of hours to days, following disposal. Consequently, the dispersion model overestimates the concentrations of radionuclides in the receiving environment and their transfer along exposure pathways.
- Members of the public who could receive the highest doses as a result of disposal operations have also been characterized to overestimate exposures arising from all relevant pathways. The values selected for the habit data (rates of ingestion of seafood, inhalation of resuspended sediment and sea spray, shore occupancy) are at the upper end of the range of realistic values and have been chosen to maximize the potential doses received by these individuals.

The models were implemented in a spreadsheet using Microsoft Excel ®.

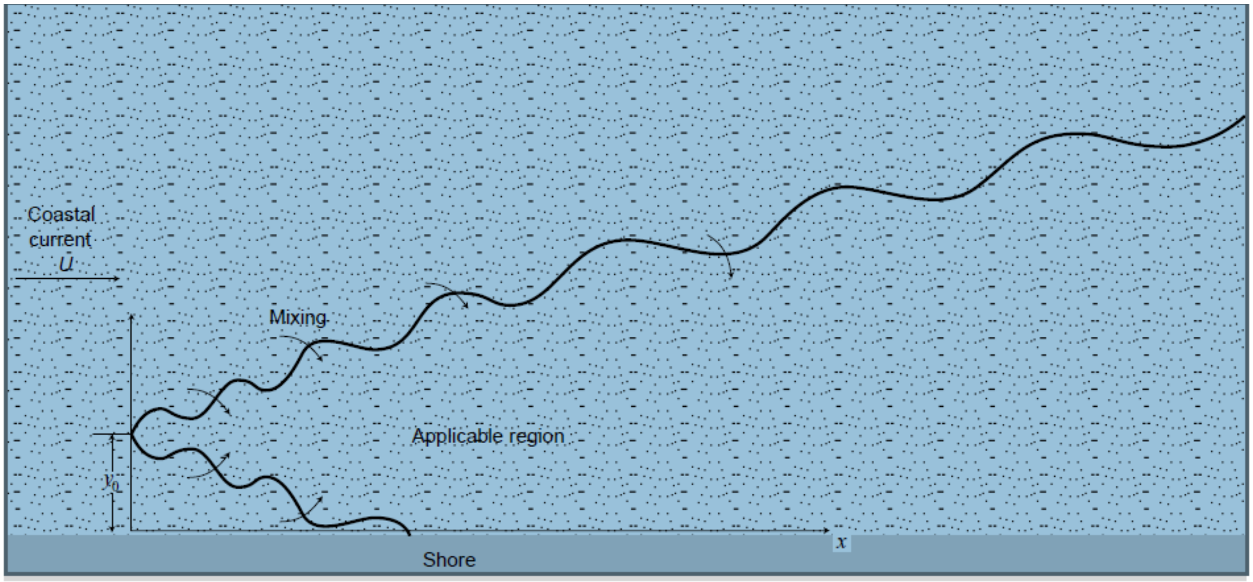

Figure 15. Coastal Waters Model Illustration (courtesy IAEA)

The conceptual model for the aquatic dispersion of radionuclides in coastal waters is presented in Figure 15. The mathematical model selected for coastal waters is based on a steady state, vertically averaged advection–diffusion equation. Longitudinal dispersion is not included, which results in a conservative estimate of the radionuclide concentration.

The calculations performed in this study are presented below in a step-by-step format. The definitions of the terms in the equations are presented in Table 8 at the end of this section. Key model parameters are presented in Appendix C.

Step 1.

Calculate radionuclides concentration for the shoreline (Eq. 1) and for fishing (Eq. 2).

$$C_{w,tot} = \frac{962\ U^{0.17} Q_i}{D x^{1.17}} exp\left[\frac{(-7.28\times10^5) U^{2.34} y_0^2}{x^{2.34}}\right] exp\left(-\frac{\lambda_i x}{U}\right) \tag{1}$$

$$C_{w,tot} = |_{y=y_0} = \frac{962\ U^{0.17} Q_i}{D x^{1.17}} exp\left(-\frac{\lambda_i x}{U}\right) \tag{2}$$

Step 2.

Calculate the dissolved (filtered) radionuclide concentration (Bq/m^3) in surface water:

$$C_{w,s} = \frac{C_{w,tot}}{1+0.001\ K_d S_s} \tag{3}$$

Calculate the radionuclide concentration adsorbed by suspended sediment:

$$C_{s,w} = \frac{0.001K_d C_{w,tot}}{1+0.001S_s K_d} = 0.001K_d C_{w,s} \tag{4}$$

Calculate the surface activity concentration of a radionuclide in shore/beach sediment:

$$C_{s,s} = \frac{(0.1)(0.001)K_d \times 60 \times C_{w,tot}}{1+0.001S_s K_d} \times \frac{1-e^{-\lambda_i T_e}}{\lambda_i T_e} = 60C_{s,b} \tag{5}$$

Step 3

Calculate the transport of radionuclides from liquid discharges to aquatic foods (for both fish and shellfish)

$$C_{af,i} = C_{w,i}B_p/1000 \tag{6}$$

Step 4

Calculate the annual effective dose to an individual due to external exposure from sediment:

$$E_m = C_{s,s}DF_{gr}O_f \tag{7}$$

Calculate the annual effective dose from inhalation:

$$E_{inh} = C_A R_{inh} DF_{inh} \tag{8}$$

Calculate the ingestion doses from terrestrial and aquatic foodstuffs

$$E_{ing,p} = C_{p,i}H_p DF_{ing} \tag{9}$$

Step 5

Calculate the annual dose from inadvertent ingestion of shore sediments:

$$E_{ing\ shore,public} = t_{public}H_{shore}\sum_j \frac{C_S(j)}{\rho_S L_B} DC_{ing}(j) \tag{10}$$

Calculate the dose from inhalation of resuspended beach sediments:

$$E_{inh\ shore,public} = t_{public}R_{inh,public}DL_{shore}\sum_j C_P(j)DC_{inh}(j) \tag{11}$$

Calculate the annual dose to members of the public from inhalation of airborne sea spray on the shore

$$E_{inh\ spray,public} = t_{public}R_{inh,public}\frac{C_{spray}}{\rho_W}\sum_j C_W(j)DC_{inh}(j) \tag{12}$$

Step 6

Calculate the collective doses to the public

$$E_{coll,shore,public} = (E_{ext,public} + E_{inh\ shore,public} + E_{inh\ spray,public}) \times \frac{O_{coll,public} L_{shore} N_{sites}}{t_{public}} \quad (13)$$

$$E_{coll\ ing,public} = N_{sites} \sum_k f_B(k) N_B(k) \sum_j C_B(j,k) DC_{ing}(j) \quad (14)$$

$$E_{coll,public} = E_{coll\ shore,public} + E_{coll\ ing,public} \quad (15)$$

3.8.2 Navigable Rivers

For navigable rivers the modeling is based on the guidance in the IAEA Report “Generic Models for Use in Assessing the impact of Discharges of Radioactive Substances to the Environment”, 2001 (Figure 16). For the river part of the route, no estimation of collective dose has been performed. The population exposed to the hazard in case of discharge in a river is difficult to estimate since the radionuclides remain in the water for the entire length downriver from the point of the discharge.

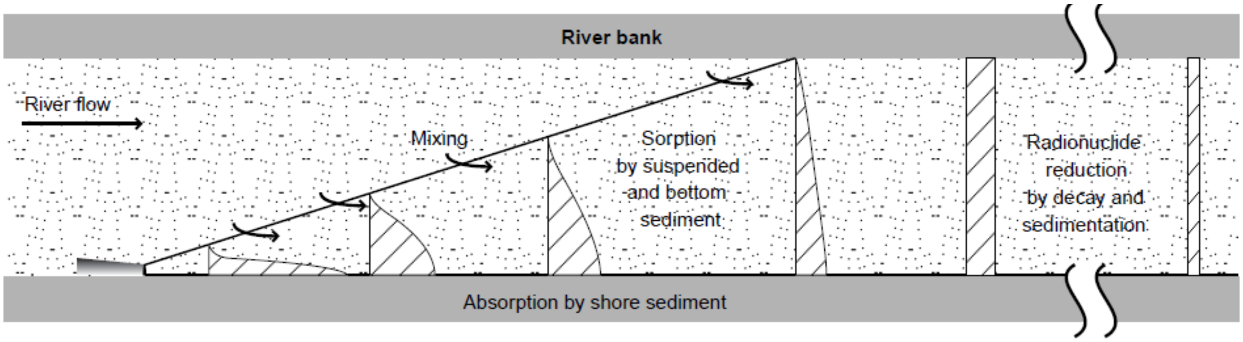

Figure 16. Navigable Rivers Model Illustration (courtesy IAEA)

Step 1

Calculate the radionuclide concentration at a downstream distance x along the river bank.

$$C_{w,tot} = \frac{Q_i}{q_r} exp\left(-\frac{\lambda_i x}{U}\right) P_r \quad (16)$$

Step 2

Calculate the radionuclide concentration adsorbed by suspended sediment using Eq. 3.

Step 3

Calculate the radionuclide concentration adsorbed by suspended sediment using Eq. 4.
Calculate the surface activity concentration of a radionuclide in shore/beach sediment using Eq. 5.

Step 4

Calculate the concentration Cv,i,1 due to direct contamination of nuclide i in and on vegetation

$$d_i = C_{w,i} \times I_w \tag{17}$$

$$C_{v,i,1} = \frac{d_i \alpha \left[1 - exp\left(-\lambda_{E_i^v} t_e\right)\right]}{\lambda_{E_i^v}} \tag{18}$$

Calculate the radionuclide concentration in vegetation arising from indirect processes from uptake from the soil and from soil adhering to the vegetation

$$C_{v,i,2} = F_v \times C_{s,i} \tag{19}$$

$$C_{s,i} = \frac{d_i \left[1 - exp\left(-\lambda_{E_i^s} t_b\right)\right]}{\rho \lambda_{E_i^s}} \tag{20}$$

Step 5

The total concentration of the radionuclide on the vegetation at the time of consumption is given by

$$C_{v,i} = \left(C_{v,i,1} + C_{v,i,2}\right)\exp(-\lambda_i t_h) \tag{21}$$

The concentration of radionuclide i in animal feed is calculated by

$$C_{a,i} = f_p C_{v,i} + \left(1 - f_p\right) C_{p,i} \tag{22}$$

Step 6

Calculate the radionuclide concentration in milk

$$C_{m,i} = F_m\left(C_{a,i} Q_m + C_{w,i} Q_w\right) exp(-\lambda_i t_m) \tag{23}$$

Calculate the radionuclide concentration in meat

$$C_{f,i} = F_m\left(C_{a,i} Q_f + C_{w,i} Q_w\right) exp\left(-\lambda_i t_f\right) \tag{24}$$

Step 7

Calculate the annual effective dose from consumption of nuclide i in foodstuff

$$E_{ing,p} = C_{p,i} H_p DF_{ing} \tag{25}$$

Table 8. Definition of Terms in Equations for Aquatic Dispersion Modeling

Item	Definition
B_p	The equilibrium ratio of the concentration of radionuclide i in aquatic food p to its dissolved concentration in water (Bq·kg^{-1}/Bq·L^{-1}, or L/kg), known as the bioaccumulation factor
C_A	The radionuclide concentration in air (Bq/m^3)
C_S	The surface contamination of the sediment on the shore
$C_W(j)$	The concentration of radionuclide j in seawater (in Bq/m^3)
$C_{a,i}$	The concentration of radionuclide i in animal feed (Bq/kg, dry matter)
$C_{a,i}$	The concentration of radionuclide i in the animal feed (Bq/kg, dry matter)
$C_{a,i}$	The concentration of radionuclide i in the animal feed (Bq/kg, dry matter)
$C_{af,i}$	The concentration of radionuclide i in aquatic food p (Bq/kg);
$C_{f,i}$	The concentration of radionuclide i in animal flesh (Bq/kg)
$C_{m,i}$	The concentration of radionuclide i in milk (Bq/L)
$C_{p,i}$	The concentration of radionuclide i in foodstuff p at the time of consumption (Bq/kg)
$C_{p,i}$	the concentration of radionuclide in stored feeds (Bq/kg, dry weight
$C_{s,b}$	The surface activity concentration of a radionuclide in beach sediment (Bq/m^2), taking account of radioactive decay occurring while the radionuclide accumulating in shore or beach sediment radioactive decay occurring while the radionuclide accumulating in shore or beach sediment
$C_{s,i}$	The concentration of radionuclide i in dry soil (Bq/kg)
$C_{s,s}$	The surface activity concentration of a radionuclide in shore sediment (Bq/m^2), taking account of radioactive decay occurring while the radionuclide accumulating in shore or beach sediment radioactive decay occurring while the radionuclide accumulating in shore or beach sediment
$C_{s,w}$	The radionuclide concentration adsorbed by suspended sediment (Bq/kg)
C_{spray}	The concentration of sea spray in the air (in kg/m^3)
$C_{w,tot}$	The total radionuclide concentration in water (Bq/m^3)
$C_{w,i}$	The concentration of dissolved radionuclide i in water (Bq/m^3);
$C_{w,s}$	The dissolved (filtered) radionuclide concentration (Bq/m^3) in surface water
$C_{v,i,1}$	The concentration due to direct contamination of nuclide i in and on vegetation, measured in Bq/kg dry matter for vegetation consumed by grazing animals and in Bq/kg fresh matter for vegetation consumed by humans

Item	Definition
$C_{v,i,2}$	The radionuclide concentration in vegetation arising from indirect processes — from uptake from the soil and from soil adhering to the vegetation — measured in Bq/kg dry matter for vegetation consumed by grazing animals and in Bq/kg fresh matter for vegetation consumed by humans
$C_{v,i}$	The total concentration of the radionuclide on the vegetation at the time of consumption, measured in Bq/kg dry matter for vegetation consumed by grazing animals and in Bq/kg fresh matter for vegetation consumed by humans
$DC_{inh}(j)$	The dose coefficient for inhalation (in Sv/Bq)
$DC_{ing}(j)$	The dose coefficient for ingestion of radionuclide j (in Sv/Bq)
DF_{gr}	The dose coefficient for exposure to ground deposits (Sv/a per Bq/m^2)
DF_{inh}	The inhalation dose coefficient (Sv/Bq) (see Table XVI)
DF_{ing}	The dose coefficient for ingestion of radionuclide i (Sv/Bq)
$E_{coll\ ing,public}$	The collective dose from seafood consumption, Ecoll, ing, public (in man Sv),
$E_{coll\ shore,public}$	The collective dose to people spending time on the shore (in man Sv/a)
$E_{coll,public}$	The total collective dose (in man Sv),
$E_{ext,public}$	The annual effective dose to members of the public from external exposure to radionuclides deposited on the shore (in Sv)
$E_{inh\ spray,public}$	The annual dose to members of the public from inhalation of airborne sea spray on the shore (in Sv/a)
E_{inh}	The annual effective dose from inhalation (Sv/a)
$E_{ing\ shore,public}$	The annual dose from inadvertent ingestion of shore sediments (in Sv)
$E_{ing,p}$	The annual effective dose from consumption of nuclide i in foodstuff p (Sv/a)
F_f	The fraction of the animal's daily intake of a radionuclide that appears in each kg of flesh at equilibrium or at the time of slaughter (d/kg)
F_m	The fraction of the animal's daily intake of the radionuclide that appears in each liter of milk at equilibrium (d/L)
F_v	The concentration factor for uptake of the radionuclide from soil by edible parts of crops (Bq/kg plant tissue per Bq/kg dry soil). It is conservatively assumed that all activity removed from the atmosphere becomes available for uptake from the soil; in addition, the selected values also implicitly take account of the adhesion of soil to the vegetation (again, for pasture forage the unit of mass is for dry matter; for vegetation consumed by humans the unit is for fresh weight)
H_p	The consumption rate for foodstuff p (kg/a)
H_p	The consumption rate for foodstuff p (kg/a)

Item	Definition
H_{shore}	The hourly ingestion rate of beach sediment by humans (in kg/h)
I_w	The average irrigation rate ($m^3 \cdot m^{-2} \cdot d^{-1}$) over the period of irrigation
K_d	The distribution coefficient
L_B	The thickness of the sediment layer
L_{shore}	The length of coastline affected by disposal operation at a single site (in m)
$N_B(k)$	The annual amount of seafood k caught in the area affected by a single dumping site (in kg);
N_{sites}	The number of dumping sites in operation
$O_{coll,public}$	The annual collective occupancy time per unit length of coastline (in (man h / m)
O_f	The fraction of the year for which a hypothetical critical group member is exposed to this particular pathway
Q_f	The amount of feed (in dry matter) consumed by the animal per day (kg/d)
Q_i	The average discharge rate of radionuclide i (Bq/s)
Q_m	The amount of feed (in dry matter) consumed by the animal per day (kg/d)
Q_w	The amount of water consumed by the animal per day (m^3/d)
$R_{inh,public}$	The inhalation rate (in m^3/h),
R_{inh}	The inhalation rate (m^3/a)
S_s	A suspended sediment concentration (kg/m^3 or g/L)
T_e	The effective accumulation time (s)
d_i	The deposition rate (from wet and dry processes) of radionuclide i on to the ground (Bq $\cdot m^{-2} \cdot d^{-1}$)
$f_B(k)$	The fraction of seafood k used for human consumption
f_p	the fraction of the year that animals consume fresh pasture vegetation (dimensionless)
q_r	The mean river flow rate (m^3/s)
t_h	A delay (hold-up) time that represents the time interval between harvest and consumption of the food (d).
t_b	The duration of the discharge of radioactive material (d)
t_e	The time period that crops are exposed to contamination during the growing season (d).
t_f	The average time between slaughter and human consumption of meat — a default value is 20 days
t_m	the average time between collection and human consumption of milk (assumed to be one day for fresh milk)

Item	Definition
t_{public}	The time spent on the shore by a member of the public in one year (in h)
$\lambda_{E_i^s}$	The effective rate constant for reduction of the activity concentration in the root zone of soils (d^{-1}), where $\lambda_{E_i^s} = \lambda_i + \lambda_s$
$\lambda_{E_i^v}$	The effective rate constant for reduction of the activity concentration of radionuclide i from crops (d^{-1}), where $\lambda_{E_i^v} = \lambda_i + \lambda_w$
λ_i	The rate constant for radioactive decay of radionuclide i (d^{-1}) or (s^{-1})
λ_s	The rate constant for reduction of the concentration of material deposited in the root zone of soils owing to processes other than radioactive decay (d^{-1})
λ_w	The rate constant for reduction of the concentration of material deposited on the plant surfaces owing to processes other than radioactive decay (d^{-1})
ρ_S	The sediment density
ρ_W	The density of seawater (in kg/m^3)
U	The net freshwater velocity (m/s)
U	Coastal current, default 0.1 m/s
x	The distance between the discharge point and the receptor (m) for rivers
x	As default, may be assumed to be 50 times the water depth for coastal model
α	The fraction of deposited activity intercepted by the edible portion of vegetation per unit mass (or mass interception factor, m^2/kg) as the result of both wet and dry deposition processes; for pasture forage the unit of mass is conventionally given in terms of dry weight, and for fresh vegetables the unit is in wet weight.
ρ	is a standardized surface density for the effective root zone in soil (kg/m^2, dry soil)

3.9 Radiological Exposures and Risk Measures

Radiological exposures for incident free transportation are reported in terms of consequence exposures for the maximally exposed individual in mrem. Collective doses to the crew, certain specific groups, i.e., first responders, inspectors, and members of the public are presented in units of person-rem. The probability of exposure to incident free transportation is 1.

Radiological exposures are reported by RADTRAN for atmospheric dispersion in terms of a consequence exposure to the maximally exposed individual in rem and a collective dose risk in person-rem that is the product of the population dose in case of an accidental release and the probability of that release.

Radiological exposure to aquatic dispersion has been calculated in this report in units of Sieverts per year (Sv/a) for the maximally exposed individual and person-Sv/a for a collective dose risk, i.e., the population dose multiplied by the probability of accidental release. Sv can be converted to rem by multiplying by 100. The results are presented in units of mrem/yr and person-rem/yr for consistency with the other analyses presented in this study.

The dose consequence of incident free transportation or accidental releases should be placed in the context of permissible exposure and the background dose. 10CFR20.1201 specifies 5 rem as the limit of the annual occupational dose to adults, while 10CFR20.1301 specifies 0.1 rem (100 mrem, 1 mSv) in a year, exclusive of the dose contributions from background radiation, as the limit for individual members of the public.

The NRC states (https://www.nrc.gov/about-nrc/radiation/around-us/doses-daily-lives.html) that:

> *On average, Americans receive a radiation dose of about 0.62 rem (620 millirem) each year. Half of this dose comes from natural background radiation.*

The collective dose from incident free transportation has been used to estimate the number of latent cancer fatalities (LCF) using 5.5E-04/person-rem for members of the public and 4.1E-04/person-rem for members of the crew. These conversion factors are from “The 2007 Recommendations of the International Commission on Radiological Protection “ Publication 103 and are slightly higher than the values used in NUREG-0586 (5.0E-04/person-rem for members of the public and 4.0E-04/person-rem for members of the crew).

No attempt has been made to estimate the LCF for accidental releases since the collective dose risk estimates are very low (less than 100 person-rem).

4 Waste Materials, Packaging, Transportation and Routes

4.1 Waste Materials

The non-radiological wastes that need to be transported from DCPP are listed in Table 9. Radiological wastes are listed in Table 10. Tables 9 and 10 also provide quantities of the wastes in short tons (2,000 lbs).

4.2 Packaging and Containers

The packaging and containers for the various types of waste consist of standard 20-foot intermodal containers, IP-1 bags, 8-120B casks, and HI-Star 100 casks. The IMCs and soft-sided IP-bags either separately or in combination serve as shipping containers for non-detect, LARW (10 CFR 20.2002), and Class A wastes. The IP-1 bags are assumed to have the same size and form factor as the IMC for this study. The NRC certified 8-120B casks are the containers for the Class B/C wastes. The NRC certified HI-STAR 100 casks are the containers for the GTTC wastes and SNF. More details on packaging and containers are in Appendix A.

4.3 Transportation

Tables 9 and 10 provide the number of trucks, rail cars, train trips, barges and tug trips (each with up to two barges) required to complete the transportation campaign. The number of trucks required is estimated assuming each one carries 20 short tons. Metals are transported in IMC and concrete/asphalt is transported in IP-1 bags or IMC with liner. If the package type is IMC, a rail car is assumed to carry six IMC. If the package type is IP-1 bags, the rail transportation assumes gondola cars, each with five IP-1 bags. Each train is assumed to have 30 cars, whether flat or gondola. Barges carrying IMC have 198 IMC. Barges carrying IP-1 bags have 216 IP-1 bags.

4.4 Routes

All of the route segments, considered in this study, along with the lengths of the route are presented in Table 11. The route maps are presented in Appendix B.

Table 9. Non- Radioactive Waste Quantities

Classification	**Physical Type**	**Tons**	**Shipments (Originating Truckloads)**	**No. of Rail Cars**	**No. of Trains**	**No. of Barges**	**No. of Trips Using Barges**	**Barge Destination**	**Final Destination**
Non-Detect (Breakwater Removal Included)	Concrete / Asphalt	794,000	39700	7940	265	184	92	Long Beach Port	La Paz, AZ
Non-Detect	Metal – Recycle	72,281	3614	603	21	19	10	Long Beach Port	Salt Lake City, UT
Non-Detect	Concrete / Asphalt – Recycle	87,887	4394	N/A	N/A	23	12	Long Beach Port	Las Vegas, NV
Other Regulated Wastes	Debris & Soil	34,263	1713	N/A	N/A	8	4	Long Beach Port	Beatty, NV
Non-Detect (Breakwater Repurposed)	Concrete / Asphalt	110,106	5505	1101	37	26	13	Long Beach Port	La Paz, AZ

Table 10. Radioactive Waste Quantities

Classification	Physical Type	Tons	Shipments (Originating Truckloads)	No. of Rail Cars	No. of Trains	No. of Barges	No. of Trips Using Barges	Barge Destination	Final Destination
LARW 20.2002	Metal	55,098	2755	460	16	14	7	Boardman, OR	US Ecology, ID
LARW 20.2002	Concrete / Asphalt	176,287	8814	1763	59	41	21	Boardman, OR	US Ecology, ID
Class A	Metal	26,089	1304	218	8	7	4	Long Beach Port	Clive, UT
Class A	Concrete / Asphalt	103,821	5191	1039	35	24	12	Long Beach Port	Clive, UT
Class B&C	Resins / Other (ft^3)	1,070	9	9	9	9	9	Long Beach Port	WCS, TX
GTCC & SNF			148	148	148	148	148	Long Beach Port	Texas CISF

Table 11. Details of Routes

Route ID	Mode	Waste Material	Type of Package	Number of Shipments/ Trains/ Barges	Route	One Way Miles	Return Trip Miles
1a	H	Non-Detect Concrete/ Asphalt	IP-1 in IMC	39700	DCPP-S to PBRY	16.5	33
1b	R	Non-Detect Concrete/ Asphalt	IP-1 in Gondola	265	PBRY to La Paz, AZ	475.0	950
1c	W	Non-Detect Concrete/ Asphalt	IP-1 on Barge	184	DCPP to LBP	305.6	612
1d	R	Non-Detect Concrete/ Asphalt	IP-1 in Gondola	265	LBP to La Paz, AZ	345.2	691

Route ID	Mode	Waste Material	Type of Package	Number of Shipments/ Trains/ Barges	Route	One Way Miles	Return Trip Miles
1e	H	Non-Detect Concrete/ Asphalt	IP-1 in IMC	39700	DCPP-N to PBRY	30.3	61
1f	H	Non-Detect Concrete/ Asphalt – Repurposed Breakwater	IP-1 in IMC	5505	DCPP-S to PBRY	16.5	33
1g	R	Non-Detect Concrete/ Asphalt – Repurposed Breakwater	IP-1 in Gondola	37	PBRY to La Paz, AZ	475.0	950
1h	W	Non-Detect Concrete/ Asphalt – Repurposed Breakwater	IP-1 on Barge	26	DCPP to LBP	305.6	612
1i	R	Non-Detect Concrete/ Asphalt – Repurposed Breakwater	IP-1 in Gondola	37	LBP to La Paz, AZ	345.2	691
1j	H	Non-Detect Concrete/ Asphalt – Repurposed Breakwater	IP-1 in IMC	5505	DCPP-N to PBRY	30.3	61
2a	H	Non-Detect Concrete/ Asphalt – Recycle	IMC with Liner	4394	DCPP-S to Las Vegas	527.5	1056
2b	W	Non-Detect Concrete/ Asphalt – Recycle	IMC with Liner on Barge	23	DCPP to LBP	305.6	612
2c	H	Non-Detect Concrete/ Asphalt – Recycle	IMC with Liner	4394	LBP to Las Vegas	293.7	588
2d	H	Non-Detect Concrete/ Asphalt – Recycle	IMC with Liner	4394	DCPP-N to Las Vegas	532.2	1065
3a	H	Non-Detect Metals – Recycle	IMC with Liner	3614	DCPP-S to PBRY	16.5	33
3b	R	Non-Detect Metals – Recycle	IMC with Liner	21	PBRY to SLC, UT	983.3	1967

Route ID	Mode	Waste Material	Type of Package	Number of Shipments/ Trains/ Barges	Route	One Way Miles	Return Trip Miles
3c	W	Non-Detect Metals – Recycle	IMC with Liner on Barge	19	DCPP to LBP	305.6	612
3d	R	Non-Detect Metals – Recycle	IMC with Liner	21	LBP to SLC, UT	790.8	1582
3e	H	Non-Detect Metals – Recycle	IMC with Liner	3614	DCPP-N to PBRY	30.3	61
10a	H	Other Regulated Wastes	IMC with Liner	1713	DCPP-S to Beatty, NV	463.9	928
10b	H	Other Regulated Wastes	IMC with Liner	1713	DCPP-N to Beatty, NV	499.2	999
10c	W	Other Regulated Wastes	IP-1 on Barge	8	DCPP to LBP	305.6	612
10d	H	Other Regulated Wastes	IP-1 in IMC	1713	LBP to Beatty, NV	341.7	684
4a	H	LARW Metal	IMC with liner	2755	DCPP-S to PBRY	16.5	33
4b	R	LARW Metal	IMC with Liner	16	PBRY to US Ecology, ID	1340.5	2682
4c	W	LARW Metal	IMC with Liner on Barge	14	DCPP to Boardman, OR	1182.9	2366
4d	H	LARW Metal	IMC with Liner	2755	Boardman, OR to US Ecology, ID	345.2	691
4e	H	LARW Metal	IMC with Liner	2755	DCPP-N to PBRY	30.3	61
5a	H	LARW Concrete/ Asphalt	IP-1 in IMC	8814	DCPP-S to PBRY	16.5	33
5b	R	LARW Concrete/ Asphalt	IP-1 in Gondola	59	PBRY to US Ecology, ID	1340.5	2682
5c	W	LARW Concrete/ Asphalt	IP-1 on Barge	41	DCPP to Boardman, OR	1182.9	2366
5d	H	LARW Concrete/ Asphalt	IP-1 in IMC	8814	Boardman, OR to US Ecology, ID	345.2	691
5e	H	LARW Concrete/ Asphalt	IP-1 in IMC	8814	DCPP-N to PBRY	30.3	61
6a	H	Class A Metal	IMC with Liner	1304	DCPP-S to PBRY	16.5	33

Route ID	Mode	Waste Material	Type of Package	Number of Shipments/ Trains/ Barges	Route	One Way Miles	Return Trip Miles
6b	R	Class A Metal	IMC with Liner	8	PBRY to Clive, UT	1021.2	2043
6c	W	Class A Metal	IMC with Liner on Barge	7	DCPP to LBP	305.6	612
6d	R	Class A Metal	IMC with Liner	8	LBP to Clive, UT	828.7	1658
6e	H	Class A Metal	IMC with Liner	1304	DCPP-N to PBRY	30.3	61
7a	H	Class A Concrete/ Asphalt	IP-1 in IMC	5191	DCPP-S to PBRY	16.5	33
7b	R	Class A Concrete/ Asphalt	IP-1 in Gondola	35	PBRY to Clive, UT	1021.2	2043
7c	W	Class A Concrete/ Asphalt	IP-1 on Barge	24	DCPP to LBP	305.6	612
7d	R	Class A Concrete/ Asphalt	IP-1 in Gondola	35	LBP to Clive, UT	828.7	1658
7e	H	Class A Concrete/ Asphalt	IP-1 in IMC	5191	DCPP-N to PBRY	30.3	61
8a	H	Class B/C	8-120B Cask	9	DCPP-S to WCS, TX	1373.4	2747
8b	H	Class B/C	8-120B Cask	9	DCPP-N to WCS, TX	1378.0	2756
8c	W	Class B/C	8-120B Cask	9	DCPP to LBP	305.6	612
8d	R	Class B/C	8-120B Cask	9	LBP to WCS, TX	1147.3	2295
9a	W	GTCC/SNF	HI-STORM 100	148	DCPP to LBP	305.6	612
9b	R	GTCC/SNF	HI-STORM 100	148	LBP to Texas CISF	1147.3	2295
9c	H	GTCC/SNF	HI-STORM 100	148	DCPP-S to PBRY	16.5	33
9d	H	GTCC/SNF	HI-STORM 100	148	DCPP-N to PBRY	30.3	61
9e	R	GTCC/SNF	HI-STORM 100	148	PBRY to Texas CISF	1339.9	2680
Mode: H denotes highway transport by truck, R denotes rail transport, and W denotes water transport by barge LBP is Long Beach Port, PBRY is Pismo Beach Rail Yard DCPP-S denotes southern route from DCPP via Avila Beach, DCPP-N denotes northern route from DCPP via Montana de Oro State Park							

5 Results

5.1 Conventional Transportation Risk Results

The conventional transportation risks in terms of fatalities are presented for the different waste materials in the following sections.

5.1.1 Clean Debris for Disposal

The conventional transportation risks for clean debris disposal to La Paz, AZ are presented in Table 12.

Table 12. Conventional Transportation Risks for Disposal of Clean Debris to La Paz, AZ

Route ID	Mode	Route	Return Trip Miles	Expected Fatalities	Expected Injuries	Expected Accidents
1a	H	DCPP-S to PBRY	33	0.018	0.480	1.640
1b	R	PBRY to La Paz, AZ	950	0.292	3.429	4.657
1c	W	DCPP to LBP	612	0.004	0.062	0.786
1d	R	LBP to La Paz, AZ	691	0.212	2.494	3.388
1e	H	DCPP-N to PBRY	61	0.034	0.886	3.027
1f	H	DCPP-S to PBRY	33	0.003	0.067	0.227
1g	R	PBRY to La Paz, AZ	950	0.041	0.479	0.650
1h	W	DCPP to LBP	612	0.001	0.009	0.111
1i	R	LBP to La Paz, AZ	691	0.030	0.348	0.473
1j	H	DCPP-N to PBRY	61	0.005	0.123	0.420

The results are summarized in Table 13. Transportation to PBRY via the northern route from DCPP results in a higher fatality risk than the southern route due to its greater length. The absolute differences are small and are approximately 5% of the total.

For land transport, the rail component of the route contributes the most. Rail fatality rates on a per mile basis are approximately 82 times the fatality rates by truck on a per mile basis. However since a single train carries either 180 IMC or 150 IP-1 bags, the overall fatality rates are lower for rail transport than for truck transport.

Repurposing the breakwater results in an 86% reduction in the transportation tonnage and hence mileage. The resultant reduction in fatality risk for any one of the selected transportation options is similarly 86%.

The option of using barges for the first leg of the route out of DCPP results in the lowest risks for fatalities, injuries and accidents.

Table 13. Summary of Fatality Risks for Disposal of Clean Debris.

Item	Expected Fatalities	Expected Injuries	Expected Accidents
Base Case			
Land Transport via Southern Route	0.311	3.909	6.297
Land Transport via Northern Route	0.326	4.315	7.685
Transport by Water and Land	0.216	2.556	4.173
Repurposed Breakwater			
Land Transport via Southern Route	0.043	0.545	0.878
Land Transport via Northern Route	0.046	0.602	1.070
Transport by Water and Land	0.030	0.357	0.584
Fatalities/Injuries/Accidents Saved by Breakwater Repurposing			
Land Transport via Southern Route	0.267	3.364	5.419
Land Transport via Northern Route	0.281	3.714	6.614
Transport by Water and Land	0.186	2.199	3.589

5.1.2 Non-Detect Metals for Recycling

The conventional transportation risks for recyclable metals to Salt Lake City are presented in Table 14.

Table 14. Conventional Transportation Risks for Recyclable Metals to Salt Lake City

Route ID	Mode	Route	Return Trip Miles	Expected Fatalities	Expected Injuries	Expected Accidents
3a	H	DCPP-S to PBRY	33	0.002	0.044	0.149
3b	R	PBRY to SLC, UT	1967	0.048	0.563	0.764
3c	W	DCPP to LBP	612	0.000	0.006	0.081
3d	R	LBP to SLC, UT	1582	0.039	0.452	0.615
3e	H	DCPP-N to PBRY	61	0.003	0.081	0.276

The results are summarized in Table 15.

Table 15. Summary of Fatality Risks for Recyclable Metals

Item	Expected Fatalities	Expected Injuries	Expected Accidents
Land Transport via Southern Route	0.050	0.606	0.913
Land Transport via Northern Route	0.051	0.643	1.040
Transport by Water and Land	0.039	0.459	0.696

The risks of land transport via the northern and southern routes are virtually identical, since the difference in length is small compared to the overall length of the route.

The option of using barges for the first leg of the route out of DCPP results in the lowest risks for fatalities, injuries and accidents.

5.1.3 Non-Detect Concrete/Asphalt for Recycling

The conventional transportation risks for recyclable concrete/asphalt to Las vegas are presented in Table 16.

Table 16. Conventional Transportation Risks for Recyclable Concrete/Asphalt to Las Vegas

Route ID	Mode	Route	Return Trip Miles	Expected Fatalities	Expected Injuries	Expected Accidents
2a	H	DCPP-S to Las Vegas	1056	0.065	1.698	5.800
2b	W	DCPP to LBP	612	0.000	0.008	0.098
2c	H	LBP to Las Vegas	588	0.036	0.946	3.230
2d	H	DCPP-N to Las Vegas	1065	0.066	1.713	5.850

The results are summarized in Table 17.

Table 17. Summary of Fatality Risks for Recyclable Concrete/Asphalt

Item	Expected Fatalities	Expected Injuries	Expected Accidents
Land Transport via Southern Route	0.065	1.698	5.800
Land Transport via Northern Route	0.066	1.713	5.850
Transport by Water and Land	0.037	0.953	3.328

The risks of land transport via the northern and southern routes are virtually identical, since the difference in length is small compared to the overall length of the route.

The option of using barges for the first leg of the route out of DCPP results in the lowest risks for fatalities, injuries and accidents.

5.1.4 Other Regulated Wastes

The conventional transportation risks for non-radioactive regulated wastes to Beatty, NV are presented in Table 18.

Table 18. Conventional Transportation Risks for Other Regulated Wastes to Beatty, NV

Route ID	Mode	Route	Return Trip Miles	Expected Fatalities	Expected Injuries	Expected Accidents
10a	H	DCPP-S to Beatty, NV	928	0.022	0.582	1.987
10b	H	DCPP-N to Beatty, NV	999	0.024	0.626	2.139
10c	W	DCPP to LBP	612	0.000	0.003	0.034
10d	H	LBP to Beatty, NV	684	0.017	0.429	1.465

The results are summarized in Table 19.

Table 19. Summary of Fatality Risks for Other Regulated Wastes

Item	Expected Fatalities	Expected Injuries	Expected Accidents
Land Transport via Southern Route	0.022	0.582	1.987
Land Transport via Northern Route	0.024	0.626	2.139
Transport by Water and Land	0.017	0.432	1.499

Risks for transportation via the northern route are about 10% higher than for the southern route, although the absolute risks are low.

The option of using barges for the first leg of the route out of DCPP results in the lowest risks for fatalities, injuries and accidents.

5.1.5 LARW 20.2002 Metals

The conventional transportation risks for LARW Metals to US Ecology, ID are presented in Table 20.

Table 20. Conventional Transportation Risks for LARW Metals to US Ecology, ID

Route ID	Mode	Route	Return Trip Miles	Expected Fatalities	Expected Injuries	Expected Accidents
4a	H	DCPP-S to PBRY	33	0.001	0.033	0.114
4b	R	PBRY to US Ecology, ID	2682	0.050	0.584	0.794
4c	W	DCPP to Boardman, OR	2366	0.001	0.018	0.231
4d	H	Boardman, OR to US Ecology, ID	691	0.027	0.697	2.380
4e	H	DCPP-N to PBRY	61	0.002	0.062	0.210

The results are summarized in Table 21.

Table 21. Summary of Fatality Risks for LARW Metals

Item	Expected Fatalities	Expected Injuries	Expected Accidents
Land Transport via Southern Route	0.051	0.618	0.908
Land Transport via Northern Route	0.052	0.646	1.004
Transport by Water and Land	0.028	0.715	2.611

The risks of land transport via the northern and southern routes are virtually identical, since the difference in length is small compared to the overall length of the route.

The option of using barges for the first leg of the route out of DCPP results in the lowest risk of fatalities. However, expected injuries and accidents are higher for the barging option since this option also includes more trucking miles and more total miles than the land transportation option.

5.1.6 LARW 20.2002 Concrete/Asphalt

The conventional transportation risks for LARW Concrete/Asphalt to US Ecology, ID are presented in Table 22.

Table 22. Conventional Transportation Risks for LARW Concrete/Asphalt to US Ecology, ID

Route ID	Mode	Route	Return Trip Miles	Expected Fatalities	Expected Injuries	Expected Accidents
5a	H	DCPP-S to PBRY	33	0.004	0.107	0.364

Route ID	Mode	Route	Return Trip Miles	Expected Fatalities	Expected Injuries	Expected Accidents
5b	R	PBRY to US Ecology, ID	2682	0.184	2.155	2.927
5c	W	DCPP to Boardman, OR	2366	0.003	0.054	0.677
5d	H	Boardman, OR to US Ecology, ID	691	0.086	2.229	7.613
5e	H	DCPP-N to PBRY	61	0.008	0.197	0.672

The results are summarized in Table 23.

Table 23. Summary of Fatality Risks for LARW Concrete/Asphalt

Item	Expected Fatalities	Expected Injuries	Expected Accidents
Land Transport via Southern Route	0.188	2.262	3.291
Land Transport via Northern Route	0.191	2.352	3.599
Transport by Water and Land	0.089	2.283	8.290

The difference in the risks of land transport via the northern and southern routes is small.

The option of using barges for the first leg of the route out of DCPP results in the lowest fatality risk. The injury risk is comparable across options and the accident risk is higher for the barging option.

5.1.7 Class A Metals

The conventional transportation risks for Class A Metals to Clive, UT are presented in Table 24.

Table 24. Conventional Transportation Risks for Class A Metals to Clive, UT

Route ID	Mode	Route	Return Trip Miles	Expected Fatalities	Expected Injuries	Expected Accidents
6a	H	DCPP-S to PBRY	33	0.001	0.016	0.054
6b	R	PBRY to Clive, UT	2043	0.019	0.223	0.302
6c	W	DCPP to LBP	612	0.000	0.002	0.030
6d	R	LBP to Clive, UT	1658	0.015	0.181	0.245
6e	H	DCPP-N to PBRY	61	0.001	0.029	0.099

The results are summarized in Table 25.

Table 25. Summary of Fatality Risks for Class A Metals

Item	Expected Fatalities	Expected Injuries	Expected Accidents
Land Transport via Southern Route	0.020	0.238	0.356
Land Transport via Northern Route	0.020	0.252	0.402
Transport by Water and Land	0.016	0.183	0.275

The risks of land transport via the northern and southern routes are virtually identical.

The option of using barges for the first leg of the route out of DCPP results in the lowest risks for fatalities, injuries and accidents.

5.1.8 Class A Concrete/Asphalt

The conventional transportation risks for Class A Concrete/Asphalt to Clive, UT are presented in Table 26.

Table 26. Conventional Transportation Risks for Class A Concrete/Asphalt to Clive, UT

Route ID	Mode	Route	Return Trip Miles	Expected Fatalities	Expected Injuries	Expected Accidents
7a	H	DCPP-S to PBRY	33	0.002	0.063	0.214
7b	R	PBRY to Clive, UT	2043	0.083	0.974	1.323
7c	W	DCPP to LBP	612	0.000	0.008	0.102
7d	R	LBP to Clive, UT	1658	0.067	0.790	1.074
7e	H	DCPP-N to PBRY	61	0.004	0.116	0.396

The results are summarized in Table 27.

Table 27. Summary of Fatality Risks for Class A Concrete/Asphalt

Item	Expected Fatalities	Expected Injuries	Expected Accidents
Land Transport via Southern Route	0.085	1.037	1.537
Land Transport via Northern Route	0.087	1.090	1.719
Transport by Water and Land	0.068	0.799	1.176

The difference in the risks of land transport via the northern and southern routes is small.

The option of using barges for the first leg of the route out of DCPP results in the lowest risks for fatalities, injuries and accidents.

5.1.9 Class B&C

The conventional transportation risks for Class B/C Wastes to WCS Texas are presented in Table 28. The "Expected Fatalities" numbers that show as zero in this table are actually not zero but less than 0.001.

Table 28. Conventional Transportation Risks for Class B/C Wastes to WCS Texas

Route ID	Mode	Route	Return Trip Miles	Expected Fatalities	Expected Injuries	Expected Accidents
8a	H	DCPP-S to WCS, TX	2747	0.000	0.009	0.031
8b	H	DCPP-N to WCS, TX	2756	0.000	0.009	0.031
8c	W	DCPP to LBP	612	0.000	0.003	0.038
8d	R	LBP to WCS, TX	2295	0.024	0.281	0.382

The results are summarized in Table 29.

Table 29. Summary of Fatality Risks for Class B/C Wastes

Item	Expected Fatalities	Expected Injuries	Expected Accidents
Land Transport via Southern Route	0.001	0.018	0.062
Land Transport via Northern Route	0.000	0.009	0.031
Transport by Water and Land	0.024	0.284	0.421

Since there are only nine shipments, the conventional transportation fatality risks of truck transport of Class B/C wastes are small. The transportation risks by barge are overestimated since the calculation is performed as if a barge is devoted to a single cask of Class B/C waste. If the same cask were transported by barge to Long Beach Port together with other wastes, the differential risks would be negligible. The same can be said for the rail component of the transport. The calculations are performed as if there are nine trains to WCS Texas, each carrying a single cask.

5.1.10 GTCC and SNF

The conventional transportation risks for GTCC/SNF to the Texas CISF are presented in Table 30. The "Expected Fatalities" numbers that show as zero in this table are actually not zero but less than 0.001.

Table 30. Conventional Transportation Risks for GTCC/SNF to the Texas CISF

Route ID	Mode	Route	Return Trip Miles	Expected Fatalities	Expected Injuries	Expected Accidents
9a	W	DCPP to LBP	612	0.003	0.050	0.632
9b	R	LBP to Texas CISF	2295	0.394	4.626	6.284
9c	H	DCPP-S to PBRY	33	0.000	0.002	0.006
9d	H	DCPP-N to PBRY	61	0.000	0.003	0.011
9e	R	PBRY to Texas CISF	2680	0.460	5.402	7.338

The results are summarized in Table 31.

Table 31. Summary of Fatality Risks for GTCC/SNF

Item	Expected Fatalities	Expected Injuries	Expected Accidents
Land Transport via Southern Route	0.460	5.404	7.344
Land Transport via Northern Route	0.460	5.406	7.349
Transport by Water and Land	0.397	4.676	6.916

The conventional transportation risks for GTCC/SNF are relatively high and reflect the underlying assumption that there will be 148 trains (and 148 barges) each transporting one cask. For barge transport this is a reasonable assumption since SNF transport will continue long after other wastes have been transported, thus eliminating the possibility of sharing the barge with other materials. Further, the fatality risks of barge transport represent only about 1% of the total risk. For rail transport on the other hand, the use of dedicated trains is not intended. No attempt has been made to apportion the fatality risks from a train accident where the DCPP cargo is only one of several cars.

5.1.11 Overall Summary of Conventional Transportation Risk Results

The results of the analysis of conventional transportation risks are summarized in Table 32 for the entire campaign.

The fatality risks of land transportation by the northern route are higher than those for the southern route by either 2.1% or 1.3% depending on whether or not the breakwater is repurposed.

The fatality risks of transport by barge and land are lower than transport by land alone by approximately 25%.

Repurposing of the breakwater results in approximately 20-22% fatality risk reduction for all three of the transportation options.

The combination of using barge transport for the first leg of the route and repurposing the breakwater results in lowering the fatality risks by more than 40%. The corresponding reduction in injury risk is approximately 32%. The overall accident/incident risk is reduced by more than 9%.

Table 32. Overall Summary of Conventional Transportation Risks

Item	**Expected Fatalities**	**Expected Injuries**	**Expected Accidents**
Base Case			
Land Transport via Southern Route	1.252	16.372	28.496
Land Transport via Northern Route	1.279	17.052	30.817
Transport by Water and Land	0.930	13.341	29.384
Breakwater Repurposed			
Land Transport via Southern Route	0.985	13.008	23.077
Land Transport via Northern Route	0.998	13.338	24.202
Transport by Water and Land	0.744	11.141	25.794

5.2 Radiological Risk Results

The radiological risks of the various transportation options are presented in the following sections.

5.2.1 LARW 20.2002 Metals

Risks from Incident Free Transportation

The radiological risks from incident free transportation of LARW metals are presented for all of the routes in Table 33. A summary of the doses and the LCF for the transportation options is presented in Table 34. It can be seen that the dose to the maximally exposed individual is several orders of magnitude lower than the limit for public exposure.

Risks due to land transport by the northern and southern routes are virtually identical. Risks for the barging option are approximately half those of land only transport.

Sensitivity Cases

The modeling of the incident free radiological risks assumes that the package meets the regulatory limits of exposure at 2 m. Using this method, the radiological risks of incident free transport are the same no matter the level of activity in the materials being transported. It is possible that the incident free radiological risks have been overestimated in this study for the sensitivity cases with the very lowest activity levels.

Risks from Truck and Rail Accidents

The consequences and risks from accidental releases of materials during transportation of LARW metals, by land, are presented in Table 35. Both the consequences and the risks from such releases are extremely low.

Sensitivity Cases

The radiological risks from accidental releases is proportional to the activity levels of the material being transported. The results in Table 35 would therefore be divided by 10 and 100 respectively for activity levels that are 1% and 0.1% of Class A limits. Since the base case consequences and risks are low, separate tables for the sensitivity cases are not presented.

Risks from Barge Accidents

The barge route for LARW metals traverses both coastal waters and the Columbia River. The radiation dose to the MEI in coastal waters is strongly influenced by the distance to the shore and hence varies by several orders of magnitude along the route. The greater the distance to the shore the lower the risk to the MEI. If the accident occurs close to shore (near the origin or destination), the risk is greater. However, close to shore, the chances of successful salvage increase due to the decreased water depths.

The individual dose values in rem per year are presented below in Figure 17. It should be noted that these values are for the loss of 100% of the cargo and dispersal of 100% of the activity in a period of 1 year. The dose values are several orders of magnitude lower than the limit for public exposure from licensed nuclear power plant operation, as well as background radiation levels.

Table 33. Incident Free Radiation Dose Details for Transportation of LARW Metals

				Collective Dose (Person-rem)								
Route ID	**Mode**	**Number of Shipments/ Trains/ Barges**	**Route**	**Population Dose Off Road**	**Population Dose On Road**	**Crew Dose**	**Rail Yard Dose**	**Stop Doses - No Release (per Stop)**	**Stop Doses - Responder (per Stop)**	**Stop Doses - Classification (per Trip)**	**Stop Doses - Inspector (per Trip)**	**MEI Dose per Trip (mrem)**
4a	H	2755	DCPP-S to PBRY	3.2E-01	1.4E+00	3.5E+00		4.7E-04	1.7E-01			6.9E-04
4b	R	16	PBRY to US Ecology, ID	2.5E+01	9.5E+00	2.1E+03	2.9E+01	4.6E+01	9.2E+00	4.3E-03	3.7E+00	6.9E-02
4c	W	14	DCPP to Boardman, OR	9.0E-01	1.2E+01	7.6E-02		2.9E-03	6.4E-02			
4d	H	2755	Boardman, OR to US Ecology, ID	4.0E+00	2.7E+01	9.5E+01		4.4E-02	1.7E-01			6.9E-04
4e	H	2755	DCPP-N to PBRY	1.2E+00	3.2E+00	6.1E+00		3.3E-02	1.7E-01			6.9E-04

Table 34. Summary of Incident Free Radiological Risks for Transportation of LARW Metals

Item	**MEI Dose (mrem)**	**Occupational Collective Dose (person-rem)**	**Public Collective Dose (person-rem)**	**Occupational Latent Cancer Fatalities**	**Public Latent Cancer Fatalities**
Land Transport via Southern Route	6.9E-02	2.2E+03	3.7E+01	8.9E-01	2.0E-02
Land Transport via Northern Route	6.9E-02	2.2E+03	3.9E+01	9.0E-01	2.2E-02
Transport by Water and Land	6.9E-04	9.5E+01	4.4E+01	3.9E-02	2.4E-02

Table 35. Radiological Risks for Accidents during Land Transportation of LARW Metals

Route ID	Mode	Type of Package	Number of Shipments/ Trains/ Barges	Route	Population Dose Risk for the Worst Accident (Person-rem)	MEI Dose (Consequence) (mrem)
4a	H	IMC with Liner	2755	DCPP-S to PBRY	3.4E-08	7.0E-04
4b	R	IMC with Liner	16	PBRY to US Ecology, ID	3.4E-07	4.2E-03
4c	W	IMC with Liner on Barge	14	DCPP to Boardman, OR		
4d	H	IMC with Liner	2755	Boardman, OR to US Ecology, ID	1.4E-07	7.0E-04
4e	H	IMC with Liner	2755	DCPP-N to PBRY	9.1E-08	7.0E-04

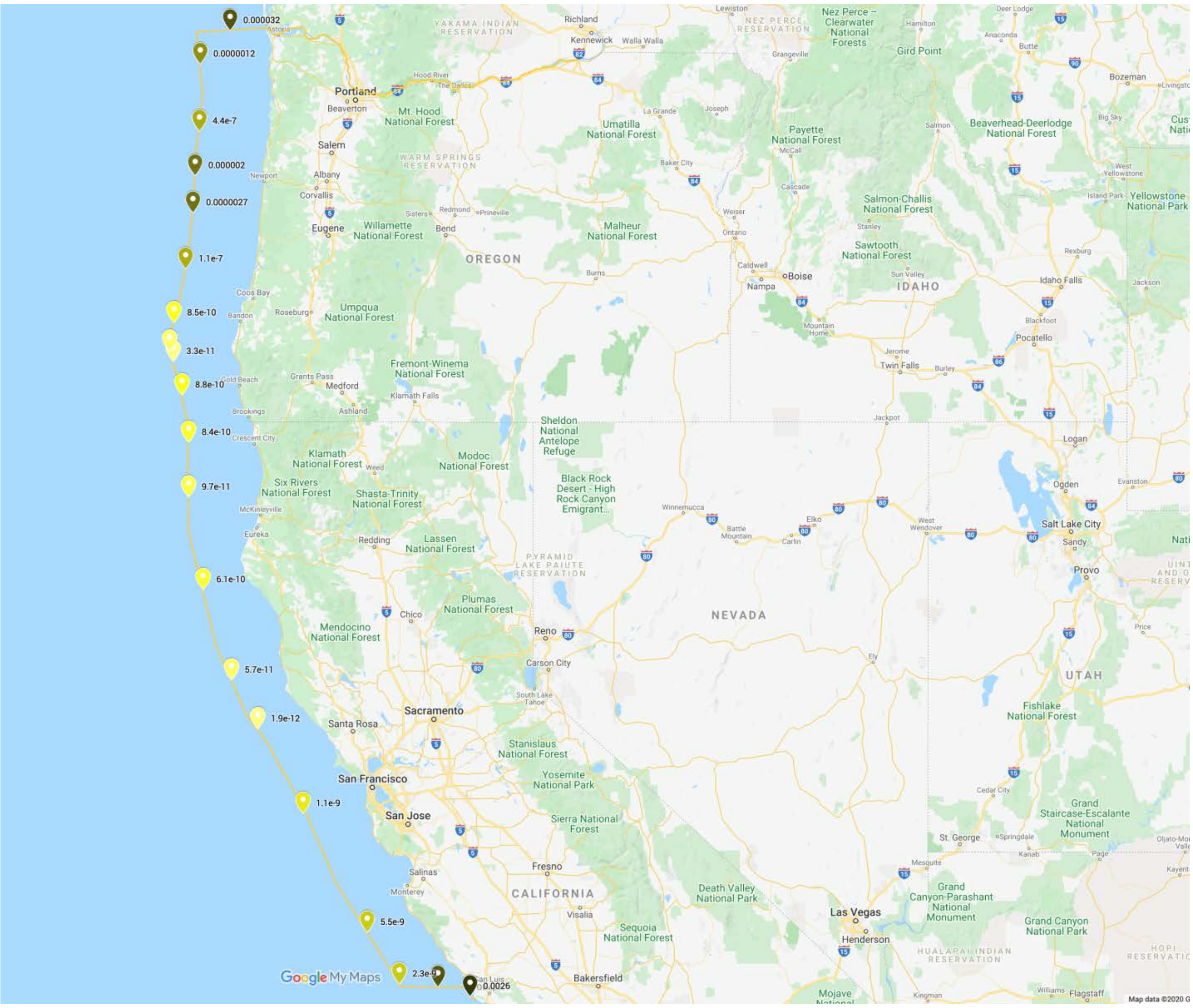

Figure 17. Individual Dose to MEI (rem/yr) along Coastal Route for LARW with Activity Levels at 10% of Class A Limits

The collective dose risk (dose multiplied by probability) to the public is presented below in Table 36. It can be seen that these values are very small.

Table 36. Collective Dose Risk to Public for Coastal Section of Barge Route to Boardman, OR

Fraction of Class A Limit Activity	LARW Metal Collective Dose Risk/Trip (person-rem/yr)	LARW Metal Collective Dose Risk (person-rem/yr)
10.0%	5.27E-06	7.38E-05
1.0%	5.27E-07	7.38E-06
0.1%	5.27E-08	7.38E-07

The individual dose to the MEI along the Columbia River is presented in Table 37. In case the activity level of the LARW is as high as 10% of Class A limits, the individual dose to the MEI would exceed the limits set for exposure to members of the public, but would still be below the average background radiation level.

Table 37. Individual Dose to MEI on the Columbia River for LARW Metal

Fraction of Class A Limit Activity	**Individual Dose for Loss of 100% of Cargo (mrem/yr)**	**Individual Dose for Loss of 20% of Cargo (mrem/yr)**
10.0%	348	70.2
1.0%	34.8	7.0
0.1%	3.48	0.7

The probability of an accident that results in any loss of cargo is 9.1E-04 on the river.

Collective doses are not estimated for the river portion of the river due to the difficulty of estimating the exposed populations[11]. The contribution of the different pathways is presented in Figure 18. In Figure 18, E_in_shore refers to ingestion of sediments on the riverbank, E_inh_shore refers to inhalation of particles on the riverbank, E_ext refers to exposure to sediments on the banks, E_ing_water refers to ingestion of water, E_ing_crop refers to ingestion of crops, E_ing_milk refers to ingestion of milk, E_ing_meat refers to ingestion of meat and E_ing_fish refers to ingestion of fish. A review of the contribution of the different exposure pathways to the MEI dose suggests that the exposure is unlikely to be localized.

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[11] The entire river downstream of the accident location is impacted.

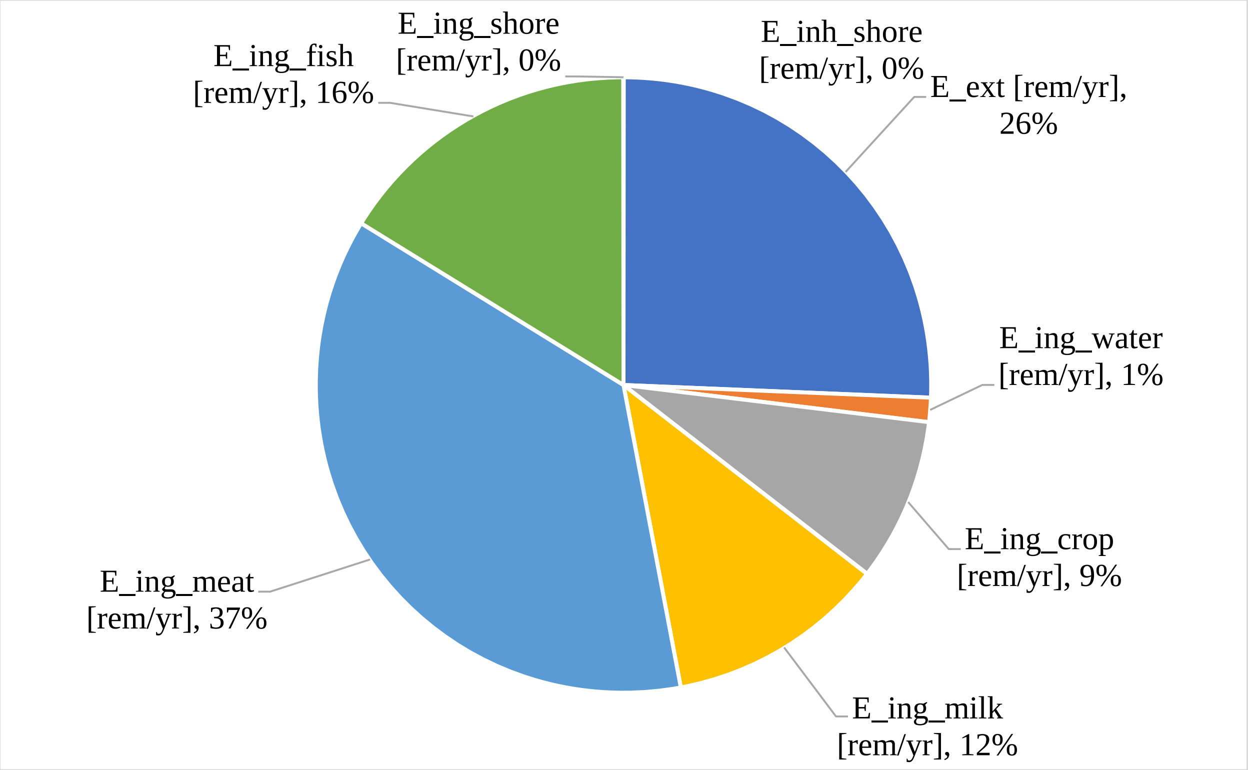

Figure 18. Contribution of Exposure Pathways to MEI Dose

5.2.2 LARW 20.2002 Concrete/Asphalt

Risks from Incident Free Transportation

The radiological risks from incident free transportation of LARW concrete/asphalt are presented for all of the routes in Table 38. A summary of the doses and the LCF for the transportation options is presented in Table 39. It can be seen that the dose to the maximally exposed individual is several orders of magnitude lower than the limit for public exposure.

Risks due to land transport by the northern and southern routes are virtually identical. Risks for the barging option are a small fraction of those for land only transport.

Sensitivity Cases

The modeling of the incident free radiological risks assumes that the package meets the regulatory limits of exposure at 2 m. Using this method, the radiological risks of incident free transport are the same no matter the level of activity in the materials being transported.

Risks from Truck and Rail Accidents

The consequences and risks from accidental releases of materials during transportation of LARW metals are presented in Table 40. Both the consequences and the risks from such releases are extremely low.

Sensitivity Cases

The radiological risks from accidental releases are proportional to the activity levels of the material being transported. The results in Table 40 would therefore be divided by 10 and 100, respectively, for activity levels that are 1% and 0.1% of Class A limits. Since the base case consequences and risks are low, separate tables for the sensitivity cases are not presented.

Table 38. Incident Free Radiation Dose Details for Transportation of LARW Concrete/Asphalt

				Collective Dose (Person-rem)								
Route ID	**Mode**	**Number of Shipments/ trains/ barges**	**Route**	**Population Dose Off Road**	**Population Dose On Road**	**Crew Dose**	**Rail Yard Dose**	**Stop Doses - No Release (per Stop)**	**Stop Doses - Responder (per Stop)**	**Stop Doses - Classification (per Trip)**	**Stop Doses - Inspector (per Trip)**	**MEI Dose per Trip (mrem)**
5a	H	8814	DCPP-S to PBRY	1.0E+00	4.4E+00	1.1E+01		4.7E-04	1.7E-01			6.9E-04
5b	R	59	PBRY to US Ecology, ID	9.2E+01	1.8E+01	7.7E+03	4.4E-02	3.7E+00	9.2E+00	4.3E-03	3.7E+00	6.9E-02
5c	W	41	DCPP to Boardman, OR	5.4E+00	7.0E+01	4.5E-01		5.8E-03	1.3E-01			
5d	H	8814	Boardman, OR to US Ecology, ID	1.3E+01	1.2E+02	1.5E+02		2.1E-01	1.7E-01			6.9E-04
5e	H	8814	DCPP-N to PBRY	4.0E+00	1.0E+01	2.0E+01		1.5E-01	1.7E-01			6.9E-04

Table 39. Summary of Incident Free Radiological Risks for Transportation of LARW Concrete/Asphalt

Item	**MEI Dose (mrem)**	**Occupational Collective Dose (person-rem)**	**Public Collective Dose (person-rem)**	**Occupational Latent Cancer Fatalities**	**Public Latent Cancer Fatalities**
Land Transport via Southern Route	6.9E-02	7.9E+03	1.2E+02	3.2E+00	6.3E-02
Land Transport via Northern Route	6.9E-02	7.9E+03	1.2E+02	3.3E+00	6.8E-02
Transport by Water and Land	6.9E-04	1.5E+02	2.1E+02	6.2E-02	1.1E-01

Table 40. Radiological Risks for Accidents during Land Transportation of LARW Concrete/Asphalt

Route ID	Mode	Type of Package	Number of Shipments/ Trains/ Barges	Route	Population Dose Risk for the Worst Accident (Person-rem)	MEI Dose (Consequence) (mrem)
5a	H	IP-1 in IMC	8814	DCPP-S to PBRY	1.1E-07	7.0E-04
5b	R	IP-1 in Gondola	59	PBRY to US Ecology, ID	7.6E-07	3.5E-03
5c	W	IP-1 on Barge	41	DCPP to Boardman, OR		
5d	H	IP-1 in IMC	8814	Boardman, OR to US Ecology, ID	4.5E-07	7.0E-04
5e	H	IP-1 in IMC	8814	DCPP-N to PBRY	3.7E-07	7.0E-04

Risks from Barge Accidents

The barge route for LARW concrete/asphalt is the same as that for LARW metals.

For the coastal portion of the route, the dose values to the MEI for the loss of 100% of the cargo and dispersal of 100% of the activity in a period of 1 year are similar to those presented in Figure 17. The dose values are several orders of magnitude lower than the limit for public exposure, as well as background radiation levels.

The collective dose risk (dose multiplied by population) to the public is presented below in Table 41. It can be seen that these values are very small.

Table 41. Collective Dose Risk for Coastal Section of Barge Route to Boardman, OR for LARW Concrete/Asphalt

Fraction of Class A Limit Activity	**Collective Dose Risk/Trip (person-rem/yr)**	**Collective Dose Risk (person-rem/yr)**
10.0%	1.76E-05	7.22E-04
1.0%	1.76E-06	7.22E-05
0.1%	1.76E-07	7.22E-06

The individual dose to the MEI along the Columbia River is presented in Table 42. In case the activity level of the LARW is as high as 10% of Class A limits, the individual dose to the MEI would exceed the limits set for exposure to members of the public, but it would still be below the average background radiation level.

Table 42. Individual Dose to MEI on the Columbia River for LARW Concrete/Asphalt

Fraction of Class A Limit Activity	**Individual Dose for Loss of 100% of Cargo (mrem/yr)**
10.0%	379
1.0%	37.9
0.1%	3.79

The probability of an accident that results in any loss of cargo is 2.7E-03 on the river.

Collective doses are not estimated for the river portion of the river due to the difficulty of estimating the exposed populations.

In the event the LARW activity payload is at the high end of the considered cases, it would be advisable to reconsider the barging of LARW concrete/asphalt in IP-1 bags up the Columbia River. Alternatives would be to:

1. Consider using IMC with liner, thereby increasing the chances of salvage
2. Consider barging to some other coastal port in Oregon instead of Boardman

3. Consider barging to Long Beach Port and then transporting to the same destination (this would result in a longer land transport route)
4. Consider barging to Long Beach Port to an alternate closer destination

The differences between LARW metals and LARW concrete/asphalt in terms of accidental risks are:

- Robustness of packaging and hence possibility of salvage. It is expected that the event tree conditional probabilities for the metals are conservative.
- The modeling assumption of dispersal of entire quantity of release activity over a year is likely more conservative for the metals than for the concrete/asphalt.

5.2.3 Class A Metals

Risks from Incident Free Transportation

The radiological risks from incident free transportation of Class A metals are presented for all of the routes in Table 43. A summary of the doses and the LCF for the transportation options is presented in Table 44. It can be seen that the dose to the maximally exposed individual is several orders of magnitude lower than the limit for public exposure.

Risks due to land transport by the northern and southern routes are virtually identical. Risks for the barging option are approximately half those of land only transport.

Sensitivity Case

The modeling of the incident free radiological risks assumes that the package meets the regulatory limits of exposure at 2 m. Using this method, the radiological risks of incident free transport are the same no matter the level of activity in the materials being transported.

Risks from Truck and Rail Accidents

The consequences and risks from accidental releases of materials during transportation of Class A metals are presented in Table 45. Both the consequences and the risks from such releases are extremely low.

Sensitivity Cases

The radiological risks from accidental releases are proportional to the activity levels of the material being transported. The results in Table 45 would therefore be divided by 10 for activity levels that are 10% of Class A limits. Since the base case consequences and risks are low, a separate table for the sensitivity case is not presented.

Table 43. Incident Free Radiation Dose Details for Transportation of Class A Metals

				Collective Dose (Person-rem)								
Route ID	**Mode**	**Number of Shipments/ trains/ barges**	**Route**	**Population Dose Off Road**	**Population Dose On Road**	**Crew Dose**	**Rail Yard Dose**	**Stop Doses - No Release (per Stop)**	**Stop Doses - Responder (per Stop)**	**Stop Doses - Classification (per Trip)**	**Stop Doses - Inspector (per Trip)**	**MEI Dose per Trip (mrem)**
6a	H	1304	DCPP-S to PBRY	1.5E-01	6.5E-01	1.7E+00		4.7E-04	1.7E-01			6.9E-04
6b	R	8	PBRY to Clive, UT	9.6E+00	2.1E+00	8.7E+02	1.1E+01	1.4E+01	9.2E+00	4.3E-03	5.5E+00	6.9E-02
6c	W	7	DCPP to LBP	4.0E-03	1.6E+00	1.1E-02		1.6E-02	6.6E-02			
6d	R	8	LBP to Clive, UT	3.7E+00	5.9E-01	5.0E+02	9.0E+00	1.8E+01	9.2E+00	4.3E-03	5.5E+00	6.9E-02
6e	H	1304	DCPP-N to PBRY	5.9E-01	1.5E+00	2.9E+00		1.5E-01	1.7E-01			6.9E-04

Table 44. Summary of Incident Free Radiological Risks for Transportation of Class A Metals

Item	**MEI Dose (mrem)**	**Occupational Collective Dose (person-rem)**	**Public Collective Dose (person-rem)**	**Occupational Latent Cancer Fatalities**	**Public Latent Cancer Fatalities**
Land Transport via Southern Route	6.9E-02	9.2E+02	1.3E+01	3.8E-01	6.9E-03
Land Transport via Northern Route	6.9E-02	9.2E+02	1.4E+01	3.8E-01	7.6E-03
Transport by Water and Land	6.9E-02	5.6E+02	5.9E+00	2.3E-01	3.2E-03

Table 45. Radiological Risks for Accidents during Land Transportation of Class A Metals

Route ID	Mode	Type of Package	Number of Shipments/ Trains/ Barges	Route	Population Dose Risk for the Worst Accident (Person-rem)	MEI Dose (Consequence) (mrem)
6a	H	IMC with Liner	1304	DCPP-S to PBRY	1.6E-07	7.0E-03
6b	R	IMC with Liner	8	PBRY to Clive, UT	1.3E-05	4.2E-02
6c	W	IMC with Liner on Barge	7	DCPP to LBP		
6d	R	IMC with Liner	8	LBP to Clive, UT	5.6E-06	4.2E-02
6e	H	IMC with Liner	1304	DCPP-N to PBRY	5.5E-07	7.0E-03

Risks from Barge Accidents

The barge route for Class A metals is limited to coastal waters. The individual dose to the MEI is presented on the route in Figure 19. The individual dose to the MEI is lower than the regulatory limit for public exposure.

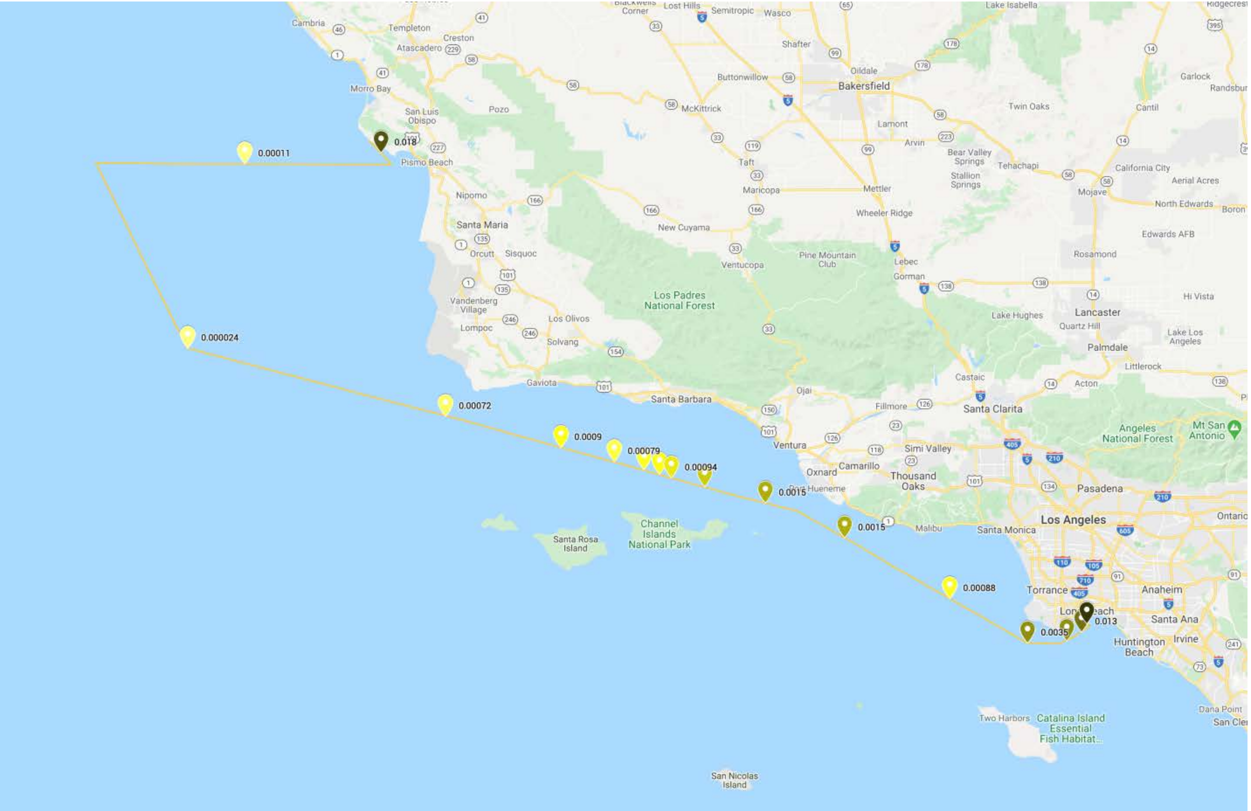

Figure 19. Individual Dose to MEI (rem/yr) for Class A Metals

The collective dose risk is presented below in Table 46.

Table 46. Collective Dose Risk to Public for Class A Metals

Fraction of Class A Limit Activity	Collective Dose Risk/Trip (person-rem/yr)	Collective Dose Risk (person-rem/yr)
100.0%	1.01E-04	7.08E-04
10.0%	1.01E-05	7.08E-05

The collective dose risk numbers are very low.

5.2.4 Class A Concrete/Asphalt

Risks from Incident Free Transportation

The radiological risks from incident free transportation of Class A concrete/asphalt are presented for all of the routes in Table 47. A summary of the doses and the LCF for the transportation options is presented in Table 48. It can be seen that the dose to the maximally exposed individual is several orders of magnitude lower than the limit for public exposure. Risks due to land transport by the northern and southern routes are virtually identical. Risks for the barging option are approximately 58% of those for land only transport.

Sensitivity Case

The modeling of the incident free radiological risks assumes that the package meets the regulatory limits of exposure at 2 m. Using this method, the radiological risks of incident free transport are the same no matter the level of activity in the materials being transported.

Risks from Truck and Rail Accidents

The consequences and risks from accidental releases of materials during transportation of Class A metals are presented in Table 49. Both the consequences and the risks from such releases are extremely low.

Sensitivity Cases

The radiological risks from accidental releases are proportional to the activity levels of the material being transported. The results in Table 49 would therefore be divided by 10 for activity levels that are 10% of Class A limits. Since the base case consequences and risks are low, a separate table for the sensitivity case is not presented.

Table 47. Incident Free Radiation Dose Details for Transportation of Class A Concrete/Asphalt

				Collective Dose (Person-rem)								
Route ID	**Mode**	**Number of Shipments/ trains/ barges**	**Route**	**Population Dose Off Road**	**Population Dose On Road**	**Crew Dose**	**Rail Yard Dose**	**Stop Doses - No Release (per Stop)**	**Stop Doses - Responder (per Stop)**	**Stop Doses - Classification (per Trip)**	**Stop Doses - Inspector (per Trip)**	**MEI Dose per Trip (mrem)**
7a	H	5191	DCPP-S to PBRY	6.1E-01	2.6E+00	6.6E+00		4.7E-04	1.7E-01			6.9E-04
7b	R	35	PBRY to Clive, UT	4.3E+01	9.3E+00	3.8E+03	4.9E+01	2.2E+01	9.2E+00	4.3E-03	5.5E+00	6.9E-02
7c	W	24	DCPP to LBP	1.3E-02	4.7E+00	3.3E-02		1.6E-02	6.6E-02			
7d	R	35	LBP to Clive, UT	1.6E+01	2.6E+00	2.2E+03	3.9E+01	1.8E+01	9.2E+00	4.3E-03	5.5E+00	6.9E-04
7e	H	5191	DCPP-N to PBRY	2.7E+00	6.0E+00	1.2E+01		1.5E-01	1.7E-01			6.9E-02

Table 48. Summary of Incident Free Radiological Risks for Transportation of Class A Concrete/Asphalt

Item	**MEI Dose per Trip (mrem)**	**Occupational Collective Dose (person-rem)**	**Public Collective Dose (person-rem)**	**Occupational Latent Cancer Fatalities**	**Public Latent Cancer Fatalities**
Land Transport via Southern Route	6.9E-02	4.1E+03	5.5E+01	1.7E+00	3.0E-02
Land Transport via Northern Route	6.9E-02	4.1E+03	6.1E+01	1.7E+00	3.3E-02
Transport by Water and Land	6.9E-02	2.4E+03	2.3E+01	1.0E+00	1.3E-02

Table 49. Radiological Risks for Accidents during Land Transportation of Class A Concrete/Asphalt

Route ID	Mode	Type of Package	Number of Shipments/ trains/ barges	Route	Population Dose Risk for the Worst Accident (Person-rem)	MEI Dose (Consequence) (mrem)
7a	H	IP-1 in IMC	5191	DCPP-S to PBRY	6.4E-07	7.0E-03
7b	R	IP-1 in Gondola	35	PBRY to Clive, UT	4.5E-06	3.5E-02
7c	W	IP-1 on Barge	24	DCPP to LBP		
7d	R	IP-1 in Gondola	35	LBP to Clive, UT	1.5E-05	3.5E-02
7e	H	IP-1 in IMC	5191	DCPP-N to PBRY	2.2E-06	7.0E-03

Risks from Barge Accidents

The barge route for Class A concrete/asphalt is the same as for metals. The individual dose to the MEI is very similar to those presented on the route in Figure 19. The individual dose to the MEI is lower than the regulatory limit for public exposure.

The collective dose risk is presented below in Table 50.

Table 50. Collective Dose Risk to Public for Class A Concrete/Asphalt

Fraction of Class A Limit Activity	Collective Dose Risk/Trip (person-rem/yr)	Collective Dose Risk (person-rem/yr)
100.0%	1.91E-04	4.59E-03
10.0%	1.91E-05	4.59E-04

The collective dose risk numbers are not significant.

5.2.5 Class B&C

Risks from Incident Free Transportation

The radiological risks from incident free transportation of Class B/C Wastes are presented for all of the routes in Table 51. A summary of the doses and the LCF for the transportation options is presented in Table 52. It can be seen that the dose to the maximally exposed individual is several orders of magnitude lower than the limit for public exposure.

The routes selected by webTRAGIS for Class B/C wastes for direct trucking are different depending on whether the northern or southern exit is selected. The risks for the northern route are less than half those for the southern route, but the contribution of Class B/C waste to the overall risk is small since the total number of shipments is small. Risks for the barging option are approximately four times those for land only transport.

Risks from Truck and Rail Accidents

The consequences and risks from accidental releases of materials during transportation of Class B/C wastes is presented in Table 53. Both the consequences and the risks from such releases are extremely low.

Table 51. Incident Free Radiation Dose Details for Transportation of Class B/C Wastes

				Collective Dose (Person-rem)								
Route ID	**Mode**	**Number of Shipments/ trains/ barges**	**Route**	**Population Dose Off Road**	**Population Dose On Road**	**Crew Dose**	**Rail Yard Dose**	**Stop Doses - No Release (per Stop)**	**Stop Doses - Responder (per Stop)**	**Stop Doses - Classification (per Trip)**	**Stop Doses - Inspector (per Trip)**	**MEI Dose per Trip (mrem)**
8a	H	9	DCPP-S to WCS, TX	7.39E-02	9.64E-01	1.37E+00		1.3E+00	1.7E-01			6.9E-04
8b	H	9	DCPP-N to WCS, TX	7.6E-02	9.0E-01	1.4E+00		1.3E+00	1.7E-01			6.9E-04
8c	W	9	DCPP to LBP	1.0E-02	3.5E+00	2.5E-02		1.6E-02	6.4E-02			
8d	R	9	LBP to WCS, TX	6.7E-02	9.5E+00	6.6E+00	2.6E-01	1.8E-01	1.7E-01	4.2E-05	1.0E-01	6.9E-04

Table 52. Summary of Incident Free Radiological Risks for Transportation of Class B/C Wastes

Item	**MEI Dose per Trip (mrem)**	**Occupational Collective Dose (person-rem)**	**Public Collective Dose (person-rem)**	**Occupational Latent Cancer Fatalities**	**Public Latent Cancer Fatalities**
Land Transport via Southern Route	6.9E-04	1.4E+00	1.0E+00	5.6E-04	5.7E-04
Land Transport via Northern Route	6.9E-04	1.4E+00	9.7E-01	5.6E-04	5.3E-04
Transport by Water and Land	6.9E-04	7.8E+00	1.3E+01	3.2E-03	7.2E-03

Table 53. Radiological Risks for Accidents during Land Transportation of Class B/C Wastes

Route ID	Mode	Type of Package	Number of Shipments/ Trains/ Barges	Route	Population Dose Risk for the Worst Accident (Person-rem)	MEI Dose (Consequence) (mrem)
8a	H	8-120B Cask	9	DCPP-S to WCS, TX	8.6E-08	3.4
8b	H	8-120B Cask	9	DCPP-N to WCS, TX	8.7E-08	3.4
8c	W	8-120B Cask	9	DCPP to LBP		
8d	R	8-120B Cask	9	LBP to WCS, TX	2.2E-07	3.4

Risks from Barge Accidents

The barge route for Class B/C casks is limited to coastal waters. The individual dose to the MEI is presented on the route in Figure 20. The individual dose to the MEI is significantly lower than the regulatory limit for public exposure.

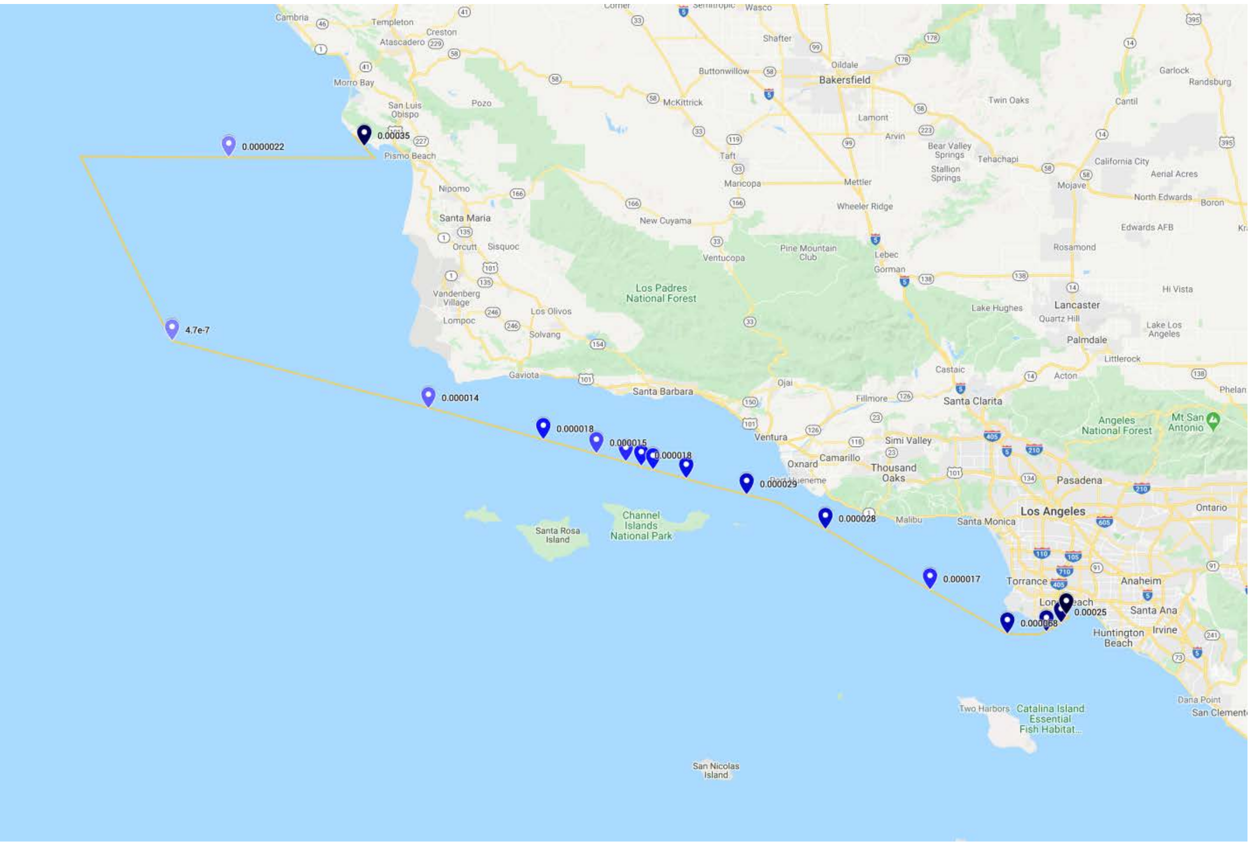

Figure 20. Individual Dose to MEI (rem/yr) for Class B/C Wastes

The collective dose risk is presented below in Table 54.

Table 54. Collective Dose Risk to Public for Class B/C Wastes

Collective Dose Risk/Trip (person-rem/yr)	Collective Dose Risk (person-rem/yr)
8.89E-08	8.00E-07

The collective dose risk numbers are very low.

Loss of Shielding Events

The consequences and risks of loss of shielding events are presented in Appendix D. Several low probability events were assessed and the resulting dose consequences and risks are quite low.

5.2.6 GTCC and SNF

Risks from Incident Free Transportation

The radiological risks from incident free transportation of GTCC/SNF are presented for all of the routes in Table 55. A summary of the doses and the LCF for the transportation options is presented in Table 56. It can be seen that the dose to the maximally exposed individual is several orders of magnitude lower than the limit for public exposure.

Risks due to land transport by the northern and southern routes are virtually identical. Risks for the barging option are approximately 10% of those for land only transport.

Risks from Truck and Rail Accidents

No accidental risks have been modeled for GTCC/SNF for land transport.

Table 55. Incident Free Radiation Dose Details for Transportation of GTCC/SNF

				Collective Dose (Person-rem)								
Route ID	**Mode**	**Number of Shipments/ trains/ barges**	**Route**	**Population Dose Off Road**	**Population Dose On Road**	**Crew Dose**	**Rail Yard Dose**	**Stop Doses - No Release (per Stop)**	**Stop Doses - Responder (per Stop)**	**Stop Doses - Classification (per Trip)**	**Stop Doses - Inspector (per Trip)**	**MEI Dose per Trip (mrem)**
9a	W	148	DCPP to LBP	1.1E-01	4.3E+01	3.0E-01		3.2E-04	4.9E-02			
9b	R	148	LBP to Texas CISF	6.8E-01	1.1E-01	3.0E-02	2.7E+00	1.0E-02	1.2E-01	2.7E-05	6.9E-02	4.4E-04
9c	H	148	DCPP-S to PBRY	1.3E-02	8.0E-02	2.6E-01		1.9E-02	1.2E-01			4.4E-04
9d	H	148	DCPP-N to PBRY	4.1E-02	2.1E-01	9.8E-01		1.0E-01	1.2E-01			4.4E-04
9e	R	148	PBRY to Texas CISF	1.4E+00	2.9E-01	4.8E-02	3.0E+00	2.4E-02	1.2E-01	2.7E-05	6.9E-02	4.4E-04

Table 56. Summary of Incident Free Radiological Risks for Transportation of GTCC/SNF

Item	**MEI Dose per Trip (mrem)**	**Occupational Collective Dose (person-rem)**	**Public Collective Dose (person-rem)**	**Occupational Latent Cancer Fatalities**	**Public Latent Cancer Fatalities**
Land Transport via Southern Route	4.4E-04	1.4E+01	1.7E+00	5.5E-03	9.6E-04
Land Transport via Northern Route	4.4E-04	1.4E+01	1.9E+00	5.8E-03	1.0E-03
Transport by Water and Land	4.4E-04	1.3E+01	4.4E+01	5.4E-03	2.4E-02

Risks from Barge Accidents

The barge route for GTCC/SNF casks is limited to coastal waters. The individual dose to the MEI is presented on the route in Figure 21. The individual dose to the MEI is significantly lower than the regulatory limit for public exposure.

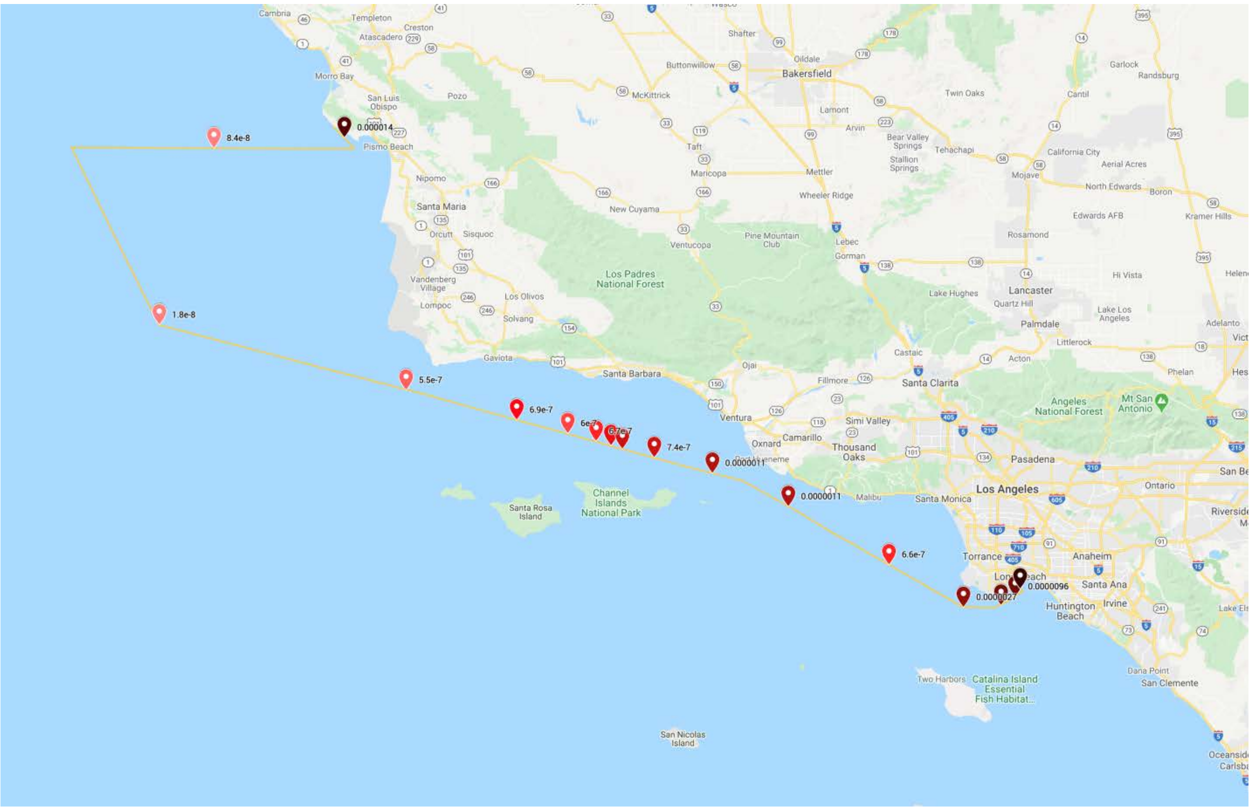

Figure 21. Individual Dose to MEI (rem/yr) for GTCC/SNF

The collective dose risk is presented below in Table 57.

Table 57. Collective Dose Risk to Public for GTCC/SNF

Collective Dose Risk/Trip (person-rem/yr)	**Collective Dose Risk (person-rem/yr)**
3.04E-09	4.51E-07

The collective dose risk numbers are very low.

5.2.7 Summary of Radiological Risk Results

The incident free radiological risks estimated in this study are summarized in Table 58. The risks for the northern and southern routes are virtually identical. Risks for the barge transportation option are about 78% lower. Most of the difference can be attributed to the lower occupational risks of transporting LARW.

Table 58. Incident Free Radiological Risks Summed By Transportation Option

Item	MEI Dose per Trip (mrem)	Occupational Collective Dose (person-rem)	Public Collective Dose (person-rem)	Occupational Latent Cancer Fatalities	Public Latent Cancer Fatalities
Land Transport via Southern Route	6.9E-02	1.5E+04	2.2E+02	6.2E+00	1.2E-01
Land Transport via Northern Route	6.9E-02	1.5E+04	2.4E+02	6.2E+00	1.3E-01
Transport by Water and Land	6.9E-02	3.3E+03	3.4E+02	1.3E+00	1.9E-01

6 Conclusions and Interpretation of the Results

6.1 Conventional Transportation Risks

The conventional risks of transportation are presented graphically in Figures 22 and 23 for the cases including and excluding breakwater removal, respectively. Land transport using the northern route results in higher risks than if using the southern route, but the difference is small. Repurposing of the breakwater results in a significant decrease in risk and should be considered, if feasible.

The lowest risks for conventional transportation are for barging. The fatality rates for barging per mile are of the same order of magnitude as for trucking, but a barge carries approximately 200 times the material that a truck carries. Second to barging for conventional risks is rail transport. On a per mile basis rail transport fatality rates are much higher than those for trucking, but the fact that a train will carry 150 or 180 times the material as a truck tips the balance in favor of rail over trucking.

The large contribution of the SNF casks is an artifact of the assessment method, whereby all of the fatality risks of rail transport for a train with many cars are assigned to the SNF cask. The same error is embedded in the calculated risks for the Class B/C wastes, but the number of shipments is only 9 vs. 148 for SNF.

The combination of using barge transport for the first leg of the route and repurposing the breakwater results in lowering the fatality risks by more than 40%. The corresponding reduction in injury risk is approximately 32%. The overall accident/incident risk is reduced by more than 9%.

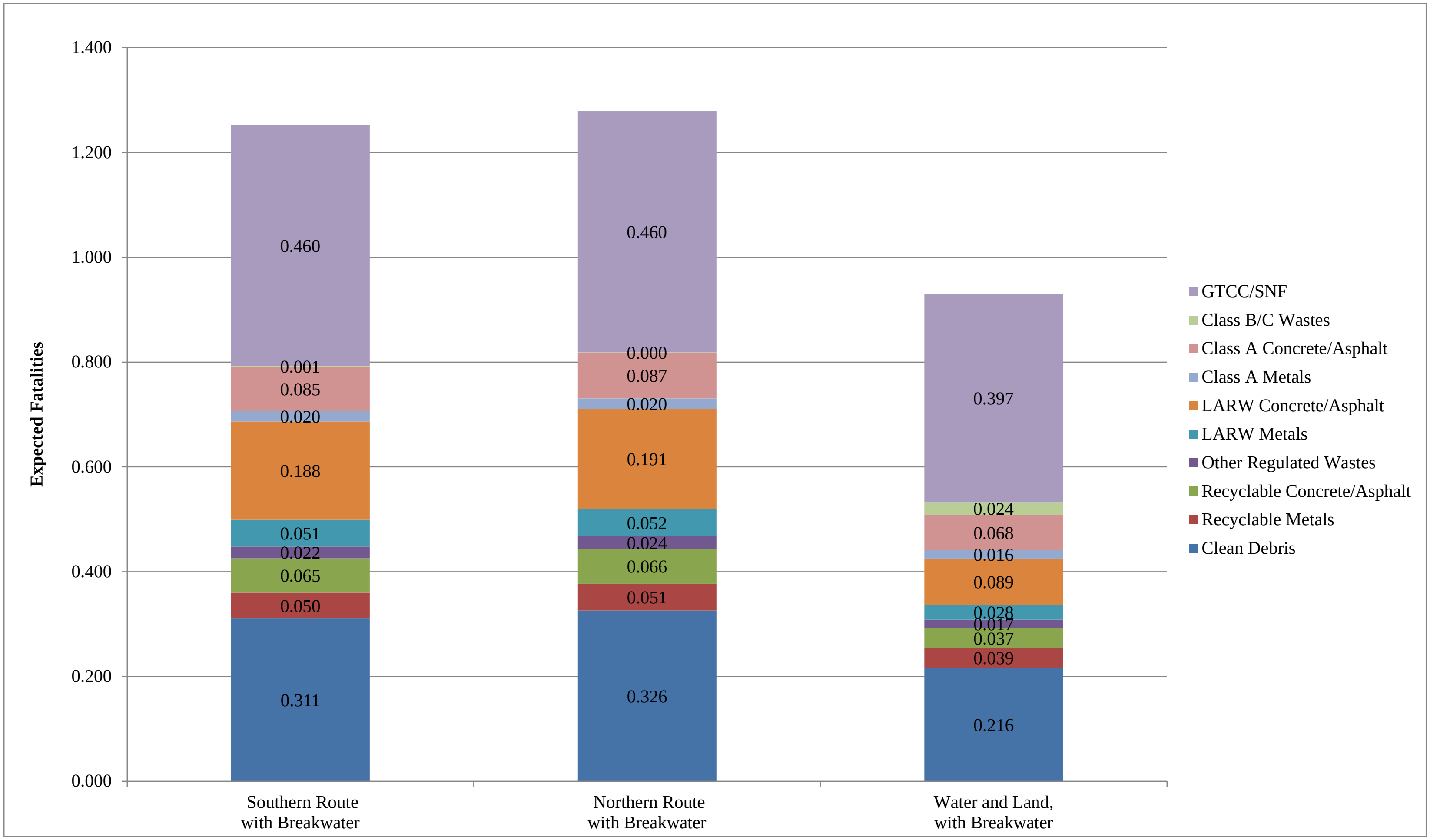

Figure 22. Conventional Risks of Transportation for Base Case (Includes Breakwater Removal)

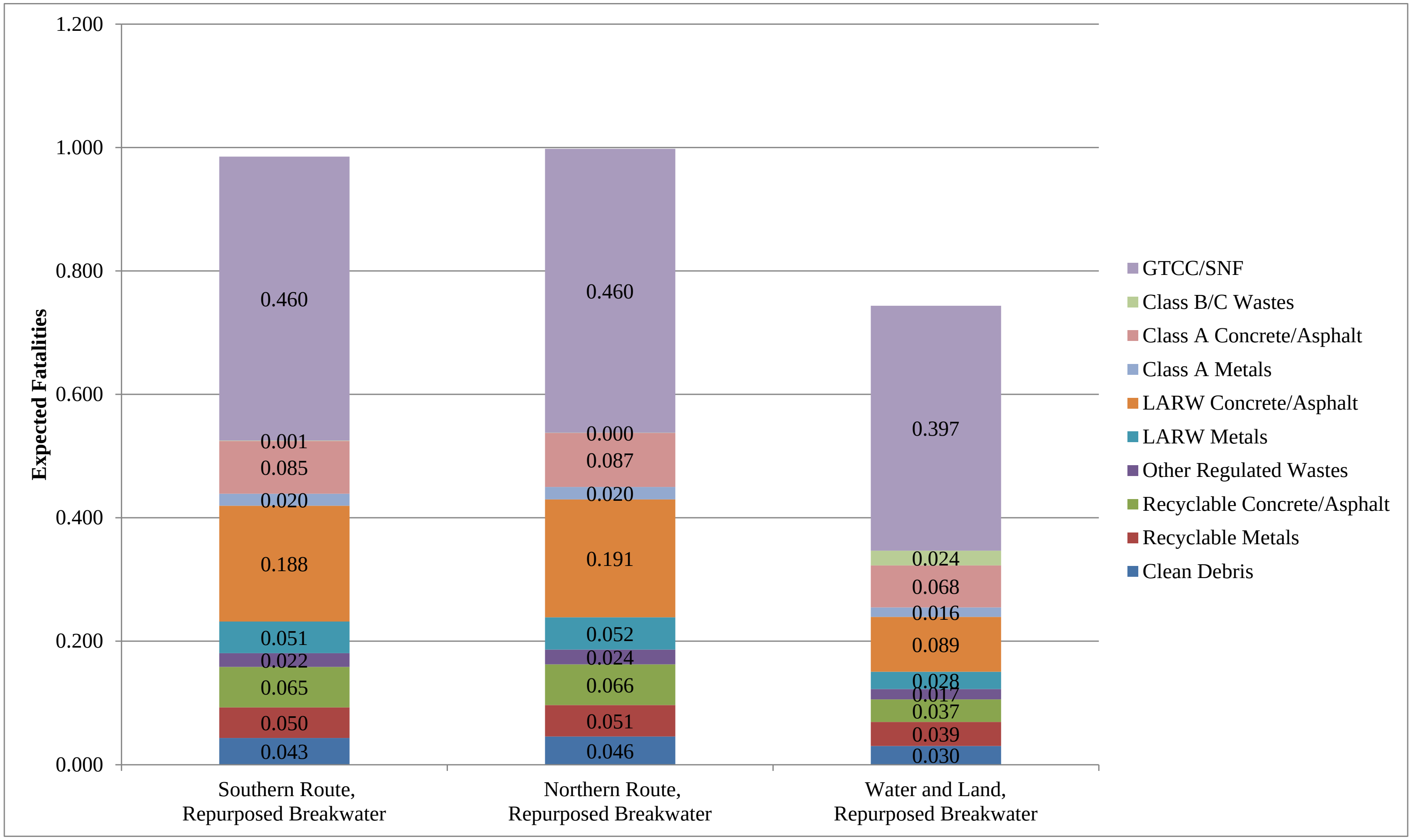

Figure 23. Conventional Risks of Transportation for "Breakwater Repurposed" Case

A comparison of the conventional transportation risks of only the first leg out of DCPP (to PBRY) by the truck is presented below in Table 59. The risks for the southern route through Avila Beach are almost half the risks for the northern route, in proportion to the length of the route. In the context of the entire campaign these differences are small. The repurposing of the breakwater also halves the risks.

Table 59. Conventional Transportation Risks for First Leg from DCPP by Truck

Item	**Expected Fatalities**	**Expected Injuries**	**Expected Accidents**
Southern Route (to PBRY) Including Breakwater Removal	0.032	0.820	2.801
Southern Route (to PBRY) with Breakwater Repurposed	0.016	0.407	1.389
Northern Route (to PBRY) Including Breakwater Removal	0.058	1.510	5.158
Northern Route (to PBRY) with Breakwater Repurposed	0.029	0.747	2.550

A good way to look at the expected values of traffic fatalities in Table 59, which are presented in terms of fractional numbers and have small values, is in terms of probabilities. For most purposes, traffic fatalities can be interpreted using the Poisson distribution. When the expected fatalities are 0.016 there is a 98.4% probability that there will be zero fatalities, a 1.6% probability that there will be one fatality, with significantly lower (but non-zero) probability of two or more fatalities during the entire multi-year campaign. In case the breakwater has to be removed, the expected fatalities on the local roads is 0.032. This implies a 96.9% probability that there are no fatalities, a 3.1% probability that there is one fatality and significantly lower (but non-zero) probability of two or more fatalities. It should be noted that this analysis is based on the totality of large truck and bus accident data. Since drivers of vehicles carrying hazardous materials have additional testing and licensing requirements, there is an expectation that the accident rates are lower than for general commercial trucking. An additional factor that is relevant is that the traffic on the local roads during decommissioning waste transportation will be lower since DCPP will be operating with a lower employee count.

The conventional risks of transportation are calculated using national average fatality rates per mile for truck, rail and barge transportation. The comparison of risks on the northern and southern routes out of DCPP is therefore based on the assumption that the expected fatality rates are similar, which in turn implies that the driving conditions are not very different. During the site visit (on September 18, 2019) by one of the authors of this report, it was observed that the northern route will require significant roadwork to make it truck worthy.

6.2 Incident Free Radiological Risks

The incident free radiological risks are presented in Figures 24 and 25 for workers and for members of the public, respectively. For workers the radiologic risks are virtually identical on the northern and southern land routes. The radiological risk for the barge option is lower, for workers, due to the greater distance between the crew and the radioactive materials. For members of the public the incident free radiological risks are about 8% higher for the northern land route option than for the southern route. The slow speed of the barge when it is close to land results in higher incident free radiological risks, but the difference is small in the context of the overall incident free radiological risks.

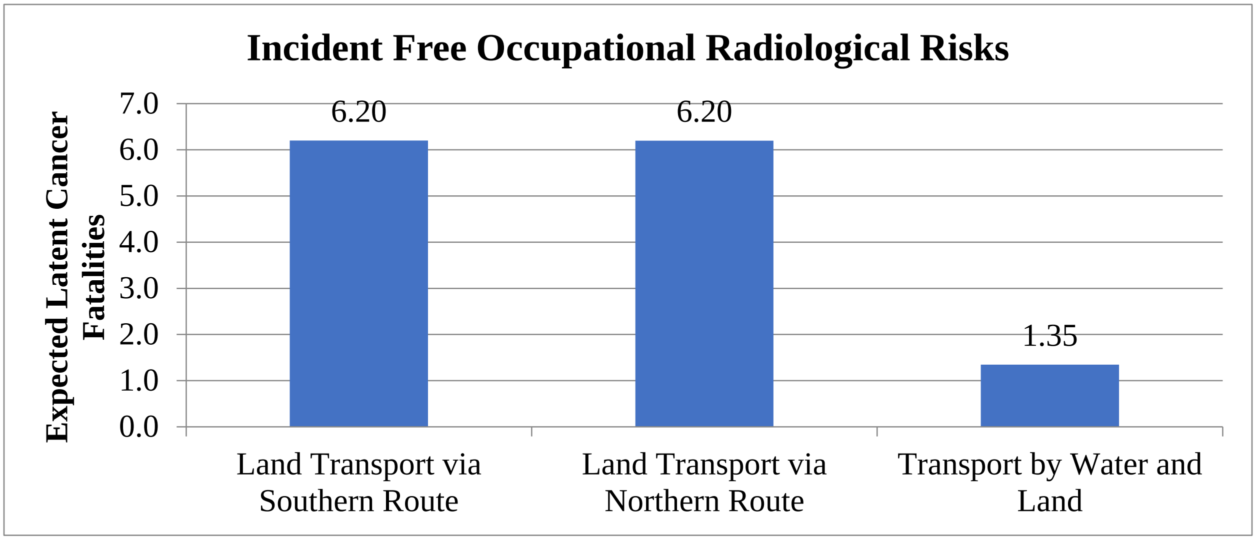

Figure 24. Incident Free Occupational Radiological Risks

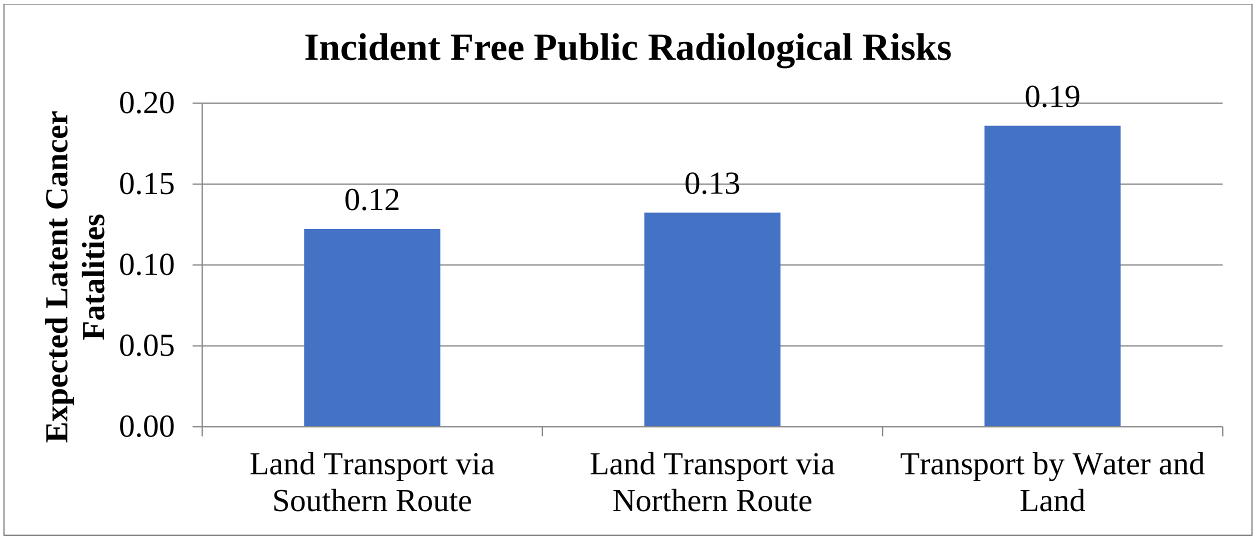

Figure 25. Incident Free Public Radiological Risks

A comparison of the incident free radiological risks of transport for the first leg by truck out of DCPP to PBRY is presented in Table 60.

Table 60. Incident Free Radiological Risks for First Leg from DCPP to PBRY

Item	**Dose to the MEI (per trip, mrem)**	**Collective Dose (person-rem)**	**Expected Latent Cancer Fatalities**
Southern Route to PBRY	6.9E-04	11.2	6.2E-03
Northern Route to PBRY	6.9E-04	29.3	1.6E-02

The risk to the MEI is identical on both routes. The collective risk is lower for the southern route than for the northern route. The collective dose is presented in this study since it is customary. It is important to note that the risk is shared over the entire campaign duration of several years by the entire exposed population. For this reason, it is important to focus on the dose to the maximally exposed individual. The MEI dose is calculated for a person standing approximately 100 ft from the truck as it passes by slowly (at a speed of 15 mph). If the speeds are higher, or the distances greater, the dose is lower. It is extremely unlikely that the same person will be exposed to multiple trucks a night in this fashion. However, if it were to happen, then that person’s exposure would come out to approximately 12 mrem over the entire multi-year campaign. This number is smaller than the background dose in a single year by a factor of about 50. The collective dose is the sum of the dose to all exposed persons, along the route, including those in vehicles sharing the road. With regard to the collective dose, it should be noted that the use of average traffic densities in the calculations results in conservative estimates, since the transportation will be undertaken at night when the traffic on the roads is expected to be lower than average.

6.3 Accidental Release Risks

The human health and safety risks from releases following a transportation accident on land and in coastal waters are so low as to be inconsequential to the selection of one transportation option over another.

6.4 Uncertainties, Study Boundaries, Recommendations

There is significant uncertainty in the characterization of the composition and activity levels of the LARW and Class A wastes. The radiological risks associated with accidental releases of the materials are proportional to assumed activity levels. However, these risks are very low both in terms of consequence to the MEI and in terms of the collective dose risk to the population. The incident free radiological risks have been assessed assuming that the dose at 2 meters from the package and the vehicle meets the regulatory limits for transporting radioactive materials. It is possible that for the loads with really low activity this results in overestimation of the risks. However, this overestimation applies to all modes of transportation and hence a comparison still yields valuable insight. The study should be revisited after site characterization work has been completed and the radioactive payloads being transported can be properly defined.

Storage, handling, loading and unloading risks should be evaluated after the most likely transportation option has been selected and detailed procedures are available.

Security risks have not been included in this study, and it is considered that such risks are best addressed by the regulators and security apparatus at the state and national levels.

The assessment of accidental release risks use average weather inputs and relatively simple dispersion models included in the RADTRAN software. Since the accidental release risks thus calculated are very small, it is considered that such modeling is adequate.

The configuration of the trains used for transportation is important for the risk estimation. If the assumption of the number of cars and number of packages per car turns out to be different than that assumed in this study, the study should be revisited.

Transportation routes have been defined using the software webTRAGIS from the DOE. It is possible that the actual routes selected are different, based on input from local authorities. If the routing is substantially different from that assumed in this study, the study should be revisited.

The study finds that the transportation option involving the use of a barge for the first leg of the trip is the one that comes with the lowest conventional transportation risks and overall incident free radiological risks. This difference is significant. This finding is subject to three caveats.

1. This study has not been able to quantify the collective dose risks of barging LARW up the Columbia River and has come to the conclusion, based on a non-quantitative

assessment, that river barging, particularly for the concrete/asphalt in IP-1 bags should be reconsidered.

2. Accidental release dose risks to humans, for barging in coastal waters, are very low. However, the probability of loss of radioactive material into the water followed by failure of salvage efforts is low but not zero. This represents a risk transfer of human health and safety risk to environmental risk.
3. For the materials for which the base case is one of direct trucking from DCPP to the final disposal site, the alternate case of barge plus land transport involves an intermediate port stop with transfer to land transportation for which the risks have not been evaluated and included in this study. The comparison of risks for barge and rail with truck and rail is a valid one, (only subject to the assumption that unloading, staging, storage and loading risks at PBRY will be similar to those at the barge port).

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8 Appendices

A - Shipping Containers
B – Route Maps (webTRAGIS and Maptitude)
C – Parameters in Aquatic Dispersion Model
D – Loss of Shielding Events during Transportation of Class B/C Wastes
E – Sample RADTRAN Input and Output Files
F – Barge Travel Data

Appendix A - Shipping Containers

GTTC AND SPENT FUEL TRANSPORT CASKS

The HI-STAR 100 transport cask is for shipping spent nuclear fuel and greater than class C waste (GTTC). The HI-STAR 100 packaging is classified as a Type B package under 10 CFR 71. As the HI- STAR 100 system is designed to transport spent nuclear fuel, the maximum activity of the contents requires that the HI-STAR 100 packaging be classified as Category I in accordance with Regulatory Guide 7.11 [1.2.10]. The HI-STAR 100 is a high-capacity, multi-purpose canister (MPC) containment system designed for either storing the spent nuclear fuel on a temporary storage pad, or transporting it over land or water by truck, rail, or barge. The version assumed in this study is a HI-STAR 100 engineered to accept one multi-purpose canister containing a 32-cell non-flux trap fuel basket for PWR fuel. The cask is certified under 10 CFR 71 for transport and under 10 CFR 72 for storage.

The HI-STAR 100 system consists of an MPC, an overpack that provides the containment boundary and a set of impact limiters that provide energy absorption capability for the normal and hypothetical accident conditions of transport. Each of these components is described below, including information with respect to component fabrication techniques and designed safety features.

There are several features in the HI-STAR 100 system design that increase its effectiveness with respect to the safe transport of spent nuclear fuel (SNF). Some of the principal features of the HI-STAR 100 System that enhance its effectiveness are as follows.

- Honeycomb design of the MPC fuel basket
- Effective distribution of neutron and gamma shielding materials within the system
- High heat rejection capability
- Structural robustness of the multi-shell overpack construction

The HI-STAR 100 MPCs are welded cylindrical structures with flat ends. Each MPC is an assembly consisting of a honeycombed fuel basket, baseplate, canister shell, lid with vent and drain ports and cover plates, and closure ring. The number of spent nuclear fuel storage locations in the MPC for transporting DCPP fuel is 32. The outer dimension of the generic MPCs is nominally 68-3/8 inches and the length is nominally 190-1/4 inches. The MPC as configured in the shipping overpack and other components is shown in Figure A-1.

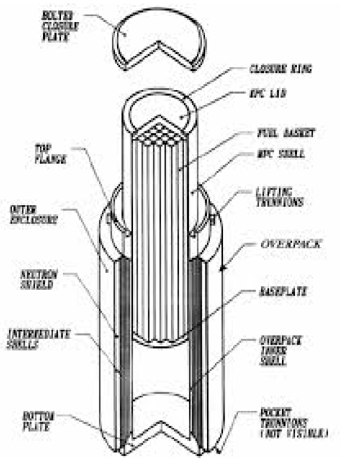


Figure A- 1. The HI-STAR 100 MPC

.

The overpack for the HI-STAR 100 is a heavy-walled steel cylindrical vessel. The inner diameter of the overpack is approximately 68-3/4 inches and the height of the internal cavity is approximately 191 inches. The outer diameter of the overpack is approximately 96 inches and the height is approximately 203 inches.

All materials used to construct the HI-STAR 100 system are ASME Code materials, except the neutron shield, neutron poison, optional aluminum heat conduction elements, thermal expansion foam, seals, pressure relief device, aluminum honeycomb, pipe couplings, and other material classified as not Important to Safety.

Approximate weights of the key components are shown in Table A-1.

Table A- 1. HI-STAR Transport Cask

Component	Weight (tons)
Overpack	77
Closure Plates	4
Impactors	18
MPC-32	45
TOTAL	144

8-120B CASKS FOR B AND C WASTES

The package consists of a steel and lead cylindrical shipping cask with a pair of cylindrical foam-filled impact limiters installed on each end. The package configuration is shown in Figure A-2. The internal cavity dimensions are 61 13/16 inches in diameter and 74 ⅞ inches high. The cylindrical cask body is comprised of a 1½ inch thick external steel shell and a ¾ inch internal steel shell. The annular space between the shells is filled with 3.35-inch-thick lead. The base of the cask consists of two 3¼ inch thick flat circular steel plates. The cask lid consists of two 3¼ inch thick flat circular steel plates. The lid is fastened to the cask body with twenty 2-8 UN bolts. There is a secondary lid in the middle of the primary lid. This secondary lid is attached to the primary lid with twelve 2-8 UN bolts. A thermal shield protects the secondary lid. The thermal shield consists of two polished stainless-steel plates that are separated by a thin air gap with stand-offs which provide an additional air gap above the secondary lid. The thermal-shield assembly is attached to the secondary lid lifting lugs with hitch-pins.

The impact limiters are 102 inches in outside diameter and extend 22 inches beyond each end of the cask. There is a 50-inch diameter void at each end. Each impact limiter has an external shell, fabricated from ductile low carbon steel, which allows it to withstand large plastic deformations without fracturing. The volume inside the shell is filled with a crushable shock and thermal insulating polyurethane foam. The polyurethane is sprayed into the shell and allowed to expand until the void is completely filled. The foam bonds to the shell, which creates a unitized construction for the impact limiters. The impact limiters' skin is 12 gage steel, including the upper impact limiter's weather cover. The lower impact limiter has a ½" thick steel cover plate.

Nominal weight of the 8-120B cask package is 37 short tons including a maximum payload weight of 7 short tons.

Features of the 8-120B cask are shown in Figure A-2.

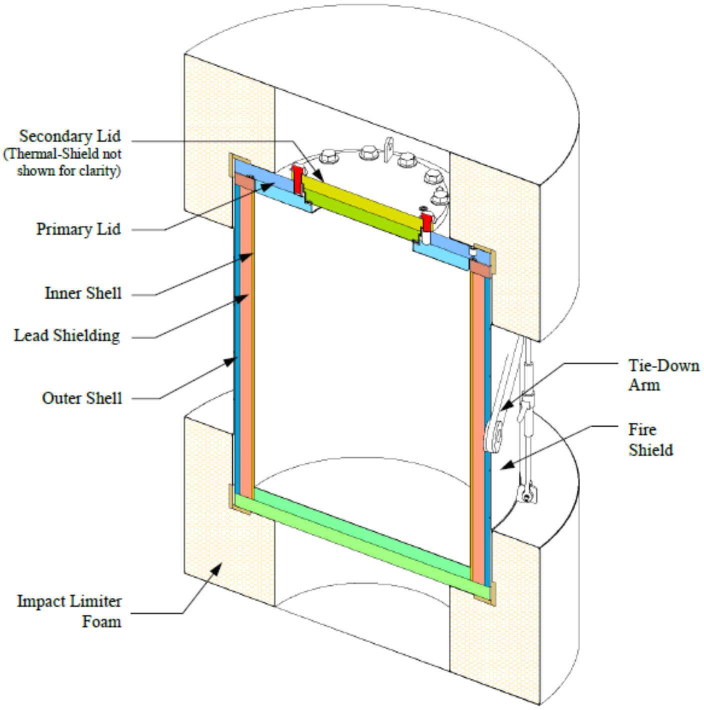


Figure A- 2. 8-120B Cask

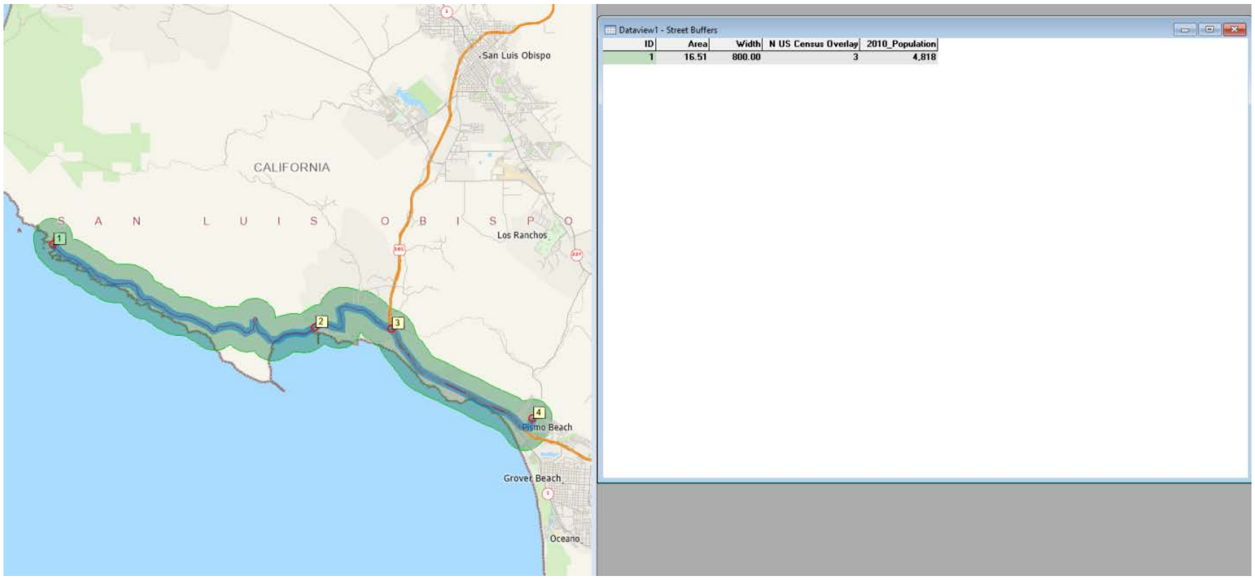
CONTAINERS FOR NON-DETECT, LARW, CFR 20.2002, AND CLASS A LLRW WASTES

Intermodal containers are used for transport of “clean,” non-detect waste and LARW debris from the DCPP site to the final disposal location. A standard 20-foot ISO dry freight container is shown Figure 8-3 having dimensions of 20 feet, by 8 feet, by 8.5 feet. Each IMC is assumed to contain 40,000 pounds of waste.

Figure A- 3. Rendering of an Intermodal Container

Soft sided bags meeting IP-1 and IP-2 criteria will be used to the maximum extent possible. IP-1 bags are assumed to have dimensions similar to the IMC able to contain 20 short tons of waste.

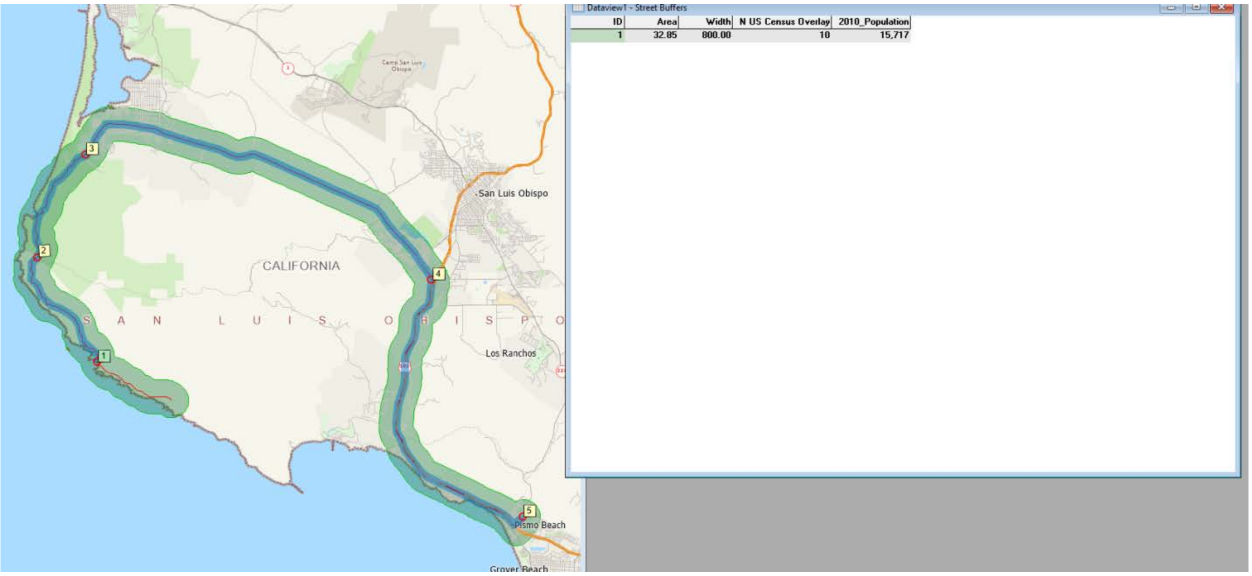
Appendix B – Route Maps (webTRAGIS and Maptitude)



Dataview1 - Street Buffers

ID	Area	Width	N US Census Overlay	2010_Population
1	16.51	800.00	3	4,818

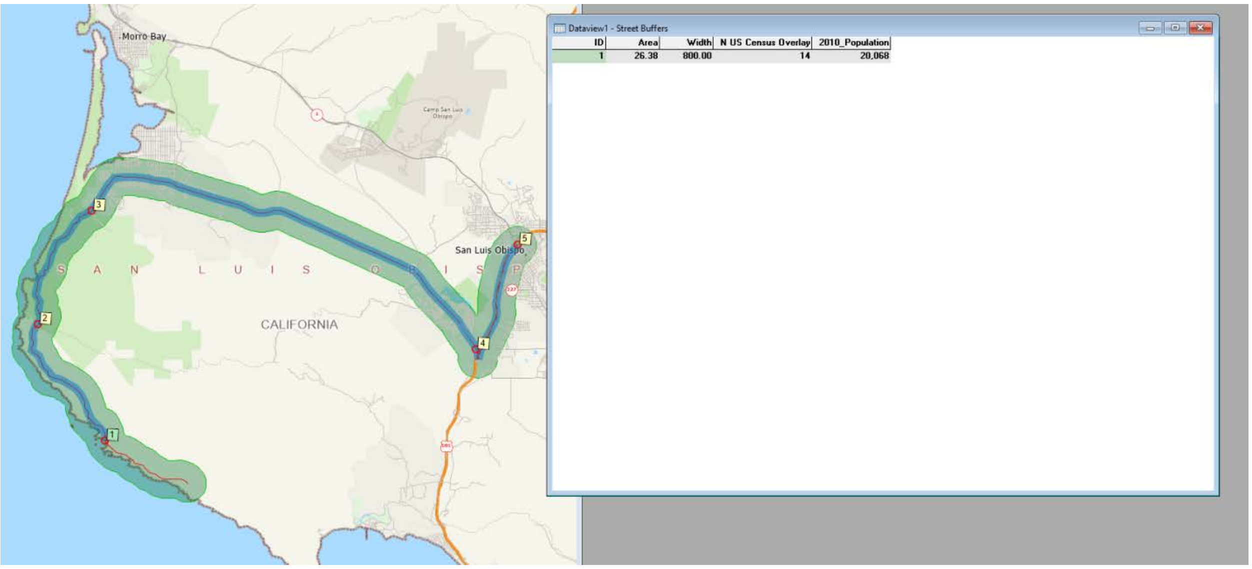
Figure B- 1. Truck Route from DCPP to Pismo Beach Rail Yard via Avila Beach (Maptitude)



Dataview1 - Street Buffers

ID	Area	Width	N US Census Overlay	2010_Population
1	32.85	800.00	10	15,717

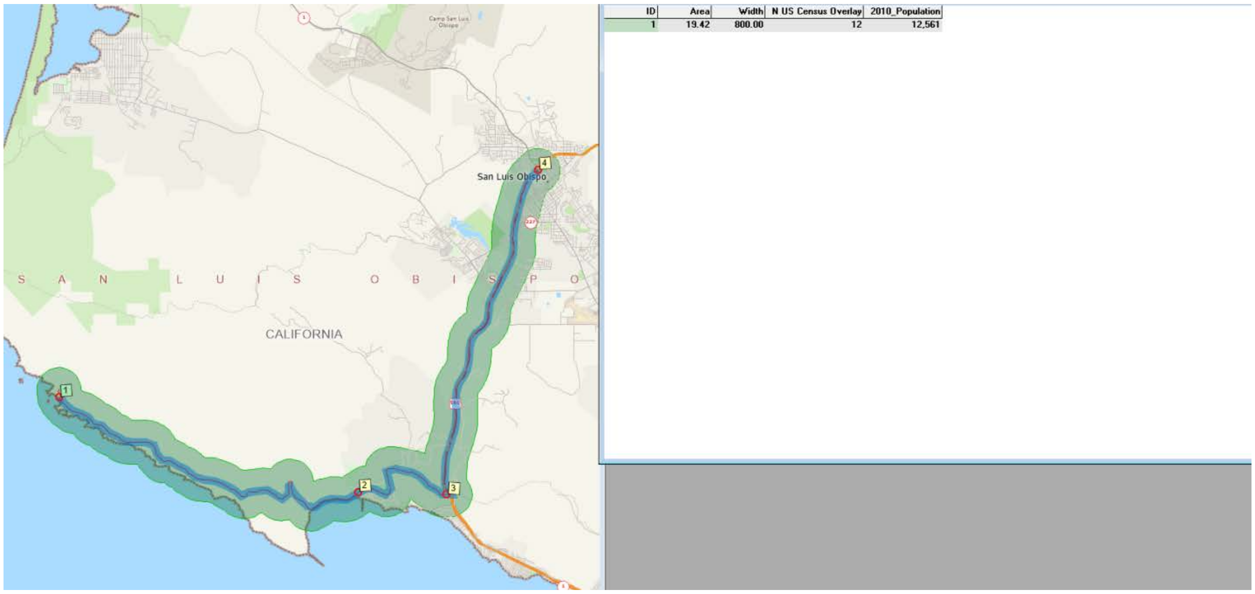
Figure B- 2. Truck Route from DCPP to Pismo Beach Rail Yard via Montana de Oro State Park (Maptitude)



Dataview1 - Street Buffers

ID	Area	Width	N US Census Overlay	2010_Population
1	26.38	800.00	14	20,068

Figure B- 3. Truck Route from DCPP to San Luis Obispo via Montana de Oro State Park (Maptitude)



ID	Area	Width	N US Census Overlay	2010_Population
1	19.42	800.00	12	12,561

Figure B- 4. Truck Route from DCPP to San Luis Obispo via Avila Beach (Maptitude)

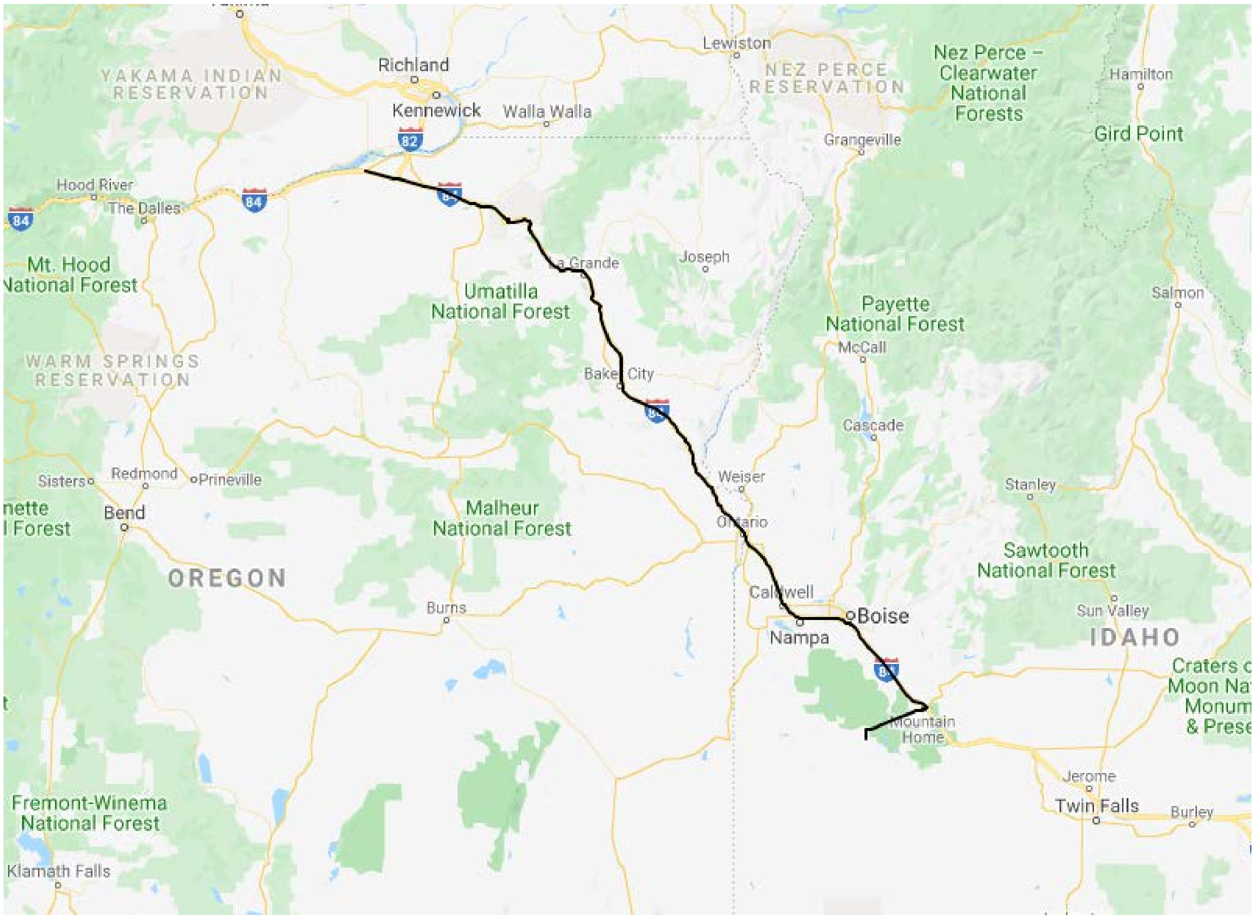


Figure B- 5. Truck Route from Boardman, OR to US Ecology, ID

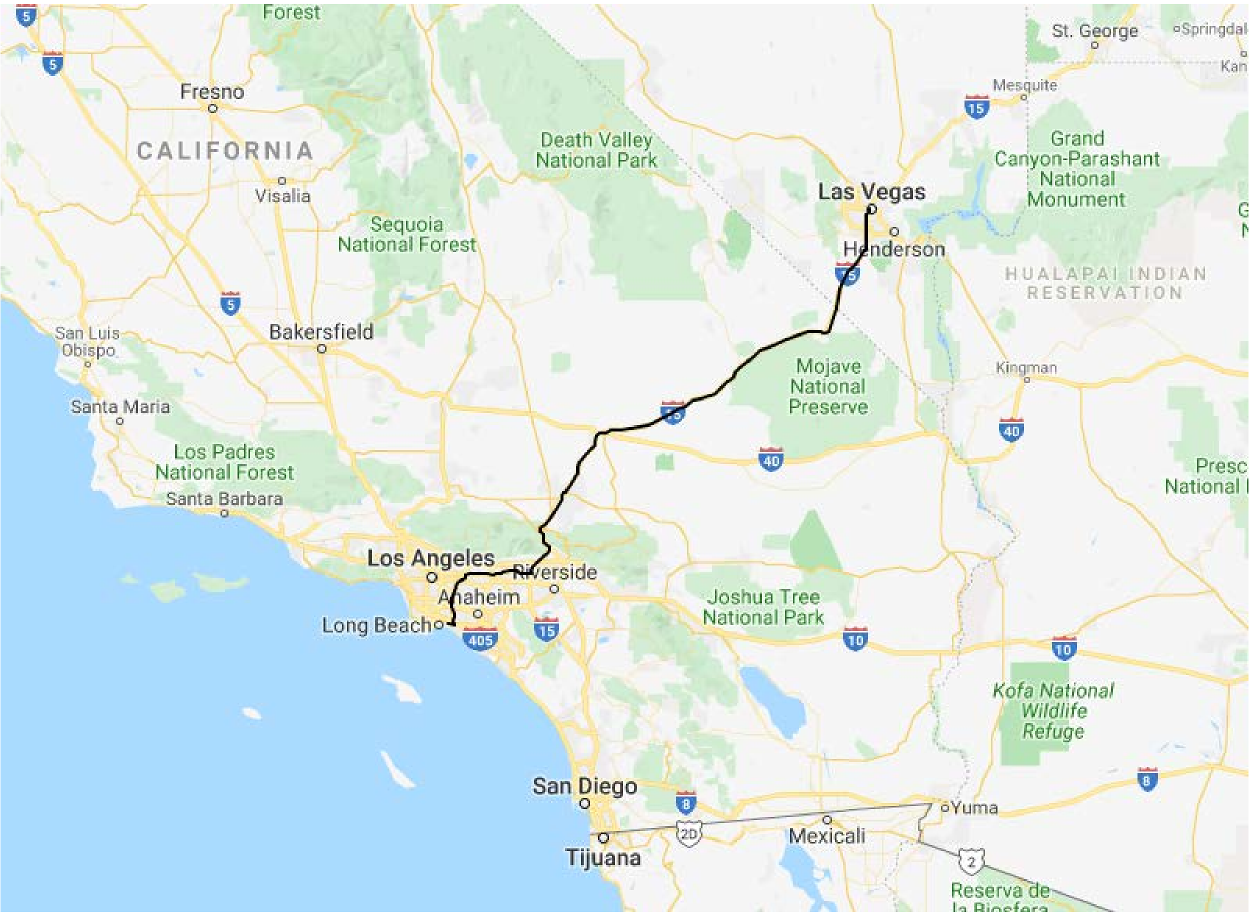


Figure B- 6. Truck Route from Long Beach Port to Las Vegas

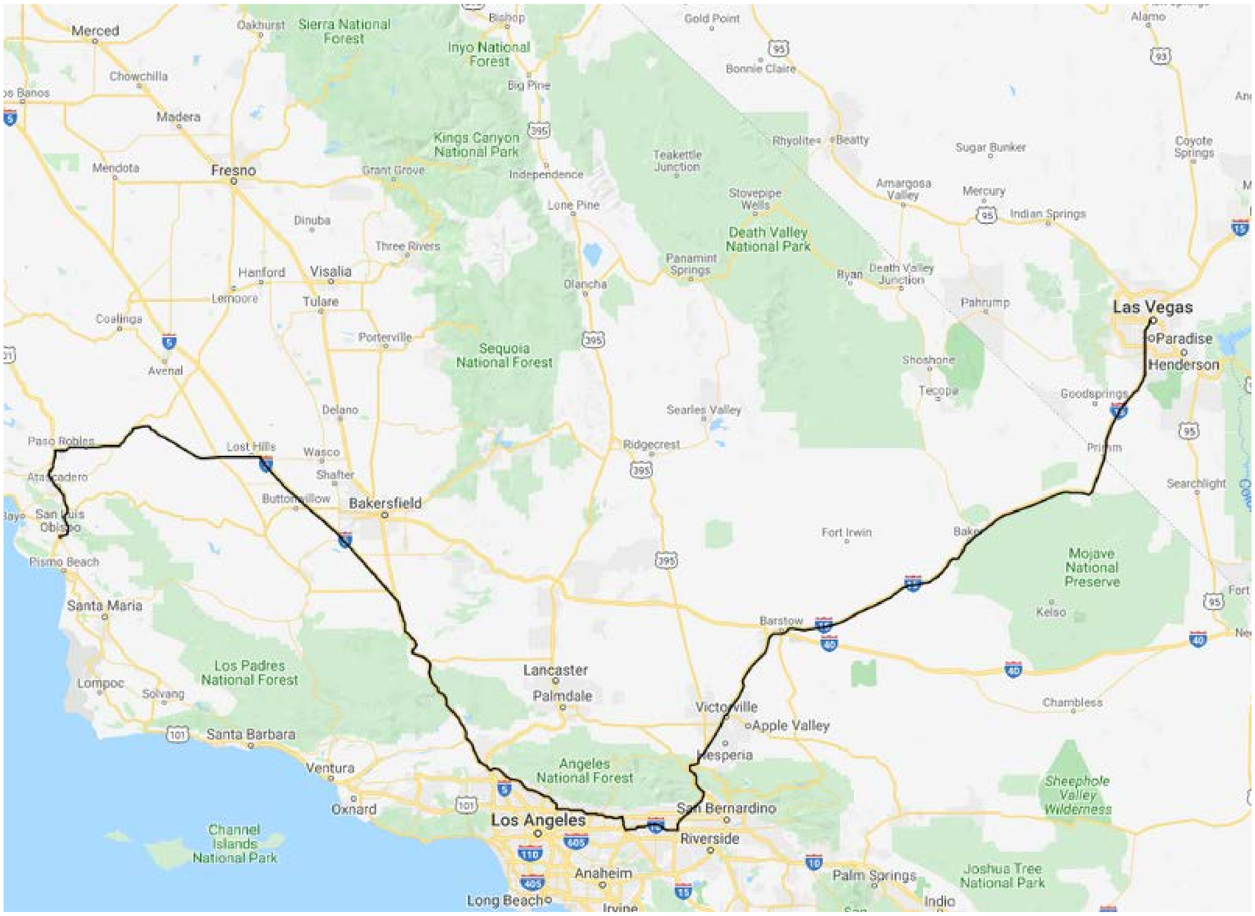


Figure B- 7. Truck Route from San Luis Obispo to Las Vegas

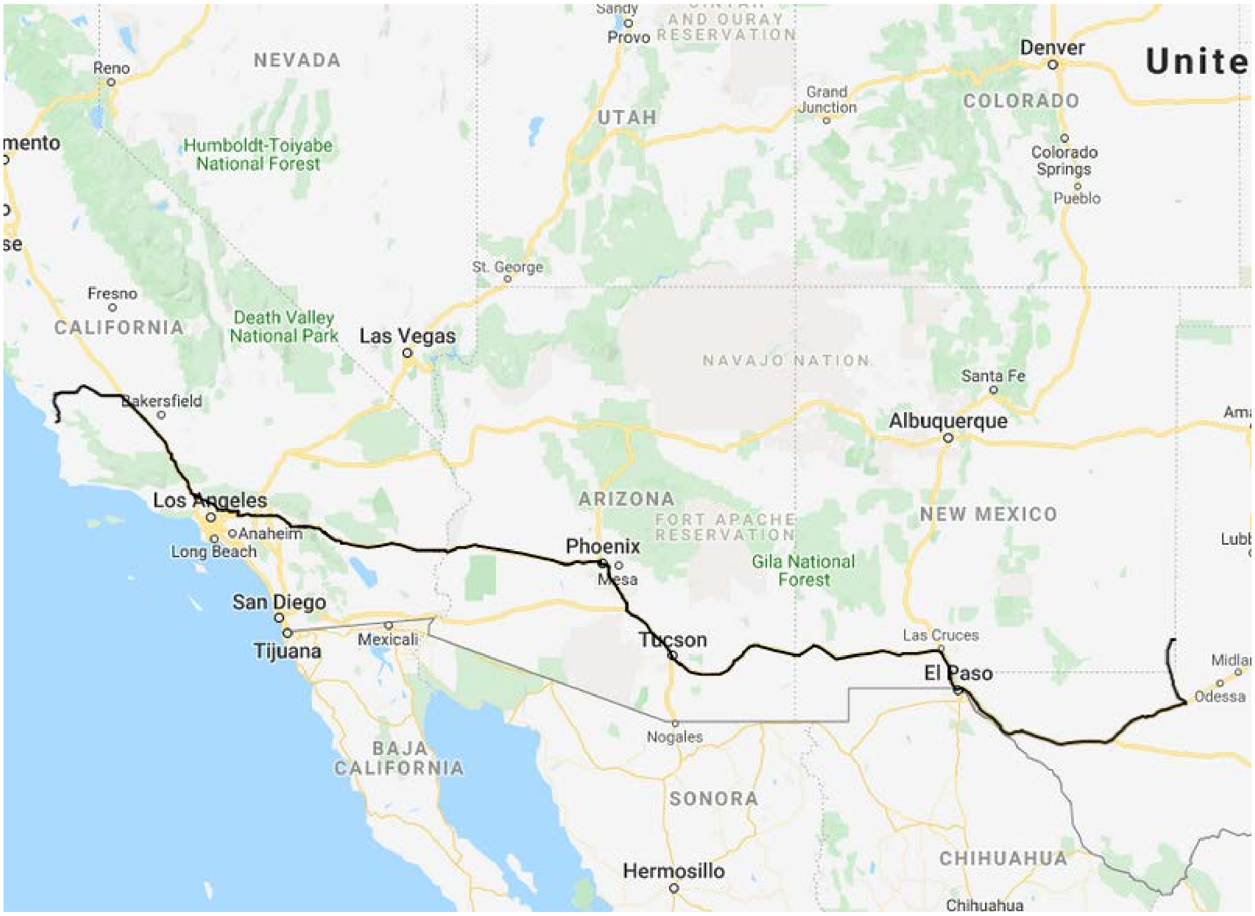


Figure B- 8. Truck Route from San Luis Obispo to WCS Texas

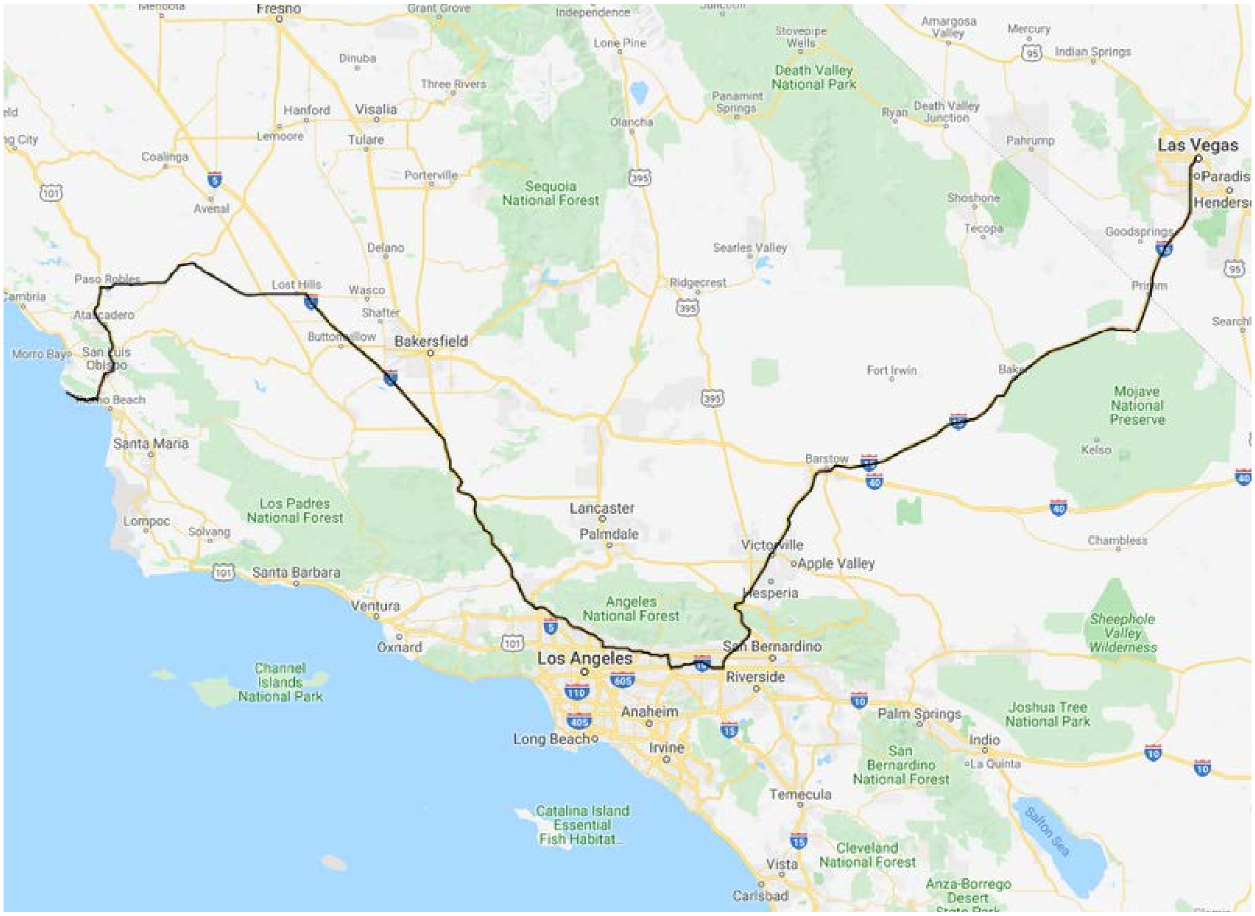


Figure B- 9. Truck Route for DCPP-South to Las Vegas

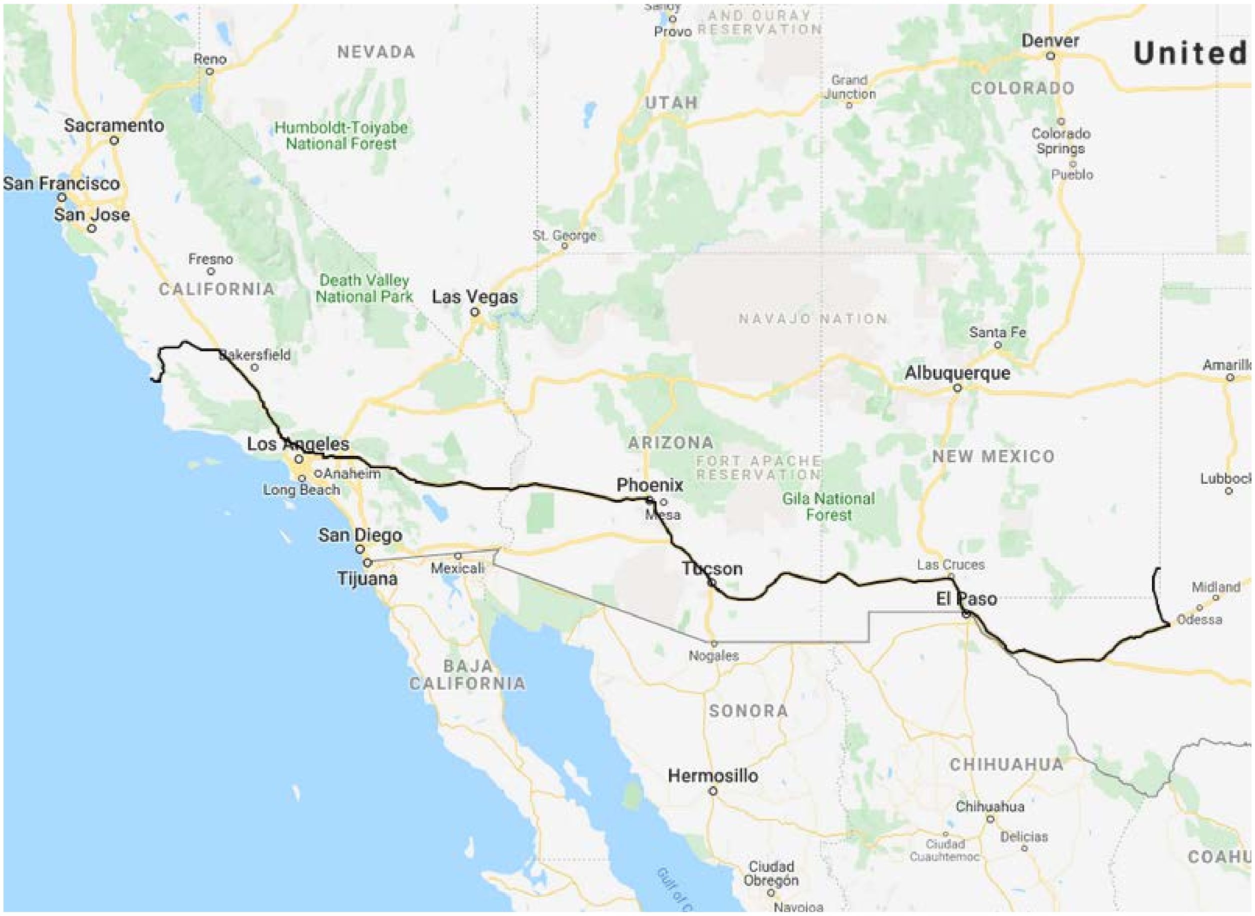


Figure B- 10. Truck Route from DCPP-N to WCS Texas

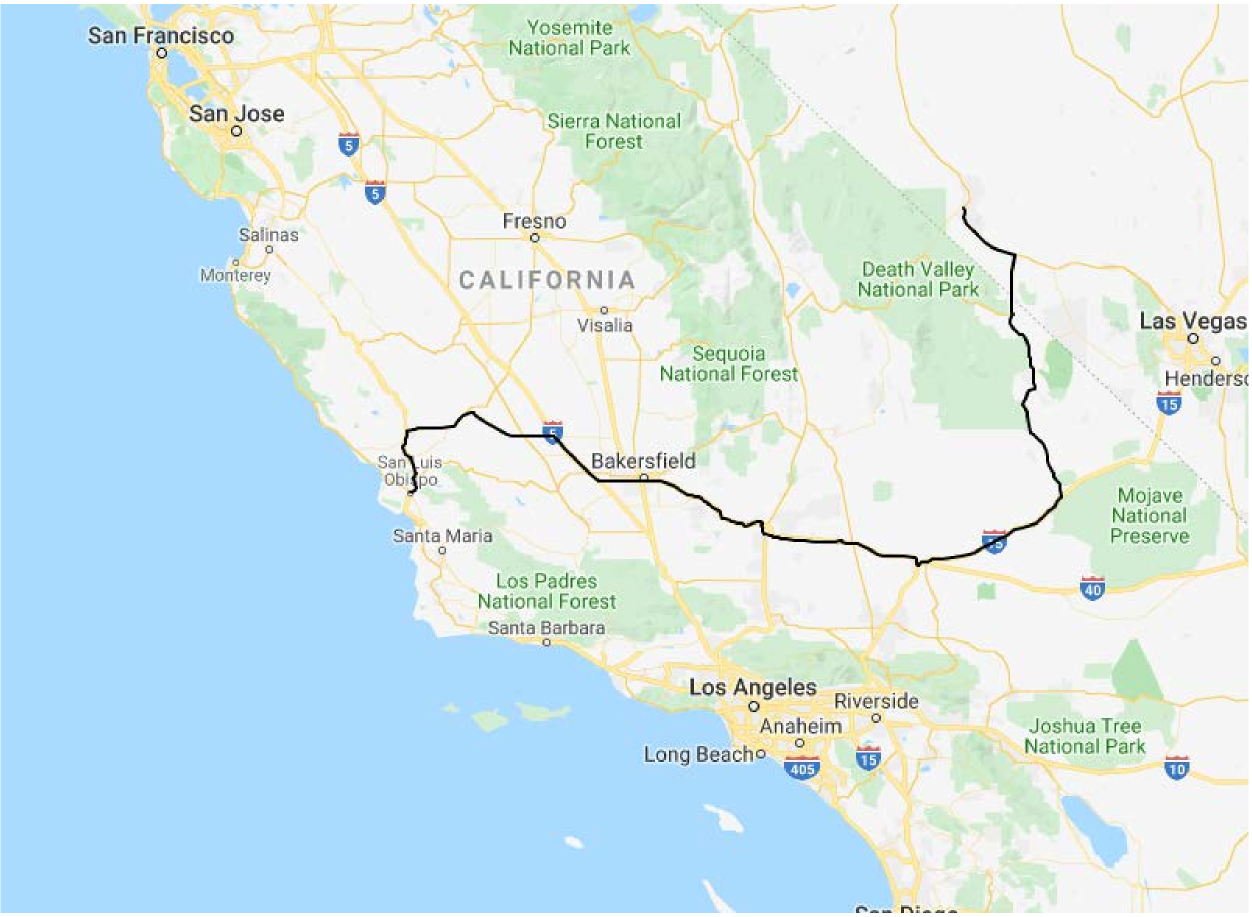


Figure B- 11. Truck Route from San Luis Obispo to US Ecology Beatty, NV

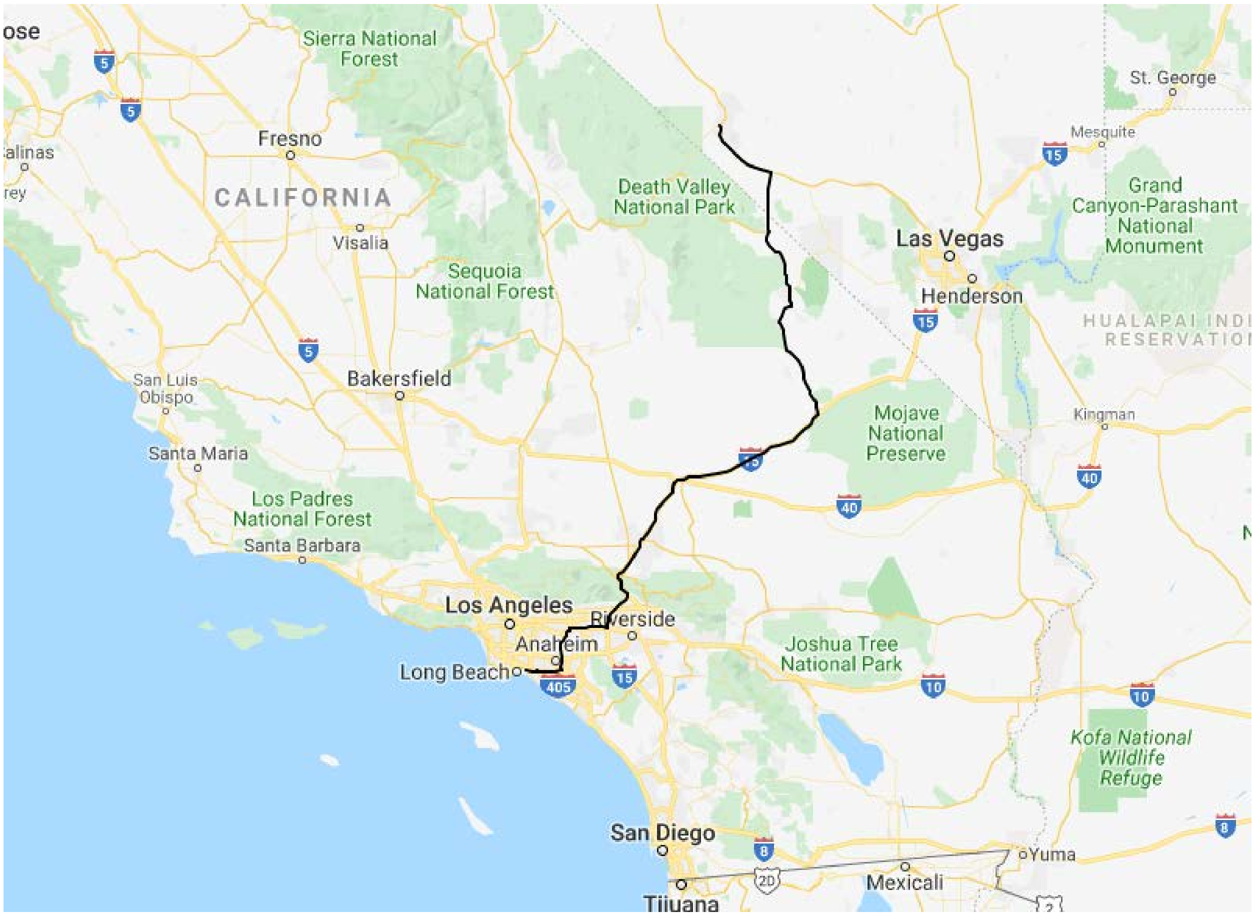


Figure B- 12. Truck Route from Long Beach Port to Beatty, NV

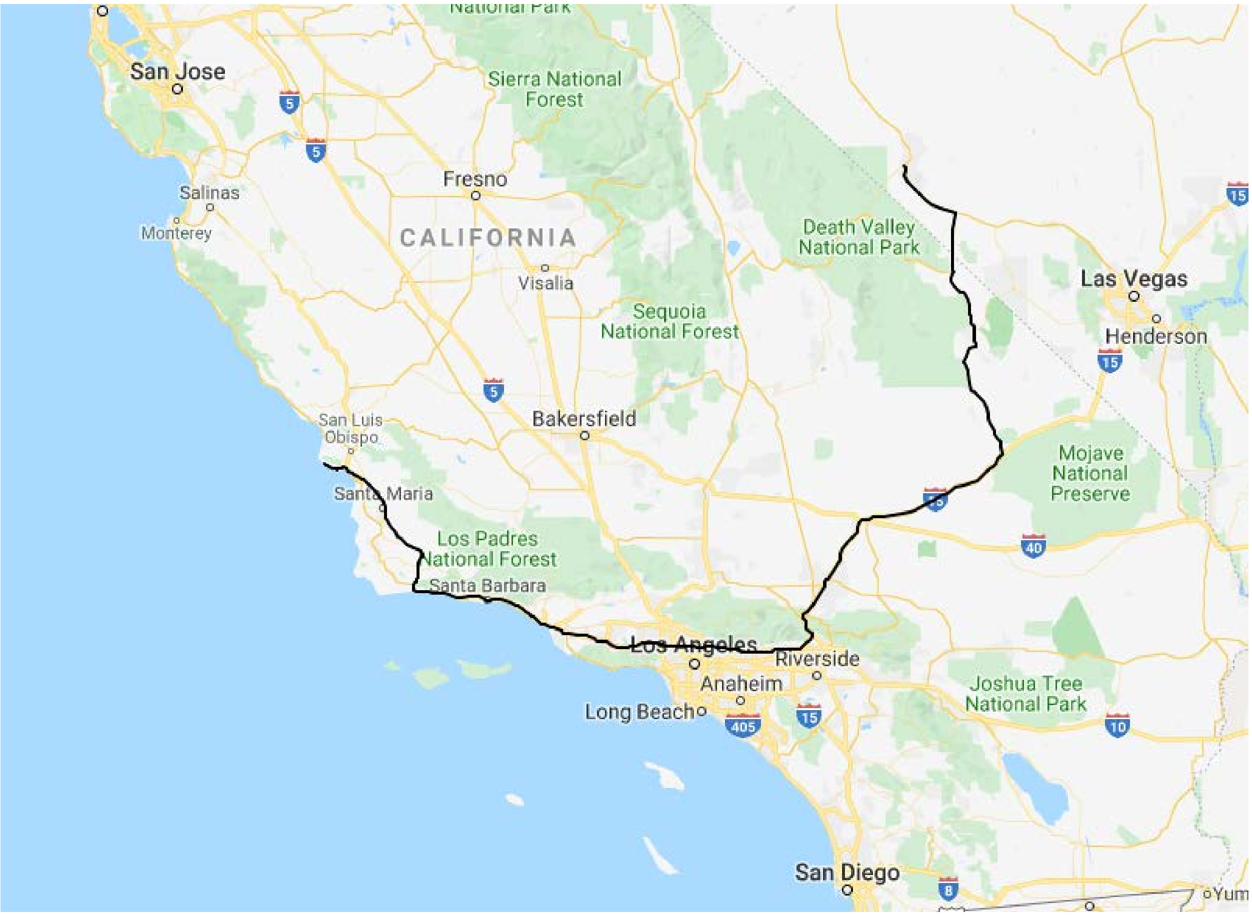


Figure B- 13. Truck Route from DCPP-S to US Ecology, Beatty, NV

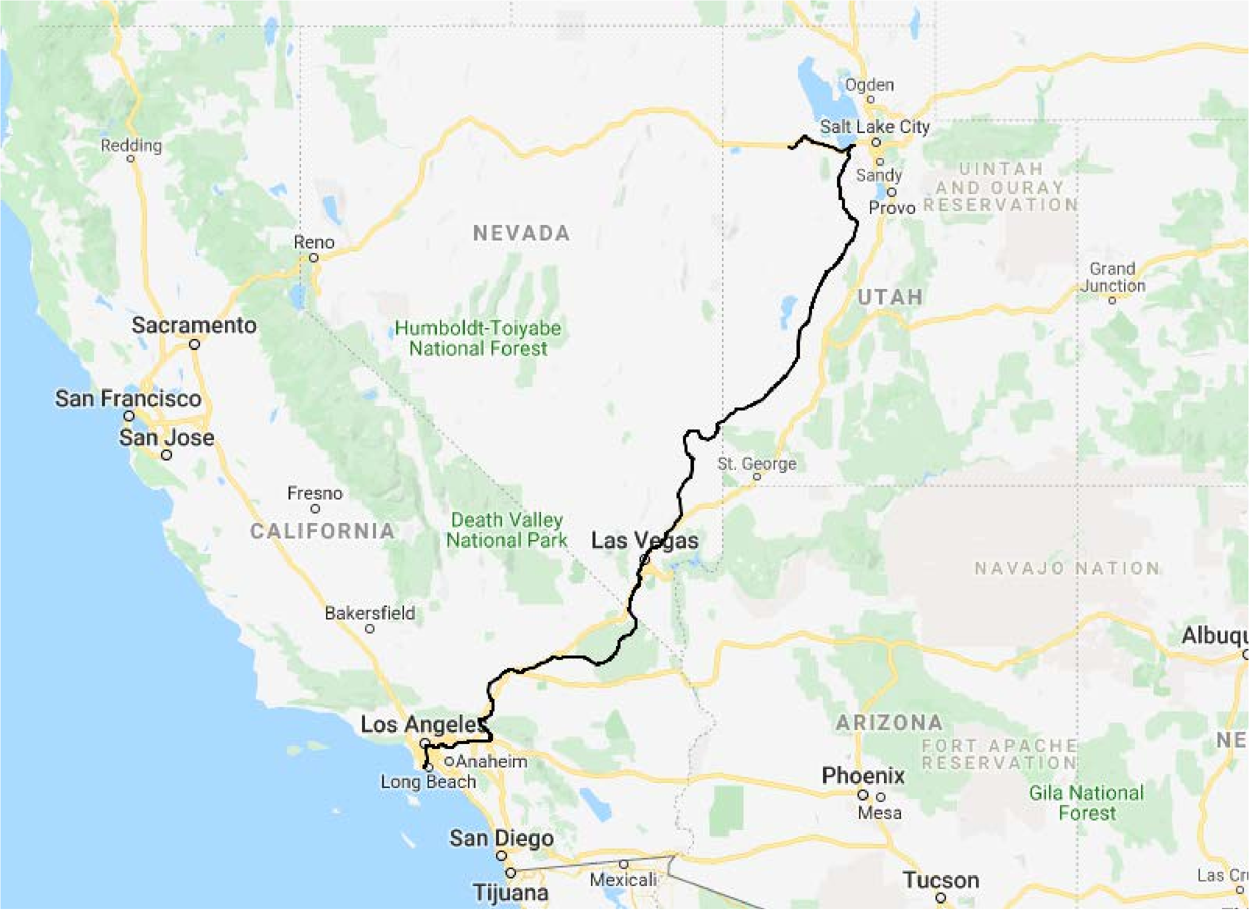


Figure B- 14. Rail Route from Long Beach Port to Clive, UT

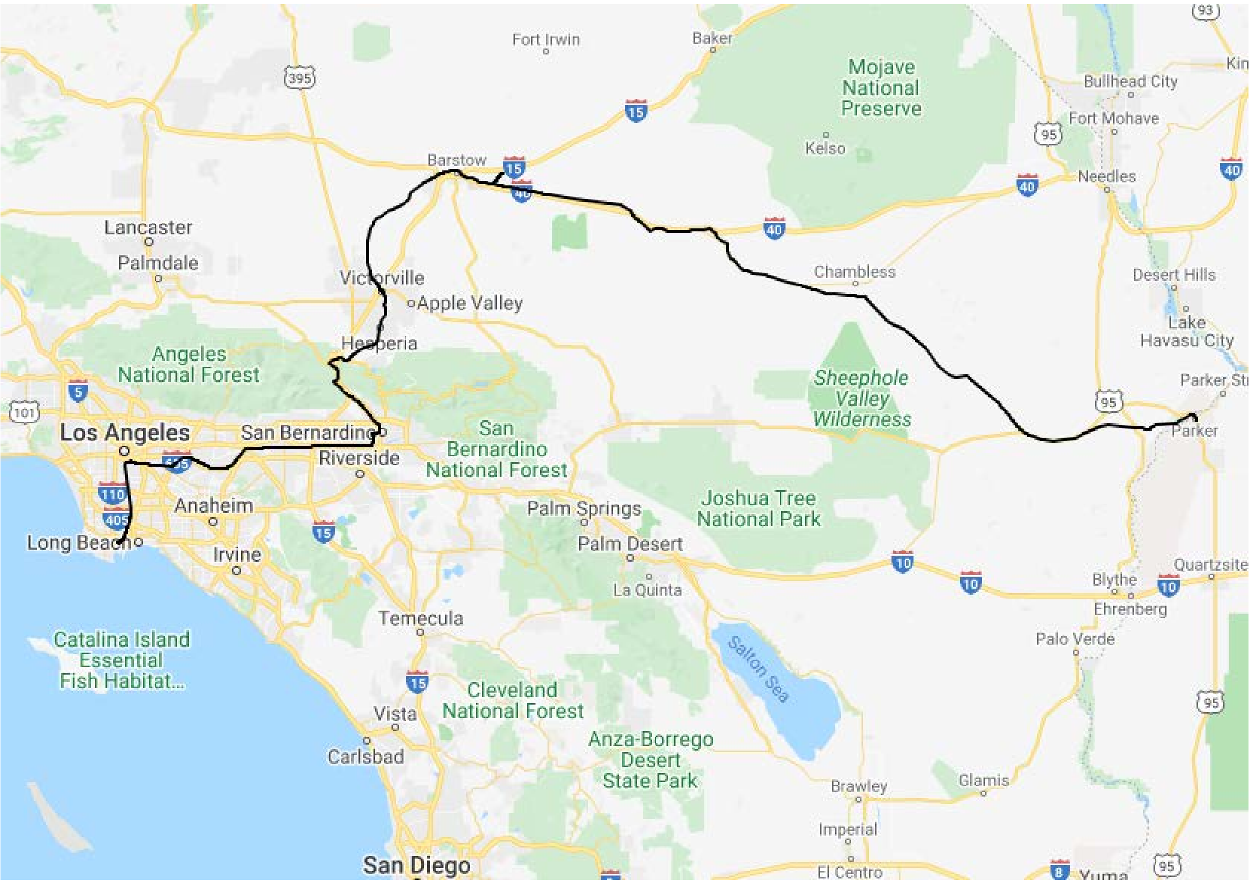


Figure B- 15. Rail Route from Long Beach Port to Parker, AZ

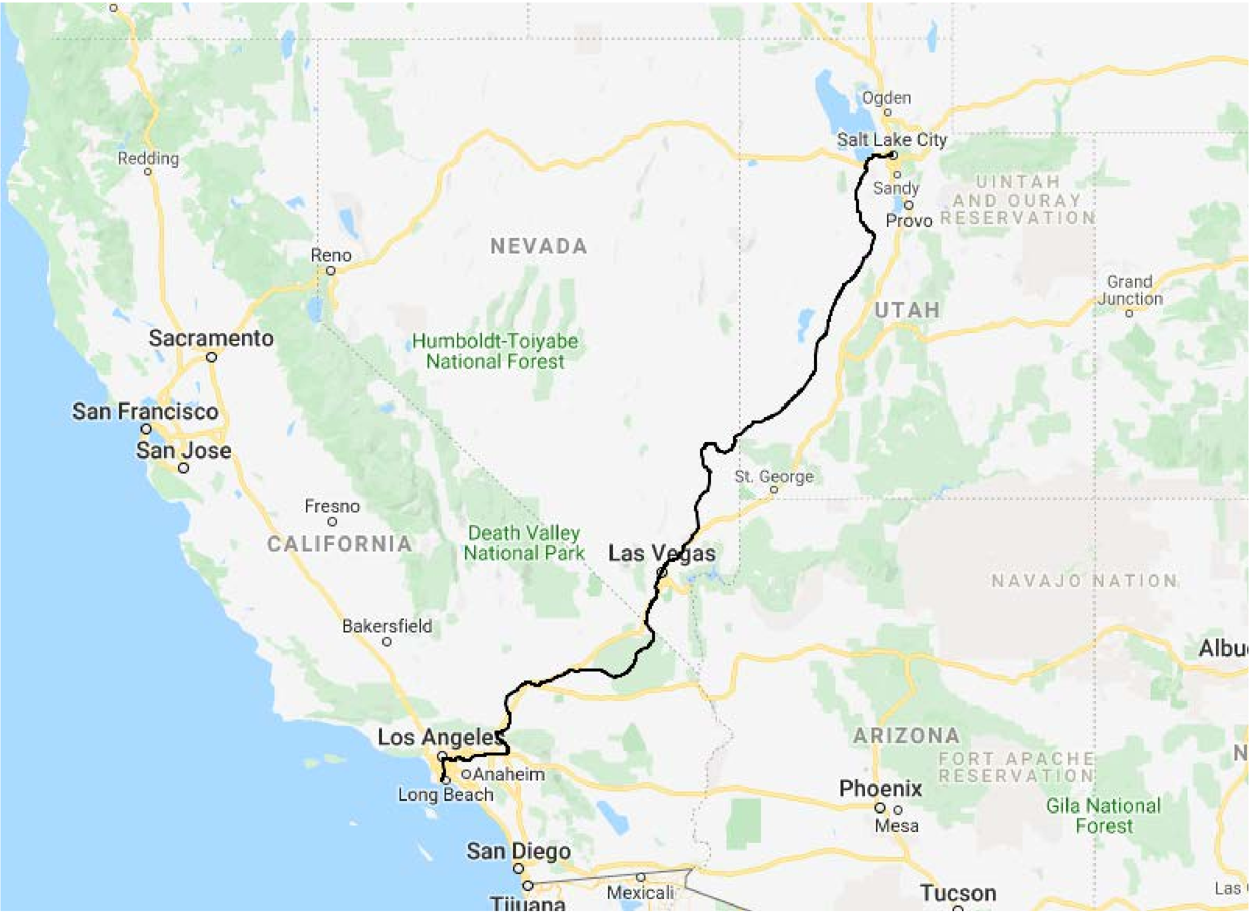


Figure B- 16. Rail Route from Long Beach Port to Salt Lake City

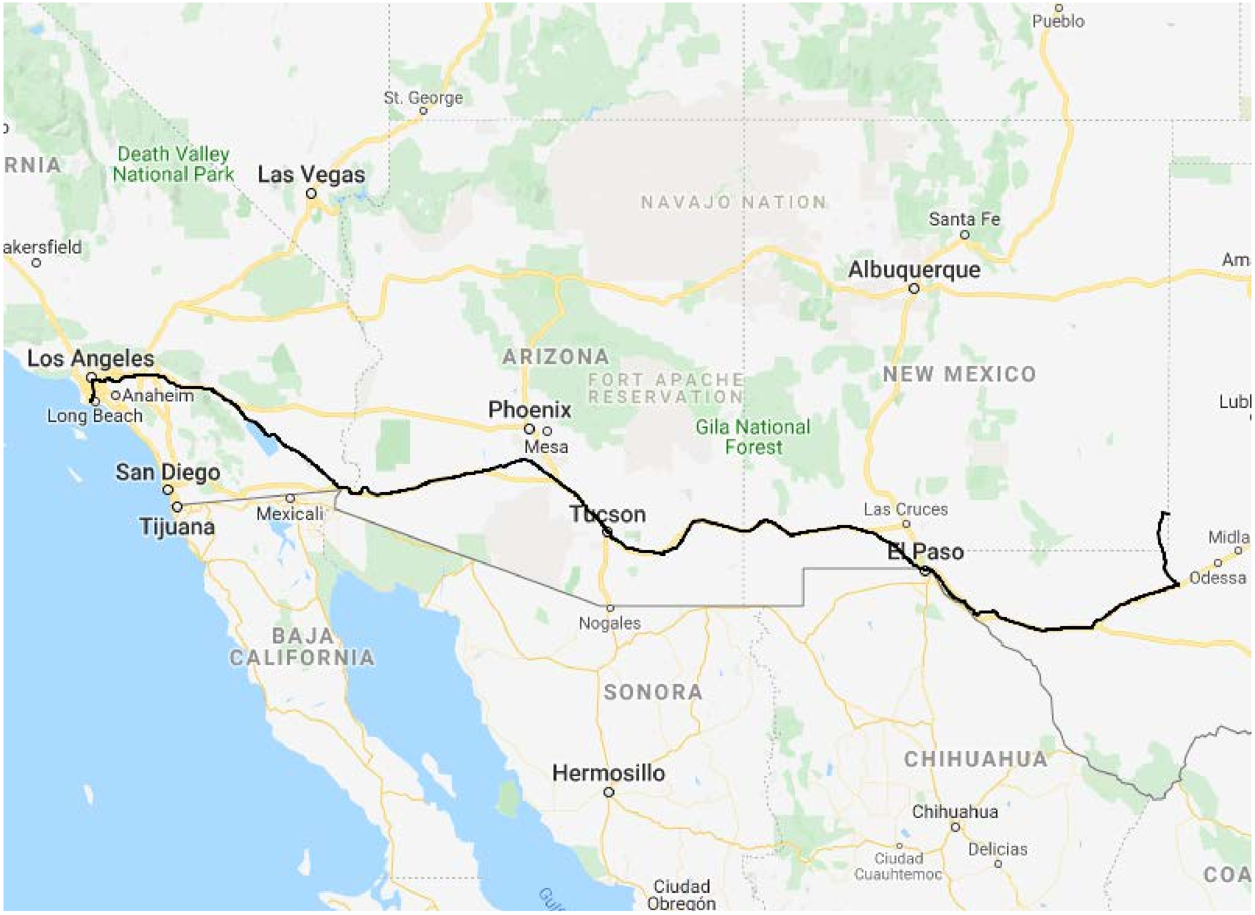


Figure B- 17. Rail Route from Long Beach Port to WCS, TX

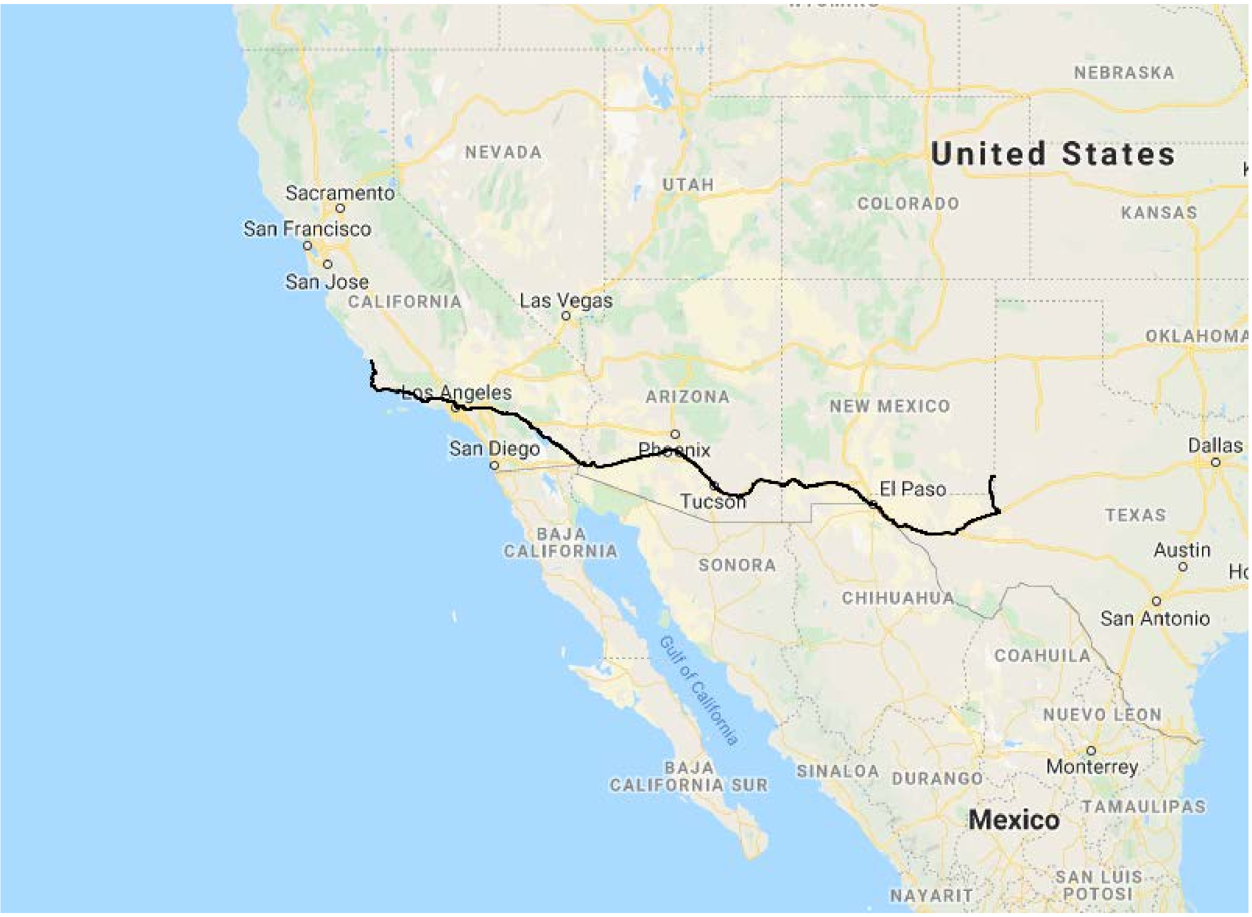


Figure B- 18. Rail Route from Pismo Beach Rail Yard to WCS, TX

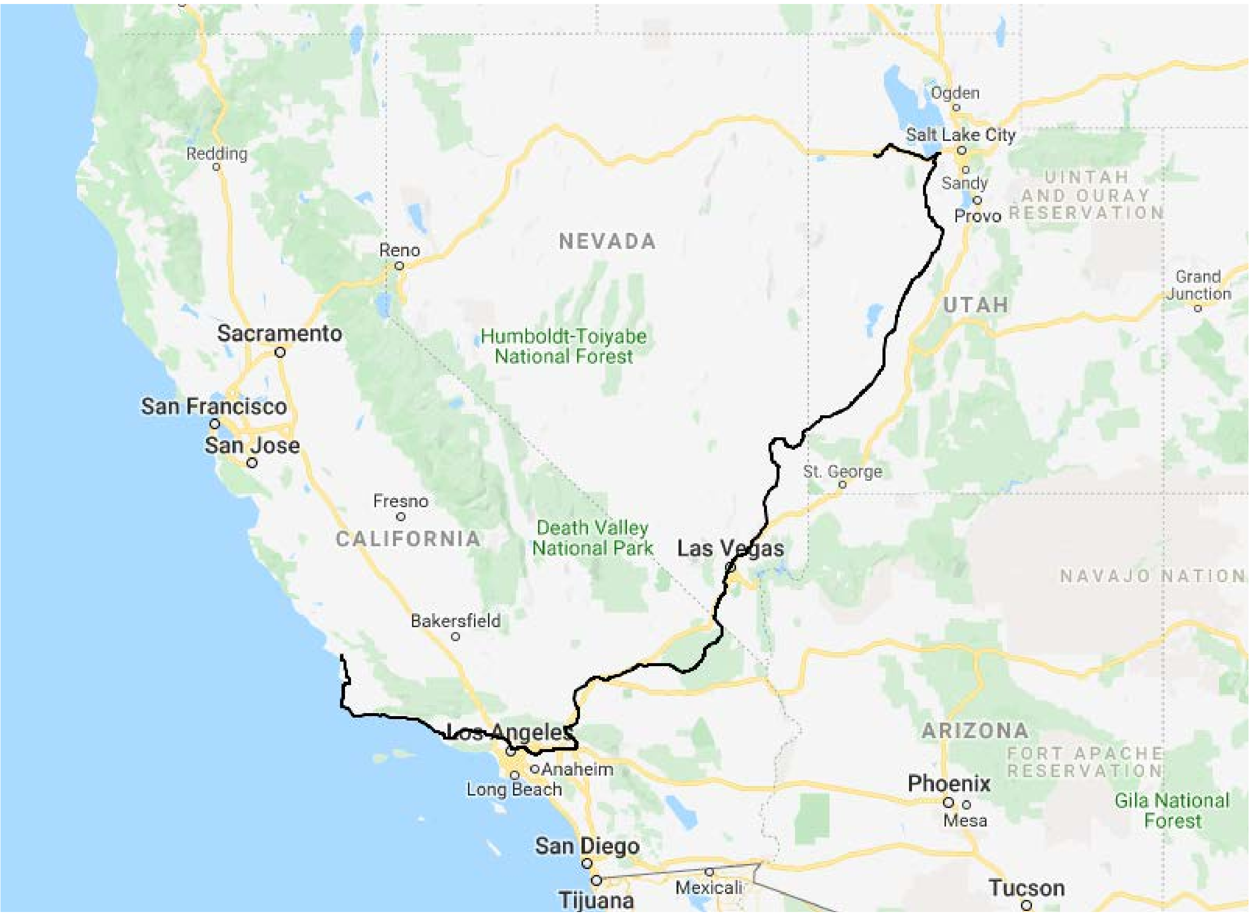


Figure B- 19. Rail Route from Pismo Beach Rail Yard to Clive, UT

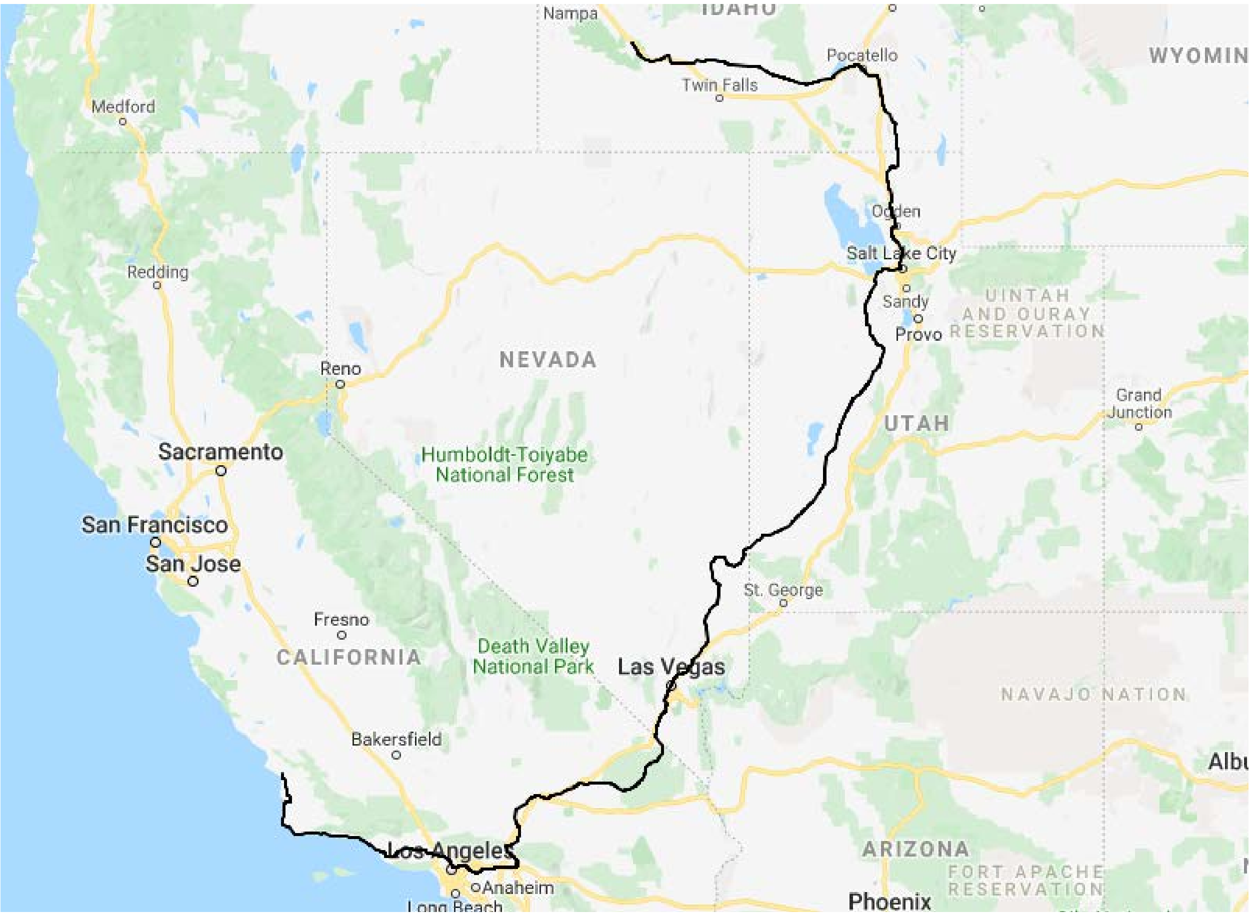


Figure B- 20. Rail Route from Pismo Beach Rail Yard to US Ecology, ID

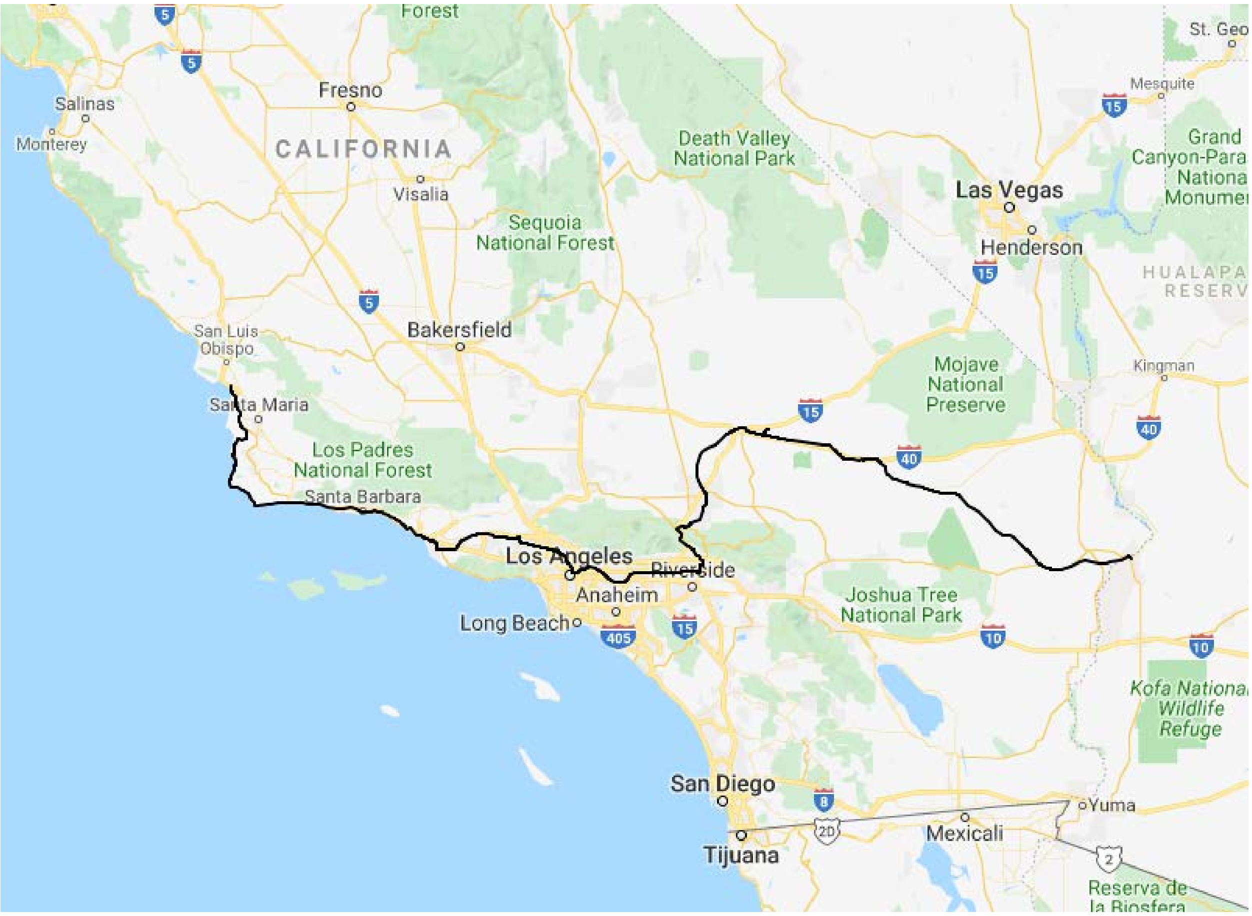


Figure B- 21. Rail Route from Pismo Beach Rail Yard to Parker, AZ

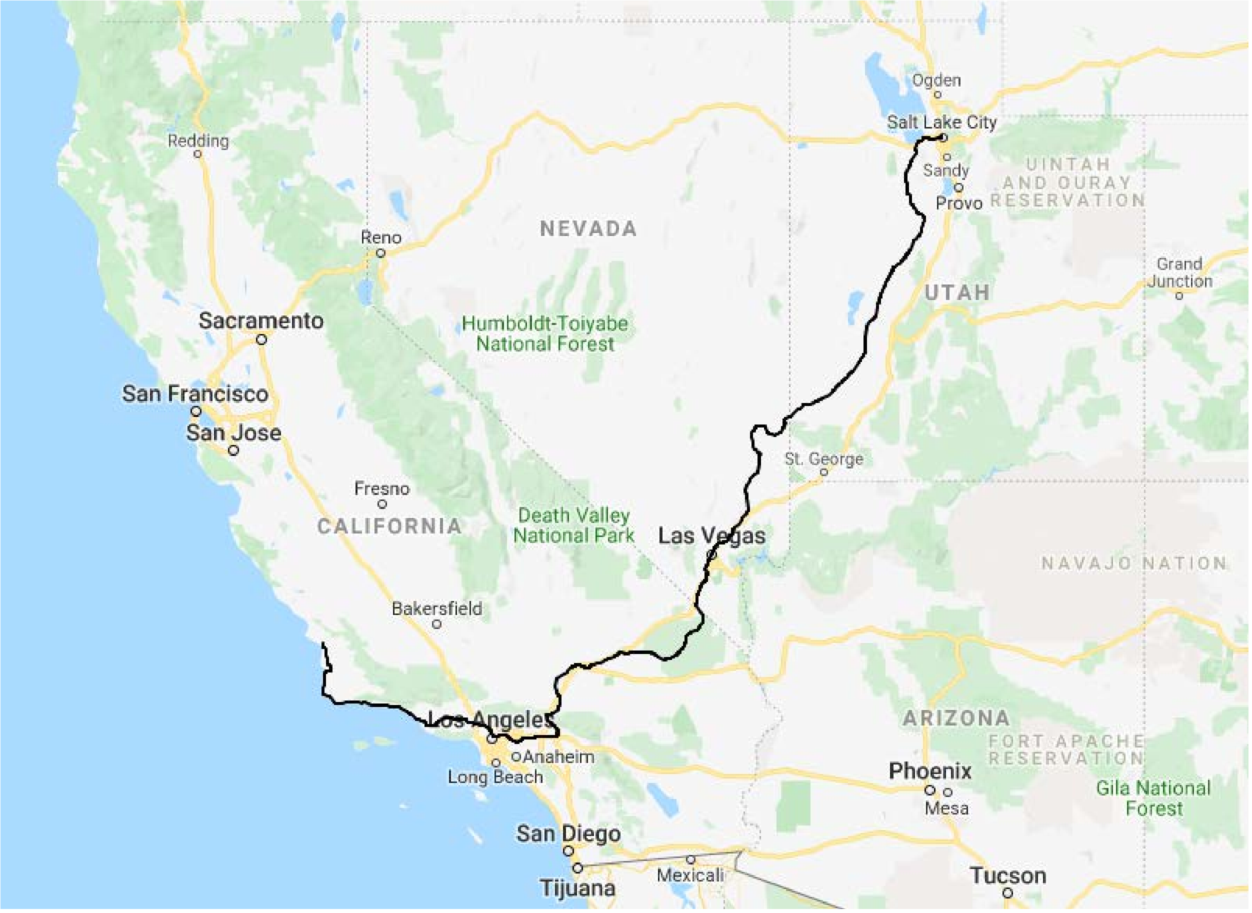


Figure B- 22. Rail Route from Pismo Beach Rail Yard to Salt Lake City

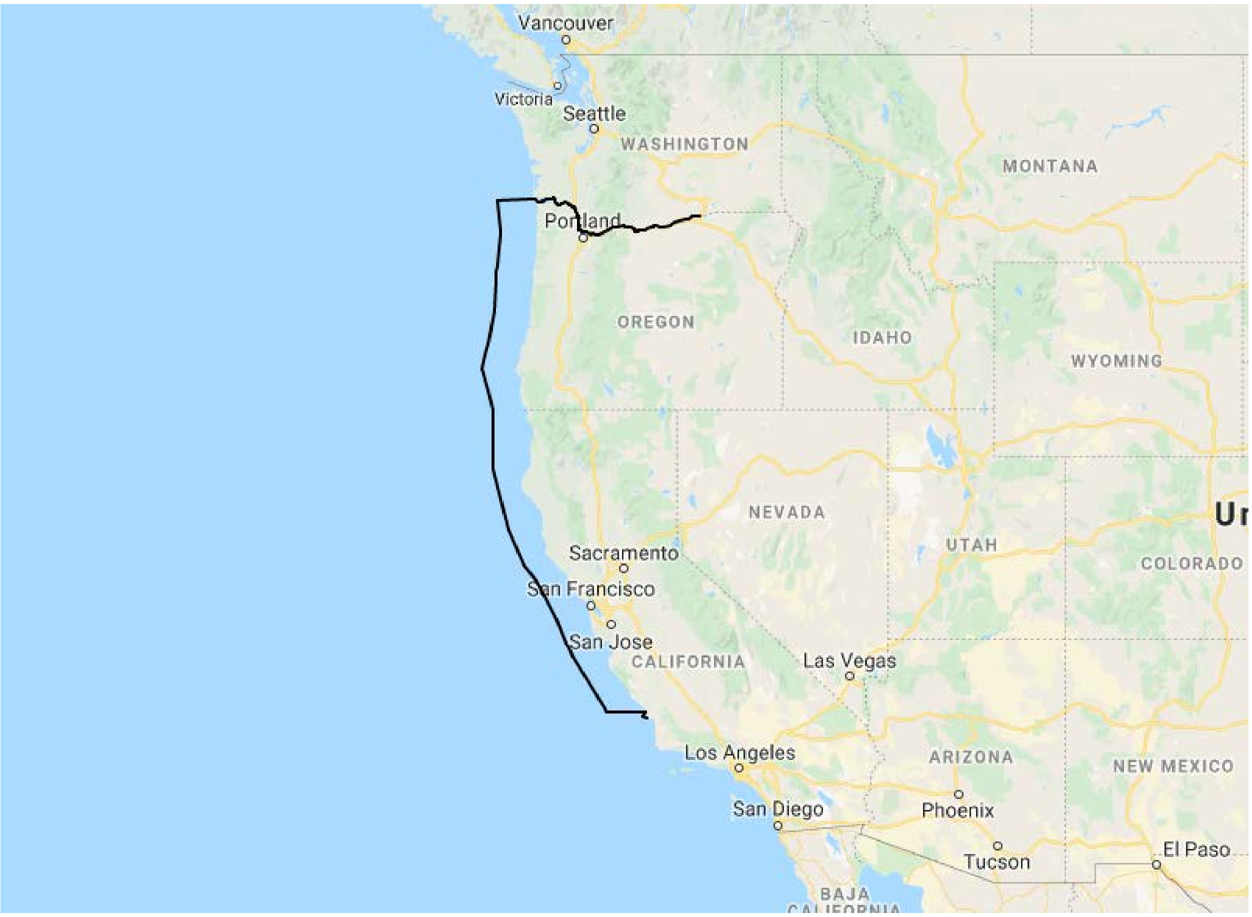


Figure B- 23. Barge Route from DCPP to Boardman, OR

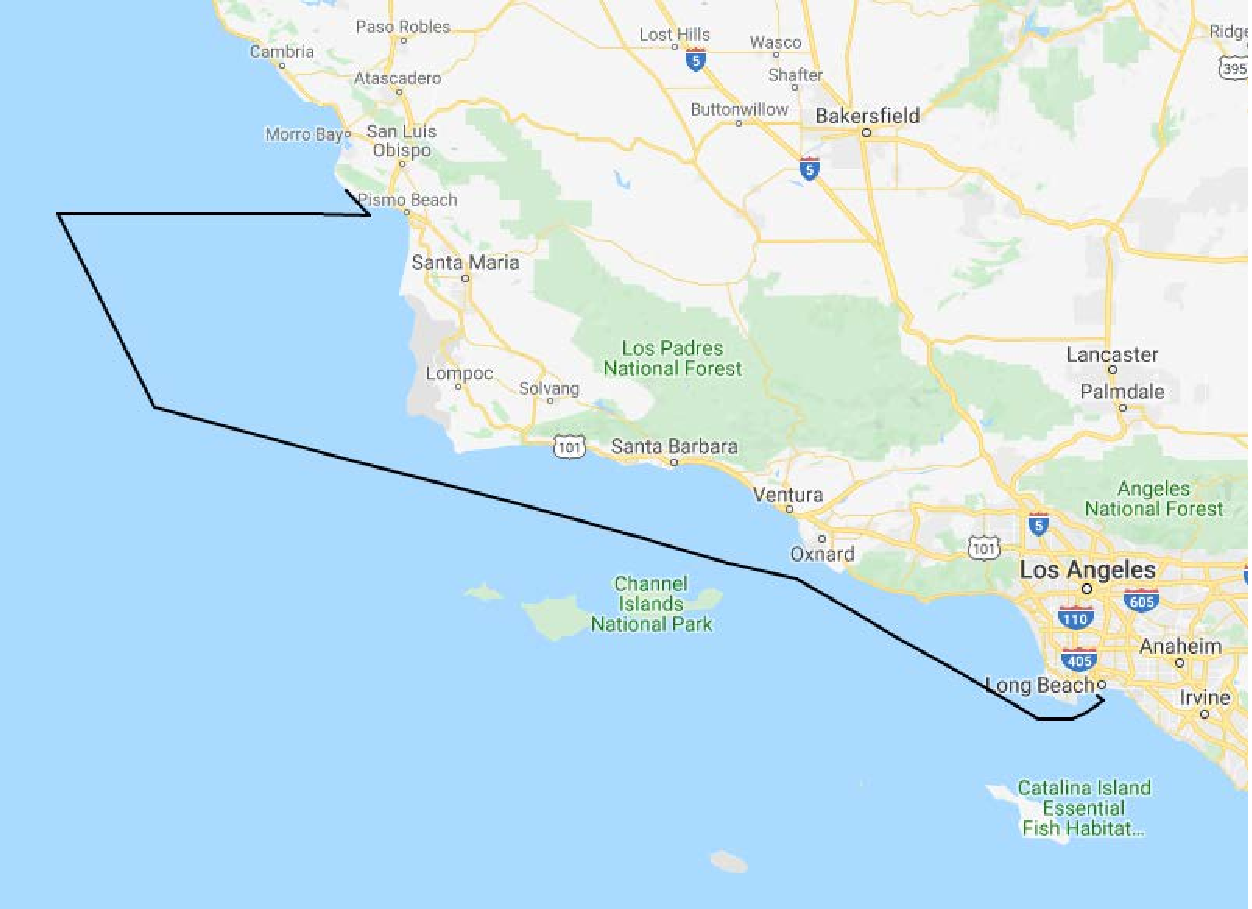


Figure B- 24. Barge Route from DCPP to Long Beach Port

Appendix C – Parameters in Aquatic Dispersion Model

In Tables C-1 and C-2 "Reference 2" means the report "Determining the Suitability of Materials for Disposal at Sea under the London Convention 1972 and London Protocol 1996: A Radiological Assessment Procedure", 2015. All other information is from the IAEA report "Generic Models for Use in Assessing the Impact of Discharges of Radioactive Substances to the Environment", 2001.

Table C- 1. Parameters in Coastal Waters Model

Parameter	Definition	Value
$U\,(m/s)$	Coastal current speed	1.00E-01
$D\,(m)$	Water depth at release point	6.67E+02
$y_0\ (m)$	Offshore distance	6.00E+00
$x_{shore}\ (m)$	Location downcurrent from release point	1.00E+04
$x_{fishing}\ (m)$	Fishing site location, default 50 times the water depth	3.34E+04
$S_s\ (kg/m^3)$	Suspended sediment concentration (Pg 54 for coastal sea)	1.00E-02
$T_e\ (s)$	Effective accumulation time	3.15E+07
O_f	Fraction of the year for which a hypothetical critical group member is exposed to this particular pathway, default values in Table XIV, chosen adult working over contaminated sediments	1.80E-01
$H_{fish}\ (kg/a)$	Consumption rate for fish from Table XVIII (North America)	4.00E+01
$H_{shellfish}\ (kg/a)$	Consumption rate for shellfish from Table XVIII (North America)	1.50E+01
$DF_{ing}\ (Sv/Bq)$	Dose coefficient for ingestion from Table XVII	
$H_{shore}\ (kg/a)$	Ingestion rate of sediment on beach (Table 8 Pg 46 Reference 2)	4.38E-02
$L_B\ (m)$	Thickness of boundary sediment layer in box (m) Table 7 Pg 46 Reference 2	1.00E-02
$d_S\ (kg/m^3)$	Bulk sediment density Table 7	1.50E+03
$C_{spray}\ (kg/m^3)$	Seaspray concentration in air Table 7	1.00E-02
$DL_{shore}\ (kg/m^3)$	Dust loading on shore	2.50E-10
$R_{inh}\ (m^3/a)$	Public breathing rate Table 8	8.06E+03
$d_w\ (kg/m^3)$	Density of seawater	1.00E+03
$g\ (Sv/a\ per\ Bq/L)$	Tritium dose rate factor	2.60E-08
$O_{Coll,public}\ (man\text{-}h/a/m)$	Table 9, Pg 46 Reference 2	5.00E+01
$L_{shore}\ (m)$	Table 9, Pg 46 Reference 2	1.00E+04
$t_{public}\ (hr)$	Table 8, Pg 46 Reference 2	1.60E+03
$f_{B,fish}$	Table 9, Pg 46 Reference 2	5.00E-01

Parameter	Definition	Value
$f_{B,shellfish}$	Table 9, Pg 46 Reference 2	3.50E-01
$N_{B,fish}$ (kg/a)	Table 9, Pg 46 Reference 2	5.00E+05
$N_{B,shellfish}$ (kg/a)	Table 9, Pg 46 Reference 2	2.00E+05
$H3_{Population}$	Derived exposed population for Collective H3 Dose. N_B_fish x f_B_fish divided by H_fish	6.25E+03

Table C- 2. Parameters in Navigable Rivers Model

Parameter	Definition	Value
$U\,(m/s)$	Coastal current speed	1.00E-01
$D\,(m)$	Water depth at release point	6.67E+02
$y_0\ (m)$	Offshore distance	6.00E+00
$x_{shore}\ (m)$	Location downcurrent from release point	1.00E+04
$x_{fishing}\ (m)$	Fishing site location, default 50 times the water depth	3.34E+04
$S_s\ (kg/m^3)$	Suspended sediment concentration (Pg 54 Rep1 for coastal sea)	1.00E-02
$T_e\ (s)$	Effective accumulation time	3.15E+07
O_f	Fraction of the year for which a hypothetical critical group member is exposed to this particular pathway, default values in Table XIV, chosen adult working over contaminated sediments	1.80E-01
$H_{fish}\ (kg/a)$	Consumption rate for fish from Table XVIII (North America)	4.00E+01
$H_{shellfish}\ (kg/a)$	Consumption rate for shellfish from Table XVIII (North America)	1.50E+01
$DF_{ing}\ (Sv/Bq)$	Dose coefficient for ingestion from Table XVII	
$H_{shore}\ (kg/a)$	Ingestion rate of sediment on beach (Table 8 Pg 46 Rep2)	4.38E-02
$L_B\ (m)$	Thickness of boundary sediment layer in box (m) Table 7 Pg 46 Rep2	1.00E-02
$d_S\ (kg/m^3)$	Bulk sediment density Table 7	1.50E+03
$C_{spray}\ (kg/m^3)$	Seaspray concentration in air Table 7	1.00E-02
$DL_{shore}\ (kg/m^3)$	Dust loading on shore	2.50E-10
$R_{inh}\ (m^3/a)$	Public breathing rate Table 8	8.06E+03
$d_w\ (kg/m^3)$	Density of seawater	1.00E+03
$g\,(Sv/a\ per\ Bq/L)$	Tritium dose rate factor	2.60E-08
$O_{Coll,public}$ $(man\text{-}h/a/m)$	Table 9, Pg 46 Rep2	5.00E+01
$L_{shore}\ (m)$	Table 9, Pg 46 Rep2	1.00E+04
$t_{public}\ (hr)$	Table 8, Pg 46 Rep2	1.60E+03
$f_{B,fish}$	Table 9, Pg 46 Rep2	5.00E-01
$f_{B,shellfish}$	Table 9, Pg 46 Rep2	3.50E-01
$N_{B,fish}\ (kg/a)$	Table 9, Pg 46 Rep2	5.00E+05

Parameter	**Definition**	**Value**
$N_{B,shellfish}$ (kg/a)	Table 9, Pg 46 Rep2	2.00E+05
$H3_{Population}$	Derived exposed population for Collective H3 Dose. N_B_fish x f_B_fish divided by H_fish	6.25E+03

Appendix D – Loss of Shielding Events during Transportation of Class B/C Wastes

Table D- 1. Consequences and Risks for Loss of Shielding During Rail Accidents (no Fire

		The Conditional Dose Risk (in MREM) to the MEI at Distances from the Cask from 1 to 5 Meters for 1 Hour for a Rail Event (No Fire)					The Dose (in MREM) to the MEI at Distances from the Cask from 1 to 5 Meters for 1 Hour for a Rail Event (No Fire)				
Fraction of Slumped Lead	**Conditional Probability**	**Distance from the Package (M)**					**Distance from the Package (M)**				
		1	**2**	**3**	**4**	**5**	**1**	**2**	**3**	**4**	**5**
1.84E-05	1.90E-06	2.72E-08	1.36E-08	9.03E-09	6.76E-09	5.42E-09	1.43E-02	7.14E-03	4.75E-03	3.56E-03	2.85E-03
2.80E-04	4.31E-07	9.14E-09	4.40E-09	2.88E-09	2.13E-09	1.69E-09	2.12E-02	1.02E-02	6.69E-03	4.95E-03	3.92E-03
3.37E-04	3.40E-10	7.82E-12	3.74E-12	2.44E-12	1.80E-12	1.42E-12	2.30E-02	1.10E-02	7.17E-03	5.30E-03	4.19E-03
1.31E-03	1.79E-11	1.03E-12	4.73E-13	3.01E-13	2.18E-13	1.70E-13	5.73E-02	2.64E-02	1.68E-02	1.22E-02	9.50E-03
3.16E-03	3.80E-06	5.09E-07	2.31E-07	1.46E-07	1.05E-07	8.13E-08	1.34E-01	6.08E-02	3.83E-02	2.76E-02	2.14E-02
3.73E-03	8.62E-07	1.38E-07	6.23E-08	3.91E-08	2.82E-08	2.18E-08	1.60E-01	7.23E-02	4.54E-02	3.27E-02	2.53E-02
4.26E-03	6.79E-10	1.25E-10	5.64E-11	3.54E-11	2.55E-11	1.98E-11	1.84E-01	8.31E-02	5.22E-02	3.76E-02	2.91E-02
5.12E-03	3.57E-11	8.03E-12	3.61E-12	2.27E-12	1.63E-12	1.26E-12	2.25E-01	1.01E-01	6.36E-02	4.57E-02	3.54E-02
1.70E-02	6.34E-07	5.46E-07	2.45E-07	1.53E-07	1.10E-07	8.50E-08	8.61E-01	3.86E-01	2.42E-01	1.73E-01	1.34E-01
2.34E-02	1.44E-07	1.79E-07	8.01E-08	5.01E-08	3.59E-08	2.78E-08	1.24E+00	5.56E-01	3.48E-01	2.49E-01	1.93E-01
6.34E-02	1.13E-10	4.42E-10	1.98E-10	1.24E-10	8.87E-11	6.85E-11	3.91E+00	1.75E+00	1.10E+00	7.85E-01	6.06E-01
7.25E-02	5.96E-12	2.72E-11	1.22E-11	7.63E-12	5.46E-12	4.21E-12	4.57E+00	2.05E+00	1.28E+00	9.16E-01	7.07E-01

Table D- 2. Consequences and Risks for Loss of Shielding During Rail Accidents (no Fire)

		The Conditional Dose Risk (in MREM) to the MEI at Distances from the Cask from 1 to 5 Meters for 1 Hour for a Rail Event (No Fire)					**The Dose (in MREM) to the MEI at Distances from the Cask from 1 to 5 Meters for 1 Hour for a Rail Event (No Fire)**			
Fraction of Slumped Lead	**Conditional Probability**	**Distance from the Package (M)**					**Distance from the Package (M)**			
		10	**20**	**50**	**100**		**10**	**20**	**50**	**100**
1.84E-05	1.90E-06	1.53E-09	3.84E-10	6.14E-11	1.53E-11		8.06E-04	2.02E-04	3.23E-05	8.06E-06
2.80E-04	4.31E-07	3.47E-10	8.71E-11	1.39E-11	3.47E-12		8.06E-04	2.02E-04	3.23E-05	8.06E-06
3.37E-04	3.40E-10	2.74E-13	6.87E-14	1.10E-14	2.74E-15		8.07E-04	2.02E-04	3.23E-05	8.06E-06
1.31E-03	1.79E-11	1.45E-14	3.62E-15	5.78E-16	1.45E-16		8.09E-04	2.02E-04	3.23E-05	8.08E-06
3.16E-03	3.80E-06	3.12E-09	7.79E-10	1.25E-10	3.11E-11		8.22E-04	2.05E-04	3.28E-05	8.18E-06
3.73E-03	8.62E-07	7.15E-10	1.78E-10	2.84E-11	7.09E-12		8.29E-04	2.07E-04	3.30E-05	8.23E-06
4.26E-03	6.79E-10	5.68E-13	1.41E-13	2.25E-14	5.62E-15		8.36E-04	2.08E-04	3.32E-05	8.28E-06
5.12E-03	3.57E-11	3.03E-14	7.57E-15	1.20E-15	3.00E-16		8.50E-04	2.12E-04	3.37E-05	8.39E-06
1.70E-02	6.34E-07	8.69E-10	2.10E-10	3.21E-11	7.80E-12		1.37E-03	3.31E-04	5.07E-05	1.23E-05
2.34E-02	1.44E-07	2.78E-10	6.60E-11	9.88E-12	2.36E-12		1.93E-03	4.58E-04	6.86E-05	1.64E-05
6.34E-02	1.13E-10	1.15E-12	2.64E-13	3.80E-14	8.76E-15		1.02E-02	2.34E-03	3.36E-04	7.75E-05
7.25E-02	5.96E-12	7.93E-14	1.82E-14	2.60E-15	5.96E-16		1.33E-02	3.05E-03	4.37E-04	1.00E-04

Table D- 3. Consequences and Risks for Loss of Shielding During Rail Accidents (With Fire)

	The Conditional Dose Risk (in MREM) to the MEI at Distances from the Cask from 1 to 5 Meters for 1 Hour for a Rail Event (With Fire)						**The Dose (in MREM) to the MEI at Distances from the Cask from 1 to 5 Meters for 1 Hour for a Rail Event (No Fire)**				
Fraction of Slumped Lead	**Conditional Probability**	**Distance from the Package (M)**					**Distance from the Package (M)**				
		1	**2**	**3**	**4**	**5**	**1**	**2**	**3**	**4**	**5**
2.01E-02	8.70E-15	1.98E-06	8.89E-07	5.55E-07	3.99E-07	3.08E-07	1.04E+00	4.68E-01	2.92E-01	2.10E-01	1.62E-01
8.14E-02	3.70E-10	2.25E-04	1.01E-06	6.29E-07	4.53E-07	3.49E-07	5.23E+02	2.34E+00	1.46E+00	1.05E+00	8.09E-01

Table D- 4. Consequences and Risks for Loss of Shielding During Rail Accidents (With Fire)

	The Conditional Dose Risk (in MREM) to the MEI at Distances from the Cask from 10 to 100 Meters for 1 Hour for a Rail Event (With Fire)						**The Dose (in MREM) to the MEI at Distances from the Cask from 1 to 5 Meters for 1 Hour for a Rail Event (With Fire)**			
Fraction of Slumped Lead	**Conditional Probability**	**Distance from the Package (M)**					**Distance from the Package (M)**			
		10	**20**	**50**	**100**		**10**	**20**	**50**	**100**
2.01E-02	8.70E-15	1.41E-17	3.37E-18	5.10E-19	5.10E-19		1.62E-03	3.87E-04	5.86E-05	5.86E-05
8.14E-02	3.70E-10	6.22E-12	1.42E-12	2.04E-13	2.04E-13		1.68E-02	3.85E-03	5.50E-04	5.50E-04

Table D- 5. Consequences and Risks for Loss of Shielding During Truck Accidents (no Fire)

	The Conditional Dose Risk (in MREM) to the MEI at Distances from the Cask from 1 to 5 Meters for 1 Hour for a Highway Event (No Fire)					**The Dose (in MREM) to the MEI at Distances from the Cask from 1 to 5 Meters for 1 Hour for a Highway Event (No Fire)**				
Conditional Probability	**Distance from the Package (M)**					**Distance from the Package (M)**				
	1	**2**	**3**	**4**	**5**	**1**	**2**	**3**	**4**	**5**
1.90E-06	2.72E-08	1.36E-08	9.03E-09	6.76E-09	5.42E-09	1.43E-02	7.14E-03	4.75E-03	3.56E-03	2.85E-03
4.31E-07	9.14E-09	4.40E-09	2.88E-09	2.13E-09	1.69E-09	2.12E-02	1.02E-02	6.69E-03	4.95E-03	3.92E-03
3.40E-10	7.82E-12	3.74E-12	2.44E-12	1.80E-12	1.42E-12	2.30E-02	1.10E-02	7.17E-03	5.30E-03	4.19E-03
1.79E-11	1.03E-12	4.73E-13	3.01E-13	2.18E-13	1.70E-13	5.73E-02	2.64E-02	1.68E-02	1.22E-02	9.50E-03
3.80E-06	5.09E-07	2.31E-07	1.46E-07	1.05E-07	8.13E-08	1.34E-01	6.08E-02	3.83E-02	2.76E-02	2.14E-02
8.62E-07	1.38E-07	6.23E-08	3.91E-08	2.82E-08	2.18E-08	1.60E-01	7.23E-02	4.54E-02	3.27E-02	2.53E-02
6.79E-10	1.25E-10	5.64E-11	3.54E-11	2.55E-11	1.98E-11	1.84E-01	8.31E-02	5.22E-02	3.76E-02	2.91E-02
3.57E-11	8.03E-12	3.61E-12	2.27E-12	1.63E-12	1.26E-12	2.25E-01	1.01E-01	6.36E-02	4.57E-02	3.54E-02
6.34E-07	5.46E-07	2.45E-07	1.53E-07	1.10E-07	8.50E-08	8.61E-01	3.86E-01	2.42E-01	1.73E-01	1.34E-01
1.44E-07	1.79E-07	8.01E-08	5.01E-08	3.59E-08	2.78E-08	1.24E+00	5.56E-01	3.48E-01	2.49E-01	1.93E-01
1.13E-10	4.42E-10	1.98E-10	1.24E-10	8.87E-11	6.85E-11	3.91E+00	1.75E+00	1.10E+00	7.85E-01	6.06E-01
5.96E-12	2.72E-11	1.22E-11	7.63E-12	5.46E-12	4.21E-12	4.57E+00	2.05E+00	1.28E+00	9.16E-01	7.07E-01

Table D- 6. Consequences and Risks for Loss of Shielding During Truck Accidents (no Fire)

	The Conditional Dose Risk (in MREM) to the MEI at Distances from the Cask from 1 to 5 Meters for 1 Hour for a Highway Event (No Fire)					**The Dose (in MREM) to the MEI at Distances from the Cask from 1 to 5 Meters for 1 Hour for a Highway Event (No Fire)**			
Conditional Probability	**Distance from the Package (M)**					**Distance from the Package (M)**			
	10	**20**	**50**	**100**		**10**	**20**	**50**	**100**
1.90E-06	1.53E-09	3.84E-10	6.14E-11	1.53E-11		8.06E-04	2.02E-04	3.23E-05	8.06E-06
4.31E-07	3.47E-10	8.71E-11	1.39E-11	3.47E-12		8.06E-04	2.02E-04	3.23E-05	8.06E-06
3.40E-10	2.74E-13	6.87E-14	1.10E-14	2.74E-15		8.07E-04	2.02E-04	3.23E-05	8.06E-06
1.79E-11	1.45E-14	3.62E-15	5.78E-16	1.45E-16		8.09E-04	2.02E-04	3.23E-05	8.08E-06
3.80E-06	3.12E-09	7.79E-10	1.25E-10	3.11E-11		8.22E-04	2.05E-04	3.28E-05	8.18E-06
8.62E-07	7.15E-10	1.78E-10	2.84E-11	7.09E-12		8.29E-04	2.07E-04	3.30E-05	8.23E-06
6.79E-10	5.68E-13	1.41E-13	2.25E-14	5.62E-15		8.36E-04	2.08E-04	3.32E-05	8.28E-06
3.57E-11	3.03E-14	7.57E-15	1.20E-15	3.00E-16		8.50E-04	2.12E-04	3.37E-05	8.39E-06
6.34E-07	8.69E-10	2.10E-10	3.21E-11	7.80E-12		1.37E-03	3.31E-04	5.07E-05	1.23E-05
1.44E-07	2.78E-10	6.60E-11	9.88E-12	2.36E-12		1.93E-03	4.58E-04	6.86E-05	1.64E-05
1.13E-10	1.15E-12	2.64E-13	3.80E-14	8.76E-15		1.02E-02	2.34E-03	3.36E-04	7.75E-05
5.96E-12	7.93E-14	1.82E-14	2.60E-15	5.96E-16		1.33E-02	3.05E-03	4.37E-04	1.00E-04

Table D- 7. Consequences and Risks for Loss of Shielding During Truck Accidents (With Fire)

	The Conditional Dose Risk (in MREM) to the MEI at Distances from the Cask from 1 to 5 Meters for 1 Hour for a Highway Event (With Fire)						**The Dose (in MREM) to the MEI at Distances from the Cask from 1 to 5 Meters for 1 Hour for a Highway Event (With Fire)**				
Fraction of Slumped Lead	**Conditional Probability**	**Distance from the Package (M)**					**Distance from the Package (M)**				
		1	**2**	**3**	**4**	**5**	**1**	**2**	**3**	**4**	**5**
2.01E-02	3.54E-15	3.68E-15	1.66E-15	1.03E-15	7.43E-16	5.73E-16	1.04E+00	4.68E-01	2.92E-01	2.10E-01	1.62E-01
8.14E-02	1.50E-10	7.85E-08	3.51E-10	2.19E-10	1.58E-10	1.21E-10	5.23E+02	2.34E+00	1.46E+00	1.05E+00	8.09E-01

Table D- 8. Consequences and Risks for Loss of Shielding During Truck Accidents (With Fire)

	The Conditional Dose Risk (in MREM) to the MEI at Distances from the Cask from 10 to 100 Meters for 1 Hour for a Highway Event (With Fire)					**The Dose (in MREM) to the MEI at Distances from the Cask from 1 to 5 Meters for 1 Hour for a Highway Event (With Fire)**			
Fraction of Slumped Lead	**Conditional Probability**	**Distance from the Package (M)**				**Distance from the Package (M)**			
		10	**20**	**50**	**100**	**10**	**20**	**50**	**100**
2.01E-02	3.54E-15	5.73E-18	1.37E-18	2.07E-19	2.07E-19	1.62E-03	3.87E-04	5.86E-05	5.86E-05
8.14E-02	1.50E-10	2.52E-12	5.78E-13	8.25E-14	8.25E-14	1.68E-02	3.85E-03	5.50E-04	5.50E-04

Appendix E – Sample RADTRAN Input File

RADTRAN Input File for Route 6a – Class A Metals from DCPP-S to PBRY by Truck

```
RADTRAN 6      July 2008

 TITLE ACCIDENT CALCULATIONS FOR ROUTE 6F SOUTH TO PBRY BY HIGHWAY METAL CLASS A WASTE
 INPUT STANDARD
 OUTPUT CI_REM
 FORM UNIT
 DIMEN 2 0 18
 PARM 0 3 3 1
 SEVERITY
    NPOP=1
       NMODE=1
        0.0 1.0

    NPOP=2
       NMODE=1
        0.0 1.0

    NPOP=3
       NMODE=1
        0.0 1.0

 RELEASE

    GROUP=PART
       RFRAC 0.0 1.0E-03

       AERSOL 0.0 1.0E-03

       RESP 0.0 0.05

       DEPVEL 0.01

 PSPROB 0.00E+00 0.00E+00 0.00E+00 1.00E+00 0.00E+00 0.00E+00

 PACKAGE IMC 14.00 1.0 0.0 6.10
Co60   1.53E+02     PART    && CLASS A WASTE
Cr51   1.21E+02     PART
Ni63   1.12E+02     PART
Fe55   6.64E+01     PART
Co58   3.43E+01     PART
Nb95   3.43E+01     PART
Zr95   2.23E+01     PART
Mn54   1.03E+01     PART
Sb125  6.30E+00     PART

 END
 VEHICLE -1 DCPP_HI 14.00 1.0 0.0 6.10 1304 1.0 3.0 0.38 2.43 IMC 1.0
 FLAGS
    IUOPT 2
    REGCHECK 0
 EOF

 LINK  NRFR1  DCPP_HI  13.93  50.11  1.5  18.918   1155  7.74E-07 1.13E-02  R  1  0.5
 LINK  NRFS2  DCPP_HI  4.676  70.44  1.5  61.441   2414  7.74E-07 1.13E-02  S  1  0
 LINK  NRFS3  DCPP_HI  7.975  87.53  1.5  283.926  2414  7.74E-07 1.13E-02  S  1  0


 STOP NO_RELEASE_ACCIDENT DCPP_HI 1 30 800 1 127
 STOP RESPONDER DCPP_HI 1.0 3.0 3.0 1.0 10

 EOF
 EOI
```

Appendix F – Barge Travel Data

Data provided by Waterborne Commerce Statistics Center.

Total miles traveled by barge nationally by barge type for calendar years 1994-2018.

CY	Vessel Type	Barge Miles
2018	Dry Cargo Barge	191,660,673
2018	Liquid Barge	48,601,760
2017	Dry Cargo Barge	190,901,644
2017	Liquid Barge	43,982,465
2016	Dry Cargo Barge	190,361,845
2016	Liquid Barge	46,123,179
2015	Dry Cargo Barge	187,677,809
2015	Liquid Barge	47,848,690
2014	Dry Cargo Barge	196,130,222
2014	Liquid Barge	49,224,755
2013	Dry Cargo Barge	177,722,978
2013	Liquid Barge	47,896,063
2012	Dry Cargo Barge	199,847,163
2012	Liquid Barge	46,262,093
2011	Dry Cargo Barge	196,925,611
2011	Liquid Barge	43,788,984
2010	Dry Cargo Barge	201,673,855
2010	Liquid Barge	42,444,551
2009	Dry Cargo Barge	193,388,933
2009	Liquid Barge	42,850,088
2008	Dry Cargo Barge	196,076,252
2008	Liquid Barge	44,789,183
2007	Dry Cargo Barge	197,717,968
2007	Liquid Barge	48,417,149
2006	Dry Cargo Barge	208,642,961
2006	Liquid Barge	48,807,779
2005	Dry Cargo Barge	205,268,406
2005	Liquid Barge	47,434,655
2004	Dry Cargo Barge	212,620,996
2004	Liquid Barge	48,805,594
2003	Dry Cargo Barge	218,395,353
2003	Liquid Barge	48,897,918
2002	Dry Cargo Barge	236,290,479
2002	Liquid Barge	48,005,560

Data provided by Waterborne Commerce Statistics Center.

Total miles traveled by barge nationally by barge type for calendar years 1994-2018.

CY	Vessel Type	Barge Miles
2001	Dry Cargo Barge	238,382,059
2001	Liquid Barge	51,184,024
2000	Dry Cargo Barge	248,640,871
2000	Liquid Barge	53,365,700
1999	Dry Cargo Barge	255,661,827
1999	Liquid Barge	52,549,766
1998	Dry Cargo Barge	242,076,814
1998	Liquid Barge	53,784,454
1997	Dry Cargo Barge	247,746,246
1997	Liquid Barge	54,804,938
1996	Dry Cargo Barge	258,657,381
1996	Liquid Barge	54,159,703
1995	Dry Cargo Barge	262,495,459
1995	Liquid Barge	54,644,740
1994	Dry Cargo Barge	242,108,731
1994	Liquid Barge	54,226,267