Railroad Carrier Employee Exposure to Radiation

Report to Congress
September 2010

U.S. Department of Transportation

Federal Railroad Administration

Office of Railroad Safety

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Contents

The Mandate

Section 411 of the Federal Railroad Safety Improvement Act of 2008 (Pub. L. No. 110-432) reads as follows:

> (a) STUDY. The Secretary of Transportation shall, in consultation with the Secretary of Energy, the Secretary of Labor, the Administrator of the Environmental Protection Agency, and the Chairman of the Nuclear Regulatory Commission, as appropriate, conduct a study of the potential hazards to which employees of railroad carriers and railroad contractors or subcontractors are exposed during the transportation of high-level radioactive waste and spent nuclear fuel (as defined in section 5101(a) of title 49, United States Code), supplementing the report submitted under section 5101(b) of that title, which may include—
> (1) an analysis of the potential application of “as low as reasonably achievable” principles for exposure to radiation to such employees with an emphasis on the need for special protection from radiation exposure for such employees during the first trimester of pregnancy or who are undergoing or have recently undergone radiation therapy;
> (2) the feasibility of requiring real-time dosimetry monitoring for such employees;
> (3) the feasibility of requiring routine radiation exposure monitoring in fixed railroad locations, such as yards and repair facilities; and
> (4) a review of the effectiveness of the Department’s packaging requirements for radioactive materials.
> (b) REPORT. Not later than 18 months after the date of enactment of this Act, the Secretary of Transportation shall transmit a report on the results of the study required by subsection (a) and any recommendations to further protect employees of a railroad carrier or of a contractor or subcontractor to a railroad carrier from unsafe exposure to radiation during the transportation of high-level radioactive waste and spent nuclear fuel to the Senate Committee on Commerce, Science, and Transportation and the House of Representatives Committee on Transportation and Infrastructure.
> (c) REGULATORY AUTHORITY. The Secretary of Transportation may issue regulations that the Secretary determines appropriate, pursuant to the report required by subsection (b), to protect railroad employees from unsafe exposure to radiation during the transportation of radioactive materials.

Executive Summary

This report was prepared by the Federal Railroad Administration (FRA) following the specific mandate of Congress to investigate occupational exposures to ionizing radiation of specific groups of employees during railroad transportation of high-level radioactive waste (HLRW) and spent nuclear fuel (SNF). Commercial shipments of these types of materials are very rare since transportation to the Yucca Mountain Repository[1] is not being conducted at this time.

In an effort to establish the known levels of exposure to the materials in question, FRA obtained exposure information from one of the Class I railroads that has been conducting exposure monitoring during shipments of SNF materials. In addition, FRA reviewed reports of exposure assessments conducted in foreign locations where transportation by rail is occurring more frequently.

Both of these sources indicate that the different classes of workers identified in the mandate were found to have levels of exposure significantly lower than those expected, and also significantly lower than the radiation exposure dose limits established by the Occupational Safety and Health Administration (OSHA) in Title 29 Code of Federal Regulations (CFR) Section 1910.1096.

The data presented in this report include theoretical predictions of potential exposure to radiation, as well as real-world exposure assessments in the United States and two European countries. Both the theoretical findings and the real-world experience indicate that potential and actual exposures are well below the currently established permissible levels. All of the current regulatory permissible levels have been established recognizing the importance of the "as low as reasonably achievable" principles in minimizing exposures.

The real-world exposures in the three studies cited all found exposures well below regulatory limits. These facts would indicate that female employees exposed during the first trimester of pregnancy would not likely face a risk of adverse health effects to themselves or the fetus.

The medical and health implications of someone undergoing radiation therapy and the interaction with on-the-job exposures cannot be presumed, given the complexity of the medical procedures and types of therapy available in today's practice of medicine.

In response to the question of the feasibility of requiring routine radiation exposure monitoring in fixed railroad locations, such as yards and repair facilities, the study found that the use of dedicated trains results in minimal dwell time in such locations, and the already significant monitoring of the packages of HLRW and SNF required by regulation, along with the known shielding properties of the packages, would make monitoring of these types of sites redundant and unnecessarily costly, and would serve no practical purpose.

[1] The Yucca Mountain Repository is the United States' designated geological repository storage facility for spent nuclear reactor fuel and other radioactive waste. It is located between the Mohave and the Great Basin Deserts in Nevada.

The real-world levels measured by Norfolk Southern Railway (NS) during actual shipments indicate that the packaging far exceeds the minimum requirements for shielding, thereby providing an extra margin of safety for employees and the general public.

The U.S. Department of Transportation (DOT) does not believe that any regulatory action is necessary at this time to further protect railroad employees from unsafe exposure to radiation during the transportation of radioactive materials.

In preparing this report, FRA coordinated closely with the DOT Pipeline and Hazardous Materials Safety Administration (PHMSA), which also issues regulations governing the transportation of hazardous materials in all modes,[2] and with DOT's Office of the Secretary. In addition, FRA consulted with the U.S. Department of Energy (DOE), the Environmental Protection Agency, the Nuclear Regulatory Commission (NRC), and OSHA.

The transportation of SNF/HLRW is thoroughly regulated, and several Government agencies play active, highly coordinated roles to ensure its safety. Over the past 45 years, approximately 600 train movements of these materials have occurred by rail without any incidents affecting the integrity of the shipping packages. At the discretion of the shipper or carrier parties involved, a majority of these shipments were made using "special" or dedicated trains.[3] The responsible agencies work continually to verify the safety of packaging, rolling stock, and procedures, and oversee the training of personnel involved in transportation.

The railroad industry also issued its own standard for movement of these commodities, that seeks to establish performance guidelines for a cask/car/train system transporting high-level radioactive material. These guidelines are designed to ensure safe transportation, minimize time in transit, and incorporate the best available technology to minimize the potential for rail accidents.

During previous work involving these materials, specifically the report to Congress titled "Use of Dedicated Trains for Transportation of High-Level Radioactive Waste and Spent Nuclear Fuel" (March 2005), also called the Dedicated Train Study (DTS) conducted under a prior mandate,[4] the safety and integrity of the packaging and shipments was reported. This report will reference the DTS to the extent that it contains information contributing to the understanding of occupational exposures, which are the subject of this mandate.

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[2] FRA and PHMSA develop hazardous materials regulations specifically applicable to the rail mode for issuance by PHMSA. FRA enforces hazardous materials regulations applicable to transportation by rail. Both agencies act by delegation from the Secretary of Transportation.

[3] As used in this report, a "special" or "dedicated" train is a train that consists only of equipment and lading associated with the transportation of SNF/HLRW. That is, the train consists only of necessary motive power, buffer cars, and cask car or cars, together with a car for escort personnel. Such a train does not transport other rail rolling stock, other revenue freight, or other company freight.

[4] Section 15 of the Hazardous Materials Transportation Uniform Safety Act of 1990 (Pub. L. No. 101-615), amended Section 116 of the Hazardous Materials Transportation Act (49 U.S.C. App. 1813).

Background

Definitions and Discussion of Technical Terms and Concepts

A number of technical terms are used to describe the measurement of and exposure to radiation. Since these terms are used throughout the report, it will be helpful to begin with definitions and a brief discussion of these terms and concepts.

Radiation is energy that is emitted or transmitted in the form of rays, waves, or particles. Radio waves, light, and heat are forms of radiation. These are low-energy forms of radiation, and are considered non-ionizing radiation.

Ionizing radiation is radiation that has enough energy to remove electrons from atoms or molecules (groups of atoms) when it passes through or collides with another material. In the process called ionization, an atom or molecule loses an electron, which results in the formation of a charged atom (or molecule) that is called an ion. The amount of ionization depends on the level of energy of the impinging individual particles or waves, not their number. A large number of particles or waves with low energy will not cause ionization.

Note: It is assumed that the term "radiation," as used in the congressional mandate, means ionizing radiation. Therefore, in this report, the use of the word "radiation" means ionizing radiation. Many types and sources of both ionizing and non-ionizing radiation are present in the railroad environment when shipments of HLRW and SNF are moved.

Ionizing radiation can take the form of subatomic particles or electromagnetic waves. The two primary types of ionizing particles are alpha particles and beta particles.

> **Alpha particles** consist of two protons and two neutrons. They are relatively heavy, high-energy particles, with a positive charge of +2 from its two protons. Because of their large mass and electric charge, alpha particles travel relatively slowly in air and rapidly lose energy. They are easily stopped by a piece of paper or by coming in contact with human skin.
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> **Beta particles** are free electrons. They have a very low mass, about 1/2000 of the mass of a proton or neutron. Due to the small mass, the amount of ionization that beta particles can cause depends on the energy level imparted to them when they are created by the decay of radioactive materials such as tritium, carbon-14, and other similar substances. Beta particles can travel several feet in open air. They are easily stopped by solid materials such as sheets of aluminum, glass, or plexiglass.

There are two types of photon-ionizing (pure energy) radiation: gamma rays and x-rays.

> **Gamma radiation** is very high-energy ionizing radiation that has about 10,000 times as much energy as the photons in the visible range of the electromagnetic spectrum (visible light). Gamma photons are pure electromagnetic energy, thus, they have no mass and no electrical charge.

X-radiation is also very high-energy ionizing radiation, similar to gamma radiation, but generally has lower wave lengths and energy levels—although the ranges of energy and wavelength overlap for both types of radiation. The primary difference between the two types is where in the atom the energy waves originate; for gamma rays it is the nucleus, for x-rays it is the electrons. X-ray photons are also pure electromagnetic energy, therefore, they have no mass and no electrical charge. Since these types possess such high energy levels, the materials used to shield against them must be very dense, such as steel or lead.

Since the focus of this report is "the potential hazards to which employees are exposed during the transportation of high-level radioactive waste and spent nuclear fuel," the terms are defined below.

SNF is fuel that has been withdrawn from a nuclear reactor following irradiation and has undergone at least 1 year's decay since being used as a source of energy in a power reactor. Further, reprocessing has not separated the constituent elements of the SNF. This fuel includes:

1) Intact, non-defective fuel assemblies
2) Failed fuel assemblies in canisters
3) Fuel assemblies in canisters
4) Consolidated fuel rods in canisters
5) Non-fuel components inserted in pressurized water reactor fuel assemblies
6) Fuel channels attached to boiling water reactor fuel assemblies
7) Non-fuel components and structural parts of assemblies in canisters [42 U.S.C. 10101(23), 40 CFR 191.02, and DOE Order 5820.2A]

HLRW results from the reprocessing of SNF in a commercial or defense facility. It includes liquid waste produced directly in reprocessing, and any solid waste derived from the liquid that contains a combination of transuranic waste and fission products in concentrations requiring permanent isolation [42 U.S.C. § 10101(12), 10 CFR Part 72.3, and DOE Order 5820.2A]. HLRW meeting this definition is shipped by modes other than rail.

SNF and HLRW are required to be transported in casks constructed to NRC requirements. The casks are secured to specially constructed rail cars capable of transporting the heavy load.[5] A cask consist includes the cask car(s) surrounded by two buffer cars and accompanied by an escort car. A dedicated train is comprised of the cask consist and multiple locomotives. A regular or key train will include the cask consist, locomotive(s), and any number of additional cars potentially containing other regulated hazardous materials, various other general cargo,

[5] A typical cask assembly weighs about 250,000 pounds, and a loaded cask car weighs about 394,500 pounds. A typical rail load weighs about 286,000 pounds. Like other cars constructed to carry heavy loads, cask cars will most likely use additional axles and span bolsters to distribute the weight over a larger portion of the track structure. Other special loads transported on the railroad include large transformers and specialized industrial equipment.

and/or empty rail cars. In 2005, DOE issued a policy statement indicating "[DOE] will use dedicated train service (DTS) for its usual rail transport of spent nuclear fuel and high-level radioactive waste to the Yucca Mountain Repository site in Nevada when the repository is operational."

Although SNF/HLRW casks are required to be well shielded by design, some forms of radiation are very difficult to stop; therefore, the casks continuously emit very low levels of radiation throughout all phases of transportation. As a result, some unavoidable radiation exposure to crew, handlers, yard personnel, and the wayside population can occur whenever a shipment takes place. The emissions are limited to acceptable, permissible levels (a maximum of 10 millirems per hour (mrem/hr) at 3.3 feet (1 meter) from the surface of the package).[6] All individuals exposed to the radiation being emitted from the cask during transport, handling, loading, and unloading will receive very low doses of radiation.

Rail cars placarded as radioactive cannot be placed next to a locomotive or an occupied caboose.[7] A buffer car loaded with non-radioactive material must be placed between a car carrying radioactive materials and a locomotive or caboose.[8]

Measuring Radiation

When discussing radiation, we measure several different phenomena. The terms "activity," "exposure," and "dose" are some of the names that are used to describe radiation and to express the interaction of radiation in the environment and with humans. Since this report is concerned with radiation exposure to railroad employees, the units of exposure and dose most relevant to the discussion and are defined here.

Exposure to ionizing radiation is usually expressed in units of roentgen (R). The R unit defines the amount of ionization present in the air from gamma rays or x-rays. One R equals the electric charge of 258 microcoulombs per kilogram of air. One roentgen of gamma- or x-ray exposure produces approximately 1 radiation-absorbed tissue dose.

Dose measures the effect of radiation on substances that absorb it. It measures what radiation does to substances, not anything specific about the radiation itself. This permits the measurement of different types of radiation (particles or waves) by measuring the effect they have on the materials.

Rad is the acronym for *radiation-absorbed dose* in traditional English units. It defines the amount of energy from any type of ionizing radiation (e.g., alpha rays, beta rays, gamma rays, neutrons, etc.) deposited in any medium (e.g., water, human tissue, air). A dose of 1 rad is equivalent to the absorption of 100 ergs (a small but measurable amount of energy) per gram of absorbing medium.

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[6] 49 CFR § 173.441
[7] 49 CFR § 174.85(b)
[8] 49 CFR § 174.85(d)

Gray (Gy) is the international system (SI)[9] unit of radiation dose expressed in terms of absorbed energy per unit mass of tissue.

- 1 Gy = 1 Joule/kilogram.
- 1 Gy = 100 rad.

Relative Biological Effectiveness (RBE) is used to define a term known as the **Quality Factor** (Q factor). Different Q factors are assigned to different types of radiation since some types are more dangerous to biological tissue than others, even if their "energy deposition" levels are the same. The value of the quality factor for each type of radiation depends on the distribution of the absorbed energy in a mass of tissue.

- The Q factor is 1 for x-rays, gamma rays, and electrons.
- The Q factor is 10 for protons and neutrons.
- The Q factor is 20 for alpha particles. (Alpha radiation is considerably more potent than x-rays, beta rays, or gamma rays in causing cancer since the alpha particles that do the damage usually are inhaled or ingested and then incorporated in body tissue where they continue to emit energy.)

The Q factor defines the relationship between rads and rems (defined below). To calculate rems from rads, or sieverts (defined below) from Gys, multiply by Q. The Q factor approximates what otherwise would be very involved computations. For example:

- Gamma rays with the energy of 10 rad and a Q factor of 1 will produce a dose of 10 rem.
- Alpha particles with the energy of 10 rad and a Q factor of 20 will produce a dose of 200 rem.

Rem is the acronym for "roentgen equivalent man." It is the English unit of measurement of exposure that describes the effects of radiation specifically on human tissue.

Sievert (Sv) is the corresponding SI unit.

- 1 Sv = 100 rem
- 1 millisievert (mSv) = 100 mrem

Occupational exposures are characterized as doses, with limits based on the rate of exposure (generally mrem/hr, as well as overall accumulated exposure for a specified period). For example, 1250 mrem (12.5 mSv) is the maximum permissible dose for whole-body exposure per calendar quarter (in accordance with OSHA guidelines).

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[9] "SI" stands for Système International

Human Exposure to Radiation

Radiation has been naturally present in the environment since the birth of this planet. As a result, life has evolved in an environment with significant levels of ionizing radiation. The radiation comes from outer space (cosmic rays), the minerals in the ground, and within our own bodies since it is present in the air we breathe, the food we eat, and the water we drink. Certain foods grown in areas with naturally high levels of radiation in the soil contain higher levels of radiation than other foods. Rice and tapioca from the State of Kerala, India, and Brazil nuts, squash, kale, beans, cassava, and oranges are examples.

Radiation is also found in the minerals used for or incorporated in the construction materials used to build our homes and other structures. Brick and stone homes have higher natural radiation levels than homes made of other building materials such as wood. Our Nation's Capitol, which is largely constructed of granite, contains higher levels of natural radiation than most homes.

The average radiation dose from exposure to natural and manmade background radiation in the United States is approximately 360 mrem per year. As a rule of thumb, this exposure level nearly doubles for each mile of elevation above sea level. Therefore, living in Denver, CO; Flagstaff, AZ; or other cities at high elevations increases the average background dose to approximately 1000 mrem per year. The increase is due to higher contributions from cosmic radiation at higher altitudes and terrestrial radiation sources such as radon gas.

Radiation Exposure from Various Sources

Source	Exposure Level
External Background Radiation	60 mrem/yr, U.S. average
Natural Potassium–40 Radioactivity in Body	40 mrem/yr
Air Travel–1 Roundtrip (NY–LA)	5 mrem
Chest X-Ray–Effective Dose	10 mrem per film
Radon in the Home	~200 mrem/yr (variable)
Manmade (medical x-rays, etc.)	~60 mrem/yr (average)

Risks Associated with Radiation Exposure

The most significant risk associated with occupational exposure to ionizing radiation is the increased risk of cancer. The amount of that increased risk depends on three factors: the total dose of radiation received, the length of time over which that dose was received, and the specific body part or parts exposed. Genetic differences, age, and other individual personal factors are also thought to affect risk.

Our understanding of the risks of radiation exposure is primarily the result of studies of Japanese atomic bomb survivors, the Chernobyl reactor accident survivors, radium dial painters, and medical patients who are exposed through selected diagnostic or therapeutic medical procedures.

From these populations we know that acute (i.e., short in duration), very high radiation doses can increase the occurrence of certain kinds of diseases (e.g., cancer) and possibly have adverse genetic effects. The types of cancer associated with high-dose exposures (greater than 50,000 mrem) include leukemia and multiple myeloma as well as breast, bladder, colon, liver, lung, esophagus, ovarian, and stomach cancers. The U.S. Department of Health and Human Services (DHHS) literature also suggests a possible association between ionizing radiation exposure and prostate, nasal cavity/sinuses, pharyngeal, laryngeal, and pancreatic cancers.[10]

Since the human body has a number of mechanisms that can repair damage caused by radiation and chemical carcinogens, the effects of radiation on living cells can result in different outcomes, including:

- Injured or damaged cells that repair themselves with no lasting damage;
- Injured or damaged cells that die and are replaced through normal tissue replacement processes (millions of cells in the body do this normally every day); or
- Cells that incorrectly repair themselves (due to damage to the genetic code that directs the cell repair mechanism), resulting in a biological change.

Although it is assumed that exposure to low levels of radiation will lead to an increased risk of cancer, medical studies have not yet seen these adverse health effects in people who have been exposed to low-level, long-term radiation doses; for example, up to 10,000 mrem above background for more than 2 years.[11] When compared to the overall cancer rate in today's society, the increased risk of cancer from normal levels of *occupational* radiation exposure is small. In the United States, the current lifetime risk of dying from all types of cancer is approximately 23 percent in males and 20 percent in females.[12]

A very simple illustration of the *theoretical* increase in risk of dying from cancer due to occupational radiation exposure would be a person who receives a lifetime radiation dose of 10 rem (10,000 mrem) to the entire body. This person would have a risk of dying from cancer of about 20%, without otherwise being exposed to radiation other than that normally present in the environment. With the added exposure stated above, the person's risk of dying from cancer would increase to 20.4%.[13]

Latency and Other Sources of Damage

The period of time between exposure to a carcinogen and the detection of cancer can be many years. This period is known as the "latent period." Those cancers that may develop as a result of radiation exposure cannot be distinguished from cancers that have a natural origin or are a result

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[10] U.S. NRC Fact Sheet–"Biological Effects of Radiation" 2009.

[11] The National Research Council Committee on the Biological Effects of Ionizing Radiation, Health Effects of Exposure to Low Levels of Ionizing Radiation, BEIR V, Washington, DC, 1990.

[12] American Cancer Society, http://www.cancer.org/docroot/CRI/content/CRI_2_6x_Lifetime_Probability_of_Developing_or_Dying_From_Cancer.asp, April 2010.

[13] U.S. Nuclear Regulatory Commission, Instruction Concerning Risks from Occupational Radiation Exposure, Regulatory Guide 8.29, Rev. 1, NRC, Washington, DC, February 1996.

of exposure to chemical carcinogens. In addition, some cancer research literature indicates that other chemical and physical hazards and lifestyle factors (e.g., smoking, alcohol consumption, and diet) significantly contribute to the incidence and severity of these same cancers.

Although radiation may cause cancer at high doses and high-dose rates, currently there is no data that unambiguously establishes the occurrence of cancer following whole-body exposure to low doses (below about 10,000 mrem (100 mSv)) and low-dose rates. For example, people living in areas such as Denver, CO, where the levels of background radiation are higher than those typical in lower-altitude cities (near or above 1,000 mrem (10 mSv) per year)[14] have not shown any evidence of an increase in radiation-induced cancer rates when compared to rates in other States and in the United States, overall.

[14] U.S. NRC Fact Sheet–"Biological Effects of Radiation," 2009.

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Radiation Safety Practice

Radiation safety, as it is currently practiced, assumes adverse effects are possible with low-level, long-term exposure to radiation (i.e., less than 10,000 mrem). Radiation safety policies and standards have been established by international and national radiation protection organizations, such as the International Commission on Radiological Protection (ICRP) and the National Council on Radiation Protection and Measurements (NCRP), to limit potentially harmful radiation effects and protect the public, radiation workers, and the environment. Many of these policies and standards are reflected in the limits of exposure established by regulatory agencies such as the NRC and OSHA. All recognize the application of the "as low as reasonably achievable" principles in keeping exposure dose to a minimum.

"As low as reasonably achievable," or ALARA, is a basic radiation protection philosophy based on the assumption that there is no safe level of exposure to radiation. This assumption requires the belief that the probability for harmful biological effects increases with increased radiation doses, no matter how small. This assumption is under debate in the scientific community, reflecting the facts we know about everyday natural and manmade exposures to radiation and the current lack of evidence of increased risk. Much of our knowledge about health effects is derived from studies of populations exposed to very high doses of ionizing radiation, not from exposures at normal everyday levels. Application of ALARA principles means making every reasonable effort to maintain exposures to ionizing radiation as far below the established dose limits as practical, taking into account the state of technology, the economics of exposure reductions in relation to state of technology, the economics of exposure reductions in relation to the benefits to the public health and safety, etc.

The risks associated with low-level medical, occupational, and environmental radiation exposure are formulated to be proportional to those observed with high-level exposure. Regulatory limits for the allowable exposure dose for both the public and workers are set by Federal agencies. The Environmental Protection Agency (EPA), OSHA, NRC, DOE and State agencies have all established standards to limit cancer risk. In addition, radiation dose limits have been established to limit other potential biological impacts on worker populations such as effects on the skin and lens of the eye.

Annual Radiation Dose Limits

Dose	Agency	Population covered
5,000 mrem	NRC	Radiation Worker–NRC Licensee workers
5,000 mrem	OSHA	Radiation Worker–non-NRC Licensee workers
100 mrem	NRC	General Public–from NRC Licensee sources
10 mrem	EPA	General Public–air pathway
4 mrem	EPA	General Public–drinking-water pathway

All of these regulatory limits recognize that there are many sources of radiation exposure. As noted above, the presence of natural "background" radiation is included in the considerations for the safety factors built into these limits.

Protection from Exposure to Radiation

Time, distance, and shielding are used to reduce dose due to exposure to known sources of ionizing radiation.

Time. Since the dose of exposure is cumulative, the amount of time spent in proximity to a radiation source of a given intensity will increase the accumulated dose. If someone is exposed each workday to 15 mrem, their exposure will be just below the OSHA quarterly dose limit of 1,250 mrem for whole-body exposure.[15] The exposure dose of 15 mrem may be incurred throughout the day at about 2 mrem per hour or it may occur over a shorter period of higher exposure with offsetting periods of lower or no exposure.

Distance. Distance is another important concept, but a little more involved. Since radiation is a physical phenomenon, the intensity of radiation energy decreases at a known rate as the distance from the source increases. The rate of this decrease follows what is known as the "inverse square rule."

The inverse square rule describes how physical phenomena spread influence equally in all directions without a limit to range—a geometrically spherical spread. The intensity of the phenomenon at any given radius (r) is the source strength divided by the area of the sphere.

This means that you can predict the intensity of the energy contained in the particles or rays of radiation at a different location if you have determined the amount of radiation at a particular distance from the source. If you measure the intensity at 1 meter and it is 200 mrem, then it will be one fourth as much at 2 meters or 50 mrem, following the inverse square rule.

Shielding. Shielding is a barrier of some kind between the source of radiation and its surroundings. Alpha and beta particle radiation is easily stopped by materials with low thicknesses and densities. As an example, a sheet of ordinary paper will stop almost all alpha radiation and a thin sheet of plastic or metal will stop beta particles. More energetic photon-type radiation—gamma rays and x-rays—require thicker, more dense shielding.

The effectiveness of a shielding material, in general, increases with its electron density. High-mass density materials like lead have high electron densities. A sheet of lead is more effective than a sheet of steel of the same thickness, since lead has a higher electron density than steel.

Another important property of shielding is that it exponentially reduces the intensity of radiation depending on its thickness.

- A lead shield that is 1 cm (0.4 in) thick reduces the level of gamma radiation by 50% (for example, from 200 mrem to 100 mrem).
- To get the same level of shielding from steel, the sheet would have to be 2.5 times as thick.

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[15] OSHA has three different permissible limits for ionizing radiation based on the body part exposed. See the reproduction of the OSHA Table G-18 in the discussion of OSHA on page 18.

Both of the examples above are the half-value layer thicknesses of lead and steel, respectively. Half-value layer thickness means that each time you add another layer of a particular material of the same thickness, the level of radiation getting through is reduced by half of the incident level at the other side of the shielding. That means:

- A lead shield that is 5 cm (2 in) would reduce the level from 200 mrem to 6.25 mrem (5 half-value layers of lead).
- It would take 5 inches of steel to provide the same level of shielding (5 half-value layers of steel).

It is also true that shielding of the same material will provide the same level of protection for a given type of radiation regardless of the source of the radiation. Therefore, x-rays, whether they are from an x-ray machine or from a radioactive material that emits x-rays during radioactive decay, can be well-shielded by lead. Lead and other high-mass density materials are also good shielding materials for gamma radiation. Gamma radiation is the same type of radiation as x-rays (electromagnetic radiation), but it may differ significantly in energy from some x-rays.

One type of radiation that is not sufficiently shielded by typical high-mass density materials is neutron radiation. Neutrons are electrically neutral particles with significant energy and can pass fairly easily through many materials since they have no charge and do not interact with the electrons of materials through which they pass. In fact, low-mass materials are better for neutron shielding since interaction with the nucleus of their atoms are more likely to result in the transfer of the neutron energy to the nucleus. Hydrogen is the lowest-mass atom, so materials with high hydrogen content, such as water and plastics or other organic materials with high hydrogen content, make good neutron shielding. Concrete is another material frequently used for neutron shielding since the chemistry of concrete incorporates water into the finished material.

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Regulatory Regimes and Exposure Limits

There are several sets of regulations that are pertinent with respect to occupational exposures to radiation that may be encountered by railroad employees. While a number of the regulations have been mentioned already, this section provides an overview.

- DOE regulates exposure to ionizing radiation for employees at DOE facilities, including both Federal and contractor employees. This includes the regulation of all aspects of DOE shipments exclusive of the regulation of cask certificates, which are regulated by NRC.
- The Department of Defense (DOD) is responsible for worker exposures to ionizing radiation in DOD facilities and operations.
- NRC regulates worker and public exposure to ionizing radiation from specific materials for which NRC issues licenses. This includes transportation of those materials in the packages that they regulate.
- OSHA regulates worker exposure to ionizing radiation in many workplaces. OSHA standards cover worker exposures from all radiation sources except those identified above. These sources include x-ray equipment, accelerators, accelerator-produced materials, electron microscopes, and naturally occurring radioactive materials (NORM).
- DOT, through enforcement of limits on package emissions[16] and, for rail transportation, placement within trains,[17] limits worker and public exposures to ionizing radiation during transportation.

Of these regulations, the ones that are most relevant to this report and the exposures discussed here are those of NRC (in conjunction with DOT) and OSHA.

Nuclear Regulatory Commission Standards and Limits

As mentioned in the discussion of SNF/HLRW, the NRC establishes permitted levels of emissions from the casks used for transporting these materials. The NRC's regulations for transporting radioactive materials are found in 10 CFR Part 71. These limits are codified for enforcement by DOT under 49 CFR § 173.441. Section 71.47 defines external radiation standards for all packages:

> § 71.47 External radiation standards for all packages.
> (a) Except as provided in paragraph (b) of this section, each package of radioactive materials offered for transportation must be designed and prepared for shipment so that under conditions normally incident to transportation the radiation level does not exceed 2 mSv/h (200 mrem/h) at any point on the external surface of the package, and the transport index does not exceed 10.
> (b) A package that exceeds the radiation level limits specified in paragraph (a) of this section must be transported by exclusive use shipment only, and the radiation levels for such shipment must not exceed the following during transportation:

[16] 49 CFR § 173.441
[17] 49 CFR § 174.85

(1) 2 mSv/h (200 mrem/h) on the external surface of the package, unless the following conditions are met, in which case the limit is 10 mSv/h (1000 mrem/h):
(i) The shipment is made in a closed transport vehicle;
(ii) The package is secured within the vehicle so that its position remains fixed during transportation; and
(iii) There are no loading or unloading operations between the beginning and end of the transportation;
(2) 2 mSv/h (200 mrem/h) at any point on the outer surface of the vehicle, including the top and underside of the vehicle; or in the case of a flat-bed style vehicle, at any point on the vertical planes projected from the outer edges of the vehicle, on the upper surface of the load or enclosure, if used, and on the lower external surface of the vehicle; and
(3) 0.1 mSv/h (10 mrem/h) at any point 2 meters (80 in) from the outer lateral surfaces of the vehicle (excluding the top and underside of the vehicle); or in the case of a flat-bed style vehicle, at any point 2 meters (6.6 feet) from the vertical planes projected by the outer edges of the vehicle (excluding the top and underside of the vehicle); and
(4) 0.02 mSv/h (2 mrem/h) in any normally occupied space, except that this provision does not apply to private carriers, if exposed personnel under their control wear radiation dosimetry devices in conformance with 10 CFR 20.1502.
(c) For shipments made under the provisions of paragraph (b) of this section, the shipper shall provide specific written instructions to the carrier for maintenance of the exclusive use shipment controls. The instructions must be included with the shipping paper information.
(d) The written instructions required for exclusive use shipments must be sufficient so that, when followed, they will cause the carrier to avoid actions that will unnecessarily delay delivery or unnecessarily result in increased radiation levels or radiation exposures to transport workers or members of the general public.

Occupational Safety and Health Administration Standards and Limits

OSHA regulates worker exposure to ionizing radiation under the authority granted by the Occupational Safety and Health Act of 1970 (the Act) (29 U.S.C. 651, et seq.). OSHA standards cover worker exposures from all other radiation sources not identified in the regulations of DOD, DOE, or NRC; including x-ray equipment, accelerators, accelerator-produced materials, electron microscopes, and NORM. OSHA continues to work with NRC, DOE, DOD, and the EPA on advances in the research and data collection dealing with worker exposure and Federal policies addressing this important issue. OSHA also continues its involvement with the Interagency Steering Committee on Radiation Standards in an effort to coordinate any future activity.

OSHA has published its standards in 29 CFR § 1910.1096 under the title, “Ionizing Radiation.” The standard was originally issued and subsequently amended as described in the following caption: [39 FR 23502, June 27, 1974, as amended at 43 FR 49746, Oct. 24, 1978; 43 FR 51759, Nov. 7, 1978; 49 FR 18295, Apr. 30, 1984; 58 FR 35309, June 30, 1993; 61 FR 5507, Feb. 13, 1996; 61 FR 31427, June 20, 1996].

Under the OSHA standard, some of the definitions previously discussed for dose and the units used to describe exposure are refined as follows:

> 1910.1096(a)(5) - Dose means the quantity of ionizing radiation absorbed, per unit of mass, by the body or by any portion of the body. When the provisions in this section specify a dose during a period of time, the dose is the total quantity of radiation absorbed, per unit of mass, by the body or by any portion of the body during such period of time. Several different units of dose are in current use. Definitions of units used in this section are set forth in paragraphs (a)(6) and (7) of this section.
>
> 1910.1096(a)(6) - Rad means a measure of the dose of any ionizing radiation to body tissues in terms of the energy absorbed per unit of mass of the tissue. One rad is the dose corresponding to the absorption of 100 ergs per gram of tissue (1 millirad (mrad)=0.001 rad).
>
> 1910.1096(a)(7) - Rem means a measure of the dose of any ionizing radiation to body tissue in terms of its estimated biological effect relative to a dose of 1 roentgen (r) of X-rays (1 millirem (mrem)=0.001 rem). The relation of the rem to other dose units depends upon the biological effect under consideration and upon the conditions for irradiation. Each of the following is considered to be equivalent to a dose of 1 rem:
>
> 1910.1096(a)(7)(i) - A dose of 1 roentgen due to X- or gamma radiation.
>
> 1910.1096(a)(7)(ii) - A dose of 1 rad due to X-, gamma, or beta radiation.
>
> 1910.1096(a)(7)(iii) - A dose of 0.1 rad due to neutrons or high energy protons.
>
> 1910.1096(a)(7)(iv) - A dose of 0.05 rad due to particles heavier than protons and with sufficient energy to reach the lens of the eye.

In Section (b) of the OSHA standard, the exposure limits are established as follows:

> (b) Exposure of individuals to radiation in restricted areas.
> (1) Except as provided in paragraph (b)(2) of this section, no employer shall possess, use, or transfer sources of ionizing radiation in such a manner as to cause any individual in a restricted area to receive in any period of one calendar quarter from sources in the employer's possession or control a dose in excess of the limits specified in Table G-18:

TABLE G-18 Rems per calendar quarter

Whole body: Head and trunk; active blood-forming organs; lens of eyes; or gonads	1-1/4 (1,250 mrem)
Hands and forearms; feet and ankles	18-3/4 (18,750 mrem)
Skin of whole body	7-1/2 (7,500 mrem)

(2) An employer may permit an individual in a restricted area to receive doses to the whole body greater than those permitted under subparagraph (1) of this paragraph, so long as:

(i) During any calendar quarter the dose to the whole body shall not exceed 3 rems; and

(ii) The dose to the whole body, when added to the accumulated occupational dose to the whole body, shall not exceed 5 (N-18) rems, where "N" equals the individual's age in years at his last birthday; and

(iii) The employer maintains adequate past and current exposure records which show that the addition of such a dose will not cause the individual to exceed the amount authorized in this subparagraph. As used in this subparagraph Dose to the whole body shall be deemed to include any dose to the whole body, gonad, active blood forming organs, head and trunk, or lens of the eye.

(3) No employer shall permit any employee who is under 18 years of age to receive in any period of one calendar quarter a dose in excess of 10 percent of the limits specified in Table G-18.

Previous Research and Predicted Levels of Exposure

As mentioned earlier, the Dedicated Train Study, or DTS, conducted under a prior congressional mandate,[18] examined the safety and integrity of the packaging and shipment of SNF/HLRW. Contributing to the information upon which the DTS was based, the John A. Volpe National Transportation Systems Center (Volpe), Accident Prevention Division (DTS-73) (Cambridge, MA), provided a technical analysis and report comparing the relative safety of regular trains versus dedicated trains used for shipping these materials.[19]

Part of the analysis contained in the DTS was an estimate of the potential radiation exposures to various populations including different groups of railroad employees involved in these shipments. Several sets of assumptions were made in estimating exposures, and those most relevant to this report are quoted below. Please note that the term "incident free" is used in the Volpe report and DTS to distinguish the risks and levels of exposure arising simply from activities associated with transportation of the materials, rather than those associated with accidents that might occur. The "incident-free" exposure estimates are relevant to this report's focus.

For those unfamiliar with a dedicated train, Figure 1, below, illustrates a typical consist.

Source Strength

The Volpe report estimated the intensity of the radiation emitted from the packages by using the

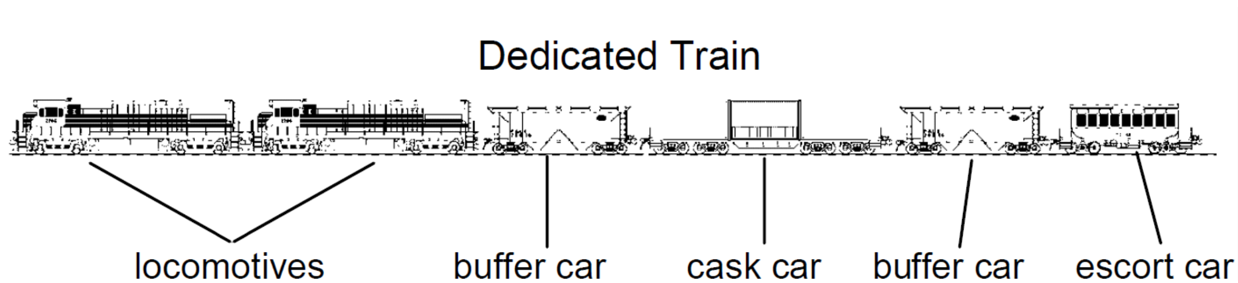

Figure 1: Dedicated Train Consist

maximum allowable limits established by the NRC. On page 20, the report states:

> Packaging, transport and disposal of radioactive materials by all modes of transportation is regulated in the United States by the NRC and the DOT. Regulations promulgated by the NRC are contained in Title 10 of the Code of Federal Regulations (10 CFR 71-73); regulations promulgated by the DOT are primarily contained in Title 49 (49 CFR 171-178). These regulations establish maximum permissible package dose rates and maximum permissible dose rates to vehicle crew members. Characteristics of radioactive material that affect incident-

[18] Section 15 of the Hazardous Materials Transportation Uniform Safety Act of 1990 (Pub. L. No. 101-615)—amended Section 116 of the Hazardous Materials Transportation Act (49 U.S.C. App. 1813)

[19] "Comparative Safety of the Transport of High-Level Radioactive Materials on Dedicated, Key and Regular Trains" Volpe Report Number DOT-VNTSC-FRA-05-06; FRA Report Number FRA/ORD-05/03.

> free transportation are the package dose rate and the fractions of gamma and neutron radiation. The package dose rate is expressed as a transportation index (TI) for certain package types. TI is defined as the highest radiation dose rate in millirem per hour (mrem/hr) from all penetrating radiation at 3.3 feet (1 meter (m)) from any accessible external surface of the package, rounded to the highest tenth (49 CFR 173.403). *For the purposes of this analysis, it was conservatively assumed that the dose rate is the regulatory limit of 10 mrem/hr at 3.3 feet (1 meter).* The estimated dose rate for the MPC cask selected for this analysis is below this regulatory limit. (*Emphasis added.*)

The next relevant section was the identification and characterization of the populations that would be exposed to radiation during the transportation SNF and HLRW by rail. On page 24, the groups of railroad employees that were identified included:

- **Train Crews:** Train crews are estimated at two per train for the dedicated, regular, and key trains.
- **Shipment Escorts:** Four escorts per train are assumed for dedicated, regular, and key trains.
- **Inspectors/Classification Yard Workers:** Railroad employees that classify or inspect the rail casks cars during stops are likely to receive close proximity exposures. Functions performed at stops include marshalling of cars, arrival and departure train inspections, and repair of damaged railcars. A determination of exact numbers of close-in rail yard workers was not established. Instead, doses for this population were estimated based on the total person-hour/meter estimate used by RADTRAN [DOE, 1986].
- **Other Rail Yard Workers:** An average of 125 workers within a 0.2 mi^2 (0.5 km^2) area at each yard is assumed based on estimates provided by consulted railroads. This gives a yard worker population density of 625 workers per mi^2 (250 workers per km^2).

Another key issue discussed was the proximity of the various groups to the radioactive sources—recognizing one of the key means of reducing exposure—distance. Beginning on page 24, the report says:

> **2.1.5 Distances from the Source**
>
> The distance from the source is a determining factor in the amount of radiation dose members of a population group receive. Distance is important because the radiation level varies with the inverse square of the distance from the cask. The various impacted populations are at different distances from the source.
>
> **Train Crew.** Train crew distances from the cask vary depending on the shipment service selected. The cask car(s) were assumed to be buffered front and rear. A 49.2 ft (15-m) car length and 6.6 ft (2 m) between cars was assumed. For regular and key train service, it was assumed that the cask car was car number 35 in a 70 car train. For dedicated service, it was assumed that the train consisted of two locomotives (with crew in first unit), buffer car, cask car, buffer car, and escort

car (see Figure 6). Crew distances were thus 2,140 ft (652.3 m) and 300 ft (91.3 m) for regular/key and dedicated service, respectively.

> **Shipment Escorts** For all service cases it was assumed that the escort distance from the cask was 96 ft (29.3 m). The cask was assumed to be buffered front and rear, with escorts in a car following the rear buffer car. Although the position of the escort railcar could differ for regular and key train service, placement used for this analysis results in the most conservative estimate.

The issue of time of exposure relative to the railroad employees was discussed. The assumptions made begin on page 26 with this statement.

> Exposure time is a determining factor in the amount of radiation members of a population group receive. In determining the total exposure durations of populations, time spent near both moving and standing trains is considered. Train operational restrictions such as train speed and run through operations impact exposure time both during stops and when en-route.

On page 27, operating crew and escort exposures are described.

> **For Moving Train.** Exposure time for moving trains is dependent on the train speed and route length ... Speeds of both 35 mph (56.3 km/hr) and 50 mph (80.4 km/hr) were used for this analysis. *For crews and escorts, transit time was calculated for each route by multiplying the average speed by the route length.* (*Emphasis added.*)
> **For Standing Trains.** Two types of stops were assumed for each route: yard stops (classification, switching, and inspection) and non-yard or siding stops (interchange and crew change). Each type has a different stop duration. Stop times for regular and dedicated trains differ since handling, inspections, routes, crew changes, and many other variables affect the time. … In general, regular and key trains stop in every yard; dedicated trains stop for crew changes (driven by hours-of-service limits) and when entering territory of a different railroad and changing locomotives (about every 350 miles (563 km)). Trains also could be stopped for inspections (the assumption for this analysis is that these inspections are done at the nearest siding/yard stop).

On page 28, crew and escort exposures are discussed further:

> Crew and escort in-transit exposure was calculated as a stop with a duration equal to the total travel time for the trip. Actual stop time for the crew is equal to the total travel time, plus two hours for each yard stop, excluding origin and destination (O-D), plus non-classification [sic] stop time. Escort stop time is equal to the total travel time, plus the full yard entry times including O-D (it is assumed escorts never leave the shipment), plus non-classification [sic] (interchange, crew change, refueling, inspection) stop times. Note that the number of non-classification stops for regular and key trains are fewer than for dedicated trains because some crew changes are assumed to occur in conjunction with classification stops.

The final element of the three protective measures that reduce exposures is shielding. The Volpe report addresses shielding on page 28 as follows:

> **2.1.7 Shielding Factors**
> The amount of shielding between the source and the affected population impacts the received dose rate.

Shielding factors are then summarized in a table. The excerpt below shows only the shielding factors affecting railroad workers.

Table 10. Shielding Factor (Attenuation)

Population	Receptor Shielding Factor	Construction Type
Crew	0.5	Reflects gamma radiation attenuation by locomotives
Escorts	1.0	No shielding
Inspectors/Handlers	1.0	No shielding
General Yard and Workers	0.1	Reflects gamma radiation attenuation by other structures in the rail yard railcars

After considering all of these factors, the Volpe study estimated the potential exposures of the different populations exposed during the transportation of the SNF/HLRW. These estimates were made using a software application called RADTRAN 5, which was developed by Sandia National Laboratories. RADTRAN 5 constructs simulations to estimate population effects of these kinds of shipments. This radiation report will look at the estimates for the railroad populations and begin with the explanation of the results on page 29 of the Volpe study.

> **2.2 INCIDENT-FREE RESULTS**
> The following section presents the radiological consequences of "incident-free" transportation of HLRW and SNF by the regular train, key train and dedicated train service modes for both the 35 mph (56.3 km/hr) and 50 mph (80.4 km/hr) speeds. The results are presented by route, service/speed, population type, and in-transit vs. stops. The intent of the incident-free analysis was to provide a general estimate of the differences between the alternate service modes and speeds. Simulations of the alternatives were conducted comparing service types for the same sets of routes. The results of these estimates are included as an example of the likely differences in exposure due to changes in service characteristics. All incident free radiological impact results are given for a single shipment, i.e., a single movement of a single cask.
>
> In general, these results show that dedicated trains expose populations to a lesser radiological dose than regular and key trains at all speeds, and that stop time risk dominates total exposure for regular and key trains.

> The term person-rem is used in this study to characterize the collective exposure dose for a particular group of people. The unit represents the product of the average dose per person times the number of people exposed (e.g., an exposure of 5 rem to each of 1,000 persons = 5,000 person-rem).

The dose estimates from the DTS that are most pertinent to this report are those for dedicated trains. It is important to note that the DOE has stated its intention to exclusively employ dedicated trains in its movements of laden casks. Those estimates are compiled below. Since it is difficult to predict with certainty the numbers of different groups of railroad workers who may be present, with the exception of the train crew and escorts, all values from the DTS estimates will assume a population of two employees in each group. The exposures will be translated from person-rems to exposure doses of mrem for comparison with OSHA and NRC regulatory limits.

Train Crew and Escorts

> "For train crews, dedicated train doses are higher than for the regular and key trains (assuming no special shielding provisions), primarily because of the closer proximity of the crew to the cask in the dedicated train. In-transit results are also speed dependent, with higher train speeds generating lower doses. Train crews could receive between a 1.17×10^{-05} and 1.62×10^{-03} person-rem dose per shipment."[20]

Since most train crews are made up of an engineer and a conductor, these values (0.0000117 to 0.00162 person-rem) translate to exposure doses that could range from 0.00585 mrem to 0.81 mrem per person per trip. (Note: It is assumed that the lower exposures reflected by the model used in the DTS are due to the shielding and distance from the source provided by the locomotive(s) used in the consist, as well as the shorter periods of exposure than the escorts, due to compliance with the hours of service law.)

> "For shipment escorts, dedicated train case doses are lower than regular and key train cases for both speed scenarios because of the shorter stop durations. Stop doses are higher than the in-transit doses for the regular and key train cases. Escorts could receive between a 0.108 and 0.041 person-rem dose per shipment."[21]

The number of escorts accompanying these shipments is not public information for security reasons. For the purposes of this report, we will use five persons to provide a basis for comparison. These values (0.108 to 0.041 person-rem) translate to exposure doses that could range from 22 mrem to 8 mrem per person per trip.

Car Inspectors and Close Proximity Yard Workers

> "Car inspectors/classification workers could receive stop doses between 0.0056 and 0.0613 person-rem per shipment. Since the exposures to this population group are for stops only (no in-transit), results are not speed dependent, but are driven

[20] Ibid., page 38
[21] Ibid., page 38

> by the number and duration of stops, which are route specific. In all cases, doses for dedicated trains are less than for regular and key trains."[22]

For two workers in this class, these values (0.0056 to 0.0613 person-rem) translate to exposure doses that could range from 2.8 mrem to 30.65 mrem per person per trip.

Rail Yard Workers

> "Rail yard workers (other than classification workers) could receive stop doses between 2.62×10^{-03} and 6.09×10^{-03} person-rem per shipment. Since the exposure for this population is for stops only (excludes intransit), results are driven by the number and duration of stops that are route specific. In all cases, doses for the dedicated train cases are less than the regular and key train cases."[23]

For two workers in this class, these values (0.00262 to 0.00609 person-rem) translate to exposure doses that could range from 1.31 mrem to 3.05 mrem per person per trip.

Conclusions about the DTS Exposure Estimates

DTS attempted to estimate the potential exposures to ionizing radiation from HLRW/SNF shipments among the various populations, including the different classes of railroad workers. Among those railroad workers, the highest potential exposures, due to proximity and time of exposure, were among the escorts.

In perspective, if escorts performed this duty over the shortest route studied, the Humboldt Nuclear Power Plant in California to Yucca Mountain—a distance of 1,090 miles—with an average speed of 33 mph, including 2½-hour stops for train crew changes every 11 hours and 1,090 miles traveled at 35 mph, the exposure would occur over 32.25 hours. If this same crew of escorts did this once a week for 50 weeks a year, their annual dose would be 1,100 mrem, just under one quarter of the OSHA permitted annual whole body dose.

Keep in mind that this is a theoretical dose estimate based on the permitted emissions from the casks, a maximum of 10 mrem/hr at 3.3 feet (1 meter) from the surface of the package (49 CFR § 173.441).

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[22] Ibid., page 39
[23] Ibid., page 40

Real-World Exposures

U.S. Railroad Data–Norfolk Southern Railway

Beginning in May of 2005, NS initiated occupational exposure monitoring of employees involved in shipments of SNF for a U.S. Government client. These shipments involved dedicated trains made up in accordance with Association of American Railroads (AAR) Recommended Practice (AAR Circular No. OT-55-J, "Recommended Railroad Operating Practices for Transportation of Hazardous Materials") as detailed in Appendix A to this report.

FRA requested and received the NS SNF shipment radiation monitoring data. This data included train information and laboratory reports showing the results of NS's personal dosimetry monitoring (anonymous) and contractor cask monitoring reports (when available).

The data covers the only trains NS operated carrying SNF/HLNW; the intent was to monitor all such trains. Eight trains were monitored from May 2005 to October 2009.

All employees actively involved with the shipment were monitored for the full duration of their exposure. The data covered 176 individual employee measurements. NS employees monitored included locomotive engineers, conductors, transportation supervisors, environmental personnel, police, and various other NS personnel involved in the actual movements. All involved employees were provided video training before participation, and were provided test results in writing after the trips were completed.

Monitoring was done by means of thermoluminescent dosimeters (TLD)[24] which detect gamma, x-ray, beta, and neutron radiation with a detection limit of 10 mrem. The shortest period of time an employee would have been exposed was 6 hours.

All of the 176 employee exposure results were less than the detection limits of the dosimeters, with one exception—an employee (conductor) whose exposure was 13 mrem. The source of the exposure was not identified, so it could have been from the shipment or another external source. In the context of relevant occupational exposure limits, this exposure could occur almost 400 times in a year (or about twice a workday) and still be below the OSHA limit for annual exposure.

In addition to employee exposure measurements, the level of radiation at the surface of and surrounding the package (cask) were measured to determine compliance with the NRC/DOT limits for this type of shipment. The highest source measurements on the consist for these shipments were taken in contact with the surface of the cask; the measurements ranged from 0.60 mrem/hr to 0.45 mrem/hr for combined gamma and neutron radiation. All of these measurements were found on the bottom surface of the cask, a location where it is unlikely any member of the crew, or other railroad workers, would be occupying.

[24] Please see Appendix B for an explanation of the TLD technology.

Surface Measurements

Location	Gamma - Neutron (mR/hr)	Location	Gamma - Neutron (mR/hr)
A	0.01 - 0.00	N	0.01 - 0.00
B	0.01 - 0.00	O	0.01 - 0.00
C	0.39 - 0.00	P	0.01 - 0.00
D	0.42 - 0.00	Q	0.01 - 0.00
E	0.41 - 0.00	R	0.01 - 0.00
F	0.53 - 0.00	S	0.01 - 0.00
G	0.01 - 0.00	T	0.01 - 0.00
H	0.01 - 0.00	U	0.01 - 0.00
I	0.01 - 0.00	V	0.01 - 0.00
J	0.01 - 0.00	W	0.01 - 0.00
K	0.01 - 0.00	X	0.01 - 0.00
L	0.01 - 0.00	Y	0.01 - 0.00
M	0.01 - 0.00		

*1 M Measurements

Location	Gamma - Neutron (mR/hr)
*1	0.01 - 0.00
*2	0.01 - 0.00
*3	0.01 - 0.00
*4	0.01 - 0.00
*5	0.01 - 0.00
*6	0.01 - 0.00
*7	0.01 - 0.00
*8	0.01 - 0.00
*9	0.01 - 0.00
*10	0.01 - 0.00
*11	0.01 - 0.00
*12	0.01 - 0.00

Please Note:
All measurements NOT reproduced for clarity

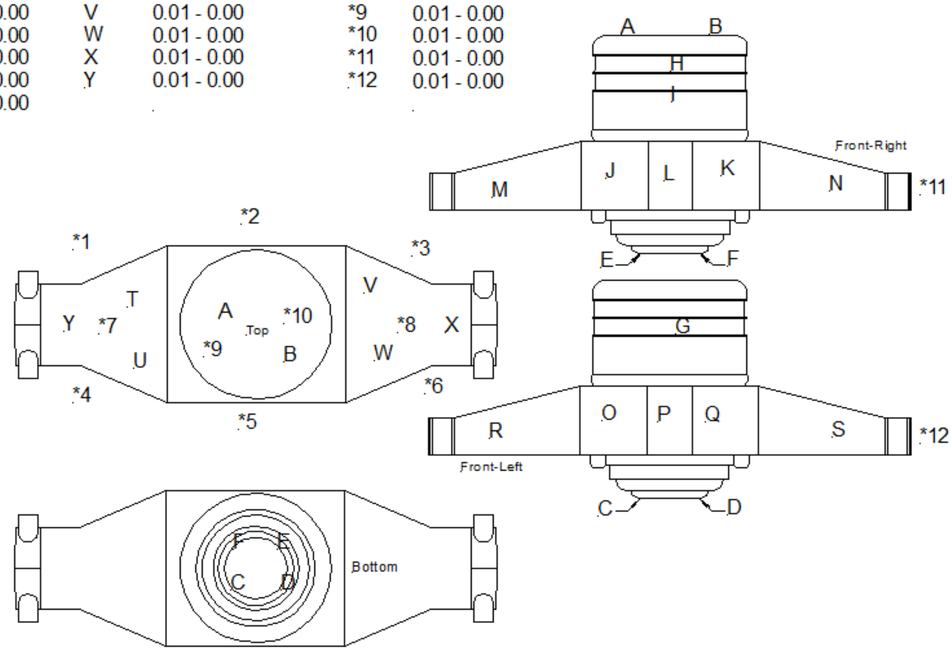

Figure 2: Cask Emission Measurements for NS 10/23/2009

The highest measurement at 1 meter from the surface of the cask for combined neutron/gamma radiation anywhere around the cask was 0.10 mrem/hr. Figure 2, above, shows a set of typical measurements and their locations around the cask. The monitoring results indicate very low potential for exposures in excess of the detection limit of the monitoring devices to NS employees involved in the shipments as measured since they began in 2005. The emission level measurements are significantly lower than those permitted by the applicable regulations and, as a result, the employee exposures were well below the permitted limits.

The actual dose measurements are consistent with the levels predicted by the DTS for most of the classes of railroad employees, and significantly lower than those predicted for the escort personnel.

The French Study

In 2004, the French Railway, Société Nationale des Chemins de fer Francais (SNCF), requested the assistance of the Institute for Radiological Protection and Nuclear Safety (IRSN)[25] to characterize the exposures of rail workers to ionizing radiation.[26] The units used to describe exposures characterized in the study were µSv/hr (micro Sieverts per hour). The following conversion was used, and all the numerical data contained in the IRSN study were converted to mrem for ease of comparison with other data in this report.

1 Sv = 100 Rem
1 mSv = 0.1 Rem = 100 mrem
= 0.1 mrem

In France, radioactive fuel and wastes are transported mainly by train and on a routine basis. The genesis of the study was recognition of this and the fact that employees are exposed. Rather than paraphrase, the essence of the study approach is summarized in the following quoted passages:

> "Radioactive fuel and wastes are frequently transported for storage and/or reprocessing purposes. The main part of this transport is generally done by train. Before, during and after the journey, operators and drivers, who work directly in contact with and in the vicinity of the wagons, are exposed to external irradiations due to the radioactive materials that are confined inside the containers."
>
> SNCF (French Railways) Directive RH 0824 relating to the prevention of accidents and protection against the risk of exposure to radiation and contamination during the carriage of radioactive goods by rail requires all shipments of this type of material to be covered by a Radiological Protection Programme (RPP). As part of this programme, SNCF is required to make an assessment of the external exposure to ionising radiation to which employees may be subjected.
>
> SNCF has asked the External Dosimetry Department of the Institute for Radiological Protection and Safety (IRSN) to carry out the necessary measurements in order to establish the values of ambient dose equivalents H(10) in the vicinity of shipments of radioactive materials, for convoys of nine different types, that are considered to be representative of all types of possible transports, involving photon[27] or mixed neutron–photon fields.

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[25] The IRSN is an agency of the French Government under the joint authority of the Defense Minister, the Environmental Minister, the Industry Minister, and the Health and Research Minister, with expert staff that perform investigations and studies in the fields of nuclear safety, protection against ionizing radiation, protection and control of nuclear material, and protection against accidents associated with these areas.

[26] "Workplace Characterisation in Case of Rail Transport of Radioactive Materials" L. Donadille, C. Itie, T. Lahaye, H. Muller, F. Trompier and J. F. Bottollier-Depois Institute for Radiological Protection and Nuclear Safety (IRSN), BP 17, F-92262 Fontenay-aux-Roses, France, Radiation Protection Dosimetry (2007), Vol. 125, No. 1-4, pp. 369-375

[27] Photon radiation measured consisted of x-rays and gamma rays.

> The measurement campaign had started in May 2004 and four types of radioactive convoys had already been investigated. By using survey meters and spectrometers, the study consisted in measuring the external exposure at different stages of the work that was done beside the wagons (e.g. coupling/decoupling two wagons, checking the brakes, etc.) and inside the locomotive (driving). For each one of these tasks, the exposure was estimated in terms of H*(10)[28] by summing the dose all along the different phases carried out by the operator. In addition, a dosimetric characterisation of each convoy was made by performing measurements along the wagons and spectrometric information about the photon and/or neutron fields were collected. This study provides helpful data to predict the dose that the operators are liable to integrate over long periods, typically 1 y."[29]

A variety of instruments were used that were more sophisticated than the TLDs used in NS's series of measurements described above. They were capable of measuring exposure over a wide range of intensities, from well below the 10 mrem lower level of detection of the TLDs to several thousand mrem. These instruments were used to ensure a variety of different types of emissions, including photon (x-rays, gamma rays) and neutron, were properly characterized. Where different types of instruments with different sensitivities were used for measuring the same emission types, the appropriate correction factors were applied to the data to ensure consistency in reporting.

In order to ensure that the measurements would not be affected by other shipments of radioactive materials, a loaded consist was placed at an isolated location. In addition, the activities of each of the groups of railroad workers who would be involved with the shipments were simulated and timed to ensure that projections of annual doses would be realistically characterized.

The exposures were then measured at locations that represented either the highest potential for exposure or where an employee would spend the most time, e.g., the cab of the locomotive. In the case of employees whose jobs required movement along the consist, which would result in exposures to different levels, the method used measured exposures at the locations, reproducing the exposure times at those locations and the movements of the employees.

[28] The instruments used in this study were designed to measure H*(10)–the dose (rate) at some place in air (not at the body of a person). This was done to estimate the dose a person would receive if he or she would be at that same place for some time. This method of measurement was created to account for changes to the radiation field caused by the body of the person who finally went to that place without requiring a person to be actually exposed to the radiation field.

[29] "Workplace Characterisation in Case of Rail Transport of Radioactive Materials" L. Donadille, C. Itie, T. Lahaye, H. Muller, F. Trompier and J. F. Bottollier-Depois Institute for Radiological Protection and Nuclear Safety (IRSN), BP 17, F-92262 Fontenay-aux-Roses, France, Radiation Protection Dosimetry (2007), Vol. 125, No. 1-4, p. 369

SNCF/IRSN Surface Measurements

Values show readings found on three different cars (wagons)

Location	Photon (mR/hr) Wagon 1	Photon (mR/hr) Wagon 2	Photon (mR/hr) Wagon 3	Neutron (mR/hr) Wagon 1	Neutron (mR/hr) Wagon 2	Neutron (mR/hr) Wagon 3
A	0.21	0.48	0.56	0.95	1.26	2.18
B	1.78	2.47	3.57	1.52	1.13	1.72
C	0.24	0.49	0.38	0.90	1.18	1.45
D	0.02	0.03	0.04	0.07	0.11	0.17
E	0.03	0.04	0.02	0.11	0.17	0.07
F	0.22	0.31	0.48	0.94	1.25	1.85
G	1.43	2.17	3.38	1.57	1.21	1.57
H	0.16	0.48	0.39	0.94	1.12	1.32

Original values shown as uSv/hr - conversion factor: 10 uSv = 1 mRem

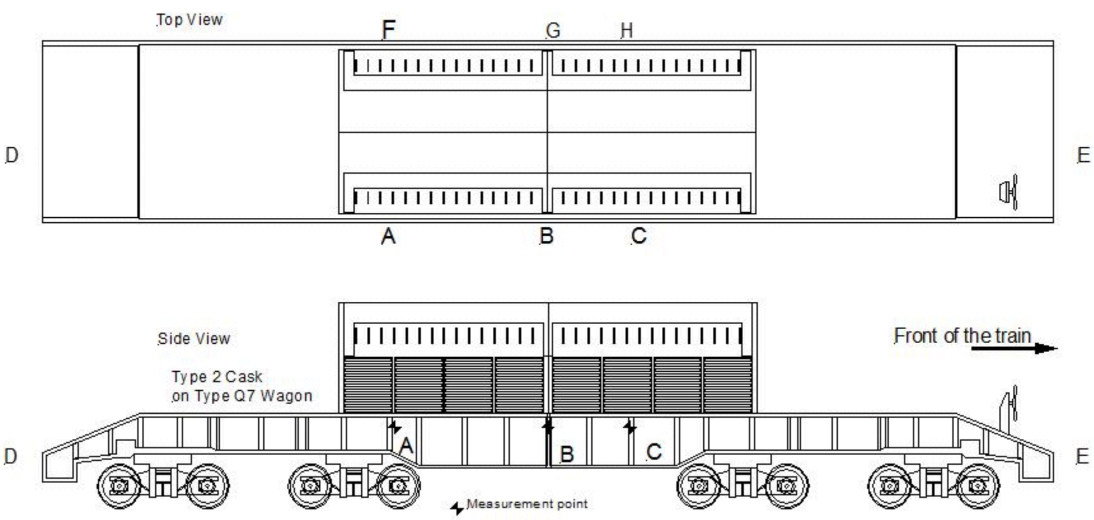

Figure 3: SNCF/IRSN Surface Measurements

The mapping of the intensities of radiation emissions in contact with each car in the consist are shown above in Figure 3. It shows a summary of the data reported in the study, with the values converted from µSv/hr to mrem/hr for ease of comparison with the values used in the United States.

For simplicity, the total dose measured is reproduced in the table below for comparison with TLD exposures reported in the NS study.

The final part of the study used the radiation exposure data and the time of exposure-by-task data to estimate an overall exposure dose. The study estimated that an employee who would conduct each of the tasks (with the exception of driving) 100 times would have an exposure of about 25 mrem. The driving task was estimated based on the hours exposed (see Table 1 below).

Table 1: SNCF/IRSN Data Table

Task	Exposure time(s)	Total Dose* mrem
Coupling engine to wagon	40	0.001
Uncoupling engine from wagon	40	0.001
Testing brakes	300	0.065
Placing and removing rear warning lamps	70	0.015
Checking train status	240	0.051
Recording train details	360	0.077
Dispatching the train	70	0.031
Total	**1,120**	**0.241**
Driving (mrem/hr)**		0.02

* Exposure, expressed in terms of H*(10), associated with the essential operational tasks.
**The results for the driving task are expressed in mrem/hr since the driving time cannot be easily estimated.

The results reported in this study indicate that, even with the different methods used to obtain exposure determinations, the exposures measured were of a similar order of magnitude as those predicted by the DTS and found in the NS studies.

The German Study

In July of 2003, a research study[30] was the basis for a presentation at the International Conference on the Safety of Transport of Radioactive Material sponsored by the International Atomic Energy Agency (IAEA). The paper summarized the principal findings and conclusions of a survey of radiation exposures incurred by workers and the public from the normal transport of radioactive material in Germany.[31]

The survey covered all major categories of radioactive materials, the large majority of these packages contained only relatively small quantities of radiopharmaceuticals, research and industrial sources, and other radioactive commodities. The study excluded consumer goods such as smoke detectors. The study covered approximately 750,000 radioactive material packages shipped annually over an 8-year period in Germany by all transportation modes, i.e., by road, rail, air, and sea. Large quantity shipments of radioactive materials, such as HLRW or SNF, accounted only for a small proportion of the total volume of radioactive material shipments within Germany.

[30] "Assessment of the Radiation Exposures associated with the Transport of Radioactive Material in Germany," G. Schwartz and F. Lange, Gesellschaft fur Anlagen und Realktorsicherheit (GRS) mbH, Schwertnergasse 1, 50667 Koln, Germany – Proc. IAEA Conference, July 7–11, 2003, Vienna, page 97.

[31] GRS mbH is a nonprofit, scientific and technical expert and research organization. It is Germany's leading expert institution in the area of nuclear safety and waste management.

The table below is an excerpt from the results of the survey and assessment in terms of occupational radiation exposures arising from the normal transport[32] of radioactive material in Germany. The transport-related doses cover a range of transport activities and cover fuel cycle and non-fuel cycle radioactive material shipments and their predominant mode of transport including the following:

- Unirradiated nuclear fuel cycle material, e.g., uranium concentrate, uranium hexafluoride, UO2-powder/pellets, fuel elements, and pins, etc.
- Irradiated nuclear fuel cycle material includes SNF, vitrified HLRW, irradiated fuel pins, etc., and large quantity radiation sources.
- Non-nuclear radioactive waste, e.g., medical and research waste.
- Supply and distribution of medical, research, and industrial isotopes.
- Radiography sources.

Table 2: Occupational Radiation Exposures Arising from Normal Transport

Material Category/Transport Activity	**Transport Mode**	**Maximum Effective Dose Per Worker (mrem/a)***
Unirradiated fuel cycle material, e.g., U3O8, UF6, UO2-powder/pellets, fuel pins & fuel assemblies, radiation sources	Road/Rail	< 100
Unirradiated/irradiated nuclear fuel cycle material and large quantity radiation sources, e.g., activated/contaminated equipment and components, radioactive waste, spent nuclear fuel, high level radioactive waste etc.	Road	100–300
	Rail	< 100

* This unit is mrem per annum (per year)–an annual dose estimate.

In discussing the findings of the report the authors stated that:

> The exposure data presented in Figure 1 and Table 1 for the recent years indicate that the occupational and public exposures (effective dose) associated with the normal transport of radioactive material have -with few exceptions -been consistently in the range of or below of 1 mSv/yr (100 mrem/yr) for transport workers and well below of 0,05 mSv/yr (5 mrem/yr) for the general public (critical group individuals) for all major transport activities and categories of radioactive material. Radiation doses in these dose ranges represent only a small

[32] "Normal transport" means transport operations that occur without unusual delay, loss of, or serious damage to a radioactive material package, or an accident involving the conveyance.

> fraction of the relevant regulatory dose limit for radiation workers and members of the public of 20 mSv/yr (2000 mrem/yr) and 1 mSv/yr (100 mrem/yr), respectively.[33]

In the conclusions to the report the authors state:

> "The comprehensive survey and assessment results confirm that the transport-related radiation doses, incurred by transport workers and members of the public are generally low for all major categories of material and transport activities under normal conditions of transport and well below the applicable regulatory dose limits (20 mSv/yr for workers and 1 mSv/yr for members of the public)."[34]

Later they state:

> "This general observation is according to a European wide assessment study performed on behalf of the European Commission broadly consistent with the operational experience in other Central European EU Member States."[35]

And:

> "The occupational and public radiation exposures data described above are believed to reflect well-managed transport and sound management practices and may thereby serve as a reasonable basis and guidance material for the establishment of an optimised level of radiological protection and safety in transport. The radiation exposure data nationally available also indicate that the implementation and application of the international transport safety standards, i.e. TS-R-1, ensure an adequate level of radiological protection of both workers and members of the public for normal conditions of transport and satisfy the radiation protection principles of the International Basic Safety Standards (BSS)."[36]

As with the NS and French studies cited previously, the results of this study are consistent in the findings of low radiation exposures among rail transportation workers.

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[33] "Assessment of the Radiation Exposures associated with the Transport of Radioactive Material in Germany," G. Schwartz and F. Lange, Gesellschaft fur Anlagen und Realktorsicherheit (GRS) mbH, Schwertnergasse 1, 50667 Koln, Germany – Proc. IAEA Conference, July 7–11, 2003, Vienna, page 100.
[34] Ibid., page 100
[35] Ibid., page 100
[36] Ibid., page 100

Conclusions in Response to the Congressional Mandates

Section 411(a) of the Federal Railroad Safety Improvement Act of 2008 (Pub. L. No. 110-432) (RSIA 2008) states:

> "STUDY. The Secretary of Transportation shall, in consultation with the Secretary of Energy, the Secretary of Labor, the Administrator of the Environmental Protection Agency, and the Chairman of the Nuclear Regulatory Commission, as appropriate, conduct a study of the potential hazards to which employees of railroad carriers and railroad contractors or subcontractors are exposed during the transportation of high-level radioactive waste and spent nuclear fuel ... (1) an analysis of the potential application of "as low as reasonably achievable" principles for exposure to radiation to such employees ..."

Response: The data presented in this report include that from the DTS, where the theoretical predictions of potential exposure to radiation were based on assumptions of emission levels from the packages at the allowed regulatory limit, and real-world exposure assessments in the United States and two European countries. Both the DTS theoretical findings and the real-world experience indicate that potential and actual exposures are well below the currently established permissible levels. All of the current regulatory permissible levels have been established recognizing the importance of the "as low as reasonably achievable" (ALARA) principles in minimizing exposures.

Section 411(a)(1) of the RSIA 2008 continues:

> "STUDY… with an emphasis on the need for special protection from radiation exposure for such employees during the first trimester of pregnancy ..."

Response: Aside from the medical and personal privacy issues raised by this question, the real-world exposures found in the three studies cited are well below regulatory limits. According to the Center for Disease Control, "Most radiation exposure events will not expose the fetus to levels likely to cause health effects. This is true for radiation exposure from most diagnostic medical exams as well as from occupational radiation exposures that fall within regulatory limits."[37]

Section 411(a)(1) of the RSIA 2008 continues:

> "STUDY … with an emphasis on the need for special protection from radiation exposure for such employees ... or who are undergoing or have recently undergone radiation therapy."

Response: Without considering the medical privacy issues raised by this question, the real-world exposures found in the three studies cited are very low. However, the medical and health

[37] Centers for Disease Control: http://www.bt.cdc.gov/radiation/prenatalphysician.asp (April 2010)

implications of someone undergoing radiation therapy can be extremely varied, and the interaction with occupational exposures cannot be presumed given the complexity of the medical procedures and types of therapy available in today's medical practice.

Section 411(a)(2) of the RSIA 2008 continues:

> "STUDY… the feasibility of requiring real-time dosimetry monitoring for such employees."

Response: Requiring real-time dosimetry for railroad or contractor employees involved in these activities does not appear to be warranted based on the exposures documented to date, nor by the very infrequent occurrence of these events.

Section 411(a)(3) of the RSIA 2008 continues:

> "STUDY… the feasibility of requiring routine radiation exposure monitoring in fixed railroad locations, such as yards and repair facilities."

Response: The use of dedicated trains minimizes the dwell-time of trains carrying HLRW/SNF in fixed locations such as yards and repair facilities. In addition, significant monitoring of the packages at the shipping point, required by regulation, along with the known shielding properties of the packages, would make monitoring in these locations redundant and would serve no practical purpose.

Section 411(a)(3) of the RSIA 2008 continues:

> "STUDY … a review of the effectiveness of the Department's packaging requirements for radioactive materials."

Response: The DTS was used to establish theoretical levels of exposure to various populations potentially exposed to radiation during rail transportation of HLRW/SNF, based on the assumption that the shielding afforded by the packages would at least meet the limits established in the regulations. The real-world levels measured by NS during actual shipments indicate that the packaging far exceeds the minimum requirements, thus providing an extra margin of safety for the employees as well as the general public.

Section 411(b) of the RSIA 2008 states:

> REPORT. Not later than 18 months after the date of enactment of this Act, the Secretary of Transportation shall transmit a report on the results of the study required by subsection (a) and any recommendations to further protect employees of a railroad carrier or of a contractor or subcontractor to a railroad carrier from unsafe exposure to radiation during the transportation of high-level radioactive waste and spent nuclear fuel …"

Response: Based on the findings of this study, it does not appear that any such recommendations are necessary at this time.

Section 411(c) of the RSIA 2008 states:

> "REGULATORY AUTHORITY. The Secretary of Transportation may issue regulations that the Secretary determines appropriate, pursuant to the report required by subsection (b), to protect railroad employees from unsafe exposure to radiation during the transportation of radioactive materials."

Response: The Secretary of Transportation does not believe that any regulatory action is necessary at this time to further protect railroad employees from unsafe exposure to radiation during the transportation of radioactive materials.

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Appendix A:

AAR Circular No. OT-55-J–Recommended Railroad Operating Practices for Transportation of Hazardous Materials

ASSOCIATION OF AMERICAN RAILROADS

K.B. Dorsey
Executive Director - Tank Car Safety

March 15, 2010

Circular No. OT-55-J

(CPC-1210, Supplement 1)

Subject: Recommended Railroad Operating Practices for Transportation of Hazardous Materials

TO: MEMBERS AND PRIVATE CAR OWNERS

On March 11, 2010, AAR's Hazardous Materials (BOE) Committee approved changes to Appendices A, B, and C which were modified to incorporate the latest information available.

Changes include:

- The addition of Hazardous Material Response Code (HMRC) - 4821029, 4921029, and 4921027 to Appendix A and B
- The addition of Hazard Class Column to Appendix A and B
- The addition of HMRC 4925224, 4925225, and 4825181 to Appendix C
- The removal of HMRC 4920183 and replaced with HMRC 4920326 in order to place the hazardous material into the appropriate HMRC classification range
- The removal of HMRC 4920196 since HMRC 4920342 already exist for the exact same hazardous material

The revised standard is included in this circular and is in effect as of the publication date of this circular. Under the provisions of Standard S-050, which may be found on the TTCI web site (www.AAR.com), this circular reflects the final action on this matter.

Sincerely,

K.B. Dorsey

Safety and Operations
425 3rd Street, SW Suite 1000, Washington, D.C. 20024
Phone (202) 639-2262; FAX (202) 639-2930; e-mail kdorsey@aar.org

ASSOCIATION OF AMERICAN RAILROADS

Phone (202) 639-2147
Fax (202) 639-2930
Email: kdorsey@aar.org

Circular No. OT-55-J
Effective March 17, 2009
Appendices revised March 15, 2010

Recommended Railroad Operating Practices For Transportation of Hazardous Materials

Road Operating Practices

I. "Key Trains"

A. Definition: A "Key Train" is any train with:

- one tank car load of Poison or Toxic Inhalation Hazard[1] (PIH or TIH) (Hazard Zone A, B, C, or D) or anhydrous ammonia, or;
- 20 car loads or intermodal portable tank loads of a combination of PIH or TIH (Hazard Zone A, B, C or D), anhydrous ammonia, flammable gas, Class 1.1 or 1.2 explosives, and environmentally sensitive chemicals, or;
- one or more car loads of Spent Nuclear Fuel (SNF), High Level Radioactive Waste (HLRW).

Attached as Appendix, A and B are lists of PIH or TIH (Hazard Zone A, B, C or D) including anhydrous ammonia, Appendix C is a list of environmentally sensitive chemicals, Appendix D is a list of time sensitive materials and Appendix E is a list of SNF and HLRW with 49 Hazmat Codes.

B. Restrictions:

1. Maximum speed -- "Key Train" - 50 MPH.

2. Unless siding or auxiliary track meets FRA Class 2 standards, a Key Train will hold main track at meeting or passing points, when practicable.

3. Only cars equipped with roller bearings will be allowed in a Key Train.

4. If a defect in a "Key Train" bearing is reported by a wayside detector, but a visual inspection fails to confirm evidence of a defect, the train will not exceed 30 MPH until it has passed over the next wayside detector or delivered to a terminal for a mechanical inspection. If the same car again sets off the next detector or is found to be defective, it must be set out from the train.

II. Designation of "Key Routes"

A. Definition: Any track with a combination of 10,000 car loads or intermodal portable tank loads of hazardous materials, or a combination of 4,000 car loadings of PIH or TIH (Hazard zone A, B, C, or D), anhydrous ammonia, flammable gas, Class 1.1 or 1.2 explosives, environmentally sensitive chemicals, Spent Nuclear Fuel (SNF), and High Level Radioactive Waste (HLRW) over a period of one year.

[1] Poison Inhalation Hazard (PIH) and Toxic Inhalation Hazard (TIH) are used interchangeably and refer to the same list of chemicals.

B. Requirements:

1. Wayside defective bearing detectors shall be placed at a maximum of 40 miles apart on "Key Routes", or equivalent level of protection may be installed based on improvements in technology.
2. Main Track on "Key Routes" is inspected by rail defect detection and track geometry inspection cars or any equivalent level of inspection no less than two times each year; sidings are similarly inspected no less than one time each year; and main track and sidings will have periodic track inspections that will identify cracks or breaks in joint bars.
3. Any track used for meeting and passing "Key Trains" must be Class 2 or higher. If a meet or pass must occur on less than Class 2 track due to an emergency, one of the trains must be stopped before the other train passes.

III. Yard Operating Practices

A. Maximum reasonable efforts will be made to achieve coupling of loaded placarded tank cars at speeds not to exceed 4 MPH.

B. Loaded placarded tank cars of PIH or TIH (Hazard zone A, B, C or D), anhydrous ammonia, or flammable gas which are cut off in motion for coupling must be handled in not more than 2-car cuts; and cars cut off in motion to be coupled directly to a loaded placarded tank car of PIH or TIH (Hazard zone A, B, C, or D), anhydrous ammonia, or flammable gas must also be handled in not more than 2-car cuts.

IV. Storage

Separation Distance for New Facilities

Loaded Tank Cars and Storage Tanks from Mainline Class 2 Track or Higher

Activity	PIH (Zone A, B, C or D), Class 3, Division 2.1, Division 2.2 and all other Hazard Classes	Combustible Liquids, Class 8, and Class 9
Loading and Unloading	100 FEET	50 FEET
Storage of Loaded Tank Cars	50 FEET	25 FEET
Storage in Tanks	100 FEET	50 FEET

Note 1 - With regard to existing facilities, maximum reasonable effort should be made to conform to this standard taking into consideration cost, physical and legal constraints.

Note 2 - The proposals apply to storage on railroad property and on chemical company property located close to railroad mainline.

V. TRANSCAER® (Transportation Community Awareness and Emergency Response Implementation of Transcaer®)

Railroads will assist in implementing TRANSCAER®, a system-wide community outreach program to improve community awareness, emergency planning and incident response for the transportation of hazardous materials. Objectives of TRANSCAER® are as follows:

- Demonstrate the continuing commitment of chemical manufacturers and transporters to the safe transportation of hazardous materials;

- Improve the relationship between manufacturers, carriers and local officials of communities through which hazardous materials are transported;

- When requested assist Local Emergency Planning Committees (LEPC's) in assessing the hazardous materials moving through their communities and the safeguards that are in place to protect against unintentional releases. Upon written request, AAR members will provide bona fide emergency response agencies or planning groups with specific commodity flow information covering at a minimum the top 25 hazardous commodities transported through the community in rank order. The request must be made using the form included as Appendix F by an official emergency response or planning group with a cover letter on appropriate letterhead bearing an authorized signature. The form reflects the fact that the railroad industry considers this information to be restricted information of a security sensitive nature and that the recipient of the information must agree to release the information only to bona fide emergency response planning and response organizations and not distribute the information publicly in whole or in part without the individual railroad's express written permission. It should be noted that commercial requirements change over time, and it is possible that a hazardous materials transported tomorrow might not be included in the specific commodity flow information provided upon request, since that information was not available at the time the list was provided;

- Assist LEPC's in developing emergency plans to cope with hazardous materials transportation incidents;

- Assist community response organizations in preparations for responding to hazardous materials incidents.

TRANSCAER® activities are also addressed in the Distribution Code of the American Chemistry Council's Responsible Care® program. Many members have joined the Responsible Care® Partnership Program to help describe and improve their ongoing safety, health and environmental programs.

An important product of the TRANSCAER® program will be to overcome the widespread belief that every local firefighter and policeman must have the expert skills and equipment to respond personally to any hazardous materials emergency. Through the awareness training and contingency planning provided through TRANSCAER®, states and local communities will be able to pool their expertise and resources with those of industry to provide for a more coordinated and better managed emergency response system.

TRANSCAER® should be highly publicized to produce the maximum desirable enhancement of public awareness.

VI. Criteria for Shipper Notification

The railroads will initiate the shipper's emergency response system by calling CHEMTREC, or the appropriate contact telephone number as required by regulation on the shipping document, when an incident occurs involving any car (load or residue) containing a hazardous material regulated in transportation by the Department of Transportation.

An incident is defined as a rail car which is derailed and not upright, or which has sustained body or tank shell damage, or has sustained a release of any amount of product.

The shipper's emergency response system should also be initiated if the carrier believes there is reason to suspect any other potential for injury to people, property or the environment.

In the event of a major rail accident, a consist (to include shipper, consignee and commodity description for each hazardous material), waybill or equivalent document, should be provided upon request to CHEMTREC or the appropriate shipper contact as identified by the emergency response telephone number displayed on the shipping document. This can be accomplished by facsimile or other appropriate and acceptable electronic means.

A major rail accident is defined as one resulting in fire, explosion, the potential for an explosion, fatalities, evacuation of the general public, or multiple releases of hazardous materials.

Anytime a consist or other document is provided to CHEMTREC or the appropriate contact a follow-up call by the carrier should be made to confirm the receipt of the information as well as to provide other additional information pertaining to the incident not contained in the facsimile or electronically transmitted document.

This practice does not preclude any carrier from notifying CHEMTREC or the appropriate shipper contact of a rail incident involving hazardous materials that does not meet the criteria outlined above.

VII Time Sensitive Materials

Railroads and shippers will be responsible for monitoring the shipments (loads & residue) of products classified by the Department of Transportation as being time sensitive.

This monitoring process will, at a minimum, provide a means to ensure the movement of rail cars containing time sensitive materials (for list see Appendix D) in order to achieve delivery of the product within the time specified by the Department of Transportation.

As warranted, railroads will implement an internal escalation process and communicate with shippers, receivers and other rail carriers concerning any rail car containing a time sensitive product that has been delayed in transit to the extent that it may not reach destination within the time specified by the Department of Transportation. In such cases, an expedited movement of the rail car, or other action as deemed appropriate by the carrier and shipper will be taken.

VIII Special Provision for Spent Nuclear Fuel (SNF) and High Level Radioactive Waste (HLRW)

When a train carrying SNF or HLRW meets another train carrying loaded tank cars of flammable gas, flammable liquids or combustible liquids in a single bore double track tunnel, one train shall stop outside the tunnel until the other train is completely through the tunnel.

IX Applicability

These recommendations are adopted by each AAR and American Short Line and Regional Railroad Association (ASLRRA) member without reservation for its operations within the United States of America.

##

Supersedes Circular No. OT-55-I dated July 17, 2006

Appendix A:
List of Poison Inhalation Hazard (PIH) or Toxic Inhalation Hazard Chemicals (TIH)
(Hazard Zone A, B, C, or D)
Sorted by Hazard Class and Proper Shipping Name
March 15, 2010

HMRC	Proper Shipping Name	UN/NA#	Packing Group	Hazard Zone	Hazard Class
NON-FLAMMABLE GASES, HAZARD CLASS 2.2					
4904210	Ammonia, Anhydrous	UN 1005			2.2
4904879	Ammonia, Anhydrous	UN 1005			2.2
4904211	Ammonia, Solution	UN 3318			2.2
POISON GASES, HAZARD CLASS 2.3					
4920359	Ammonia, Anhydrous	UN 1005		D	2.3
4920360	Ammonia, Solution	UN 3318		D	2.3
4920135	Arsine	UN 2188		A	2.3
4920349	Boron Trichloride	UN 1741		C	2.3
4920522	Boron Trifluoride	UN 1008		B	2.3
4920715	Bromine Chloride	UN 2901		B	2.3
4920343	Carbon Monoxide and Hydrogen mixture, Compressed	UN 2600			2.3
4920399	Carbon Monoxide, Compressed	UN 1016		D	2.3
4920511	Carbon Monoxide, refrigerated liquid	NA 9202		D	2.3
4920559	Carbonyl Fluoride	UN 2417		B	2.3
4920351	Carbonyl Sulfide	UN 2204		C	2.3
4920523	Chlorine	UN 1017		B	2.3
4920189	Chlorine Pentafluoride	UN 2548		A	2.3
4920352	Chlorine Trifluoride	UN 1749		B	2.3
4920516	Chloropicrin and Methyl Bromide mixtures	UN 1581		B	2.3
4920547	Chloropicrin and Methyl Bromide mixtures	UN 1581		B	2.3
4920392	Chloropicrin and Methyl Chloride mixtures	UN 1582		B	2.3
4920527	Coal Gas, Compressed	UN 1023		C	2.3
4920101	Compressed Gas, toxic, corrosive, n.o.s.	UN 3304		A	2.3
4920324	Compressed Gas, toxic, corrosive, n.o.s.	UN 3304		B	2.3
4920301	Compressed Gas, toxic, corrosive, n.o.s.	UN3304		D	2.3
4920331	Compressed Gas, toxic, corrosive, n.o.s.	UN 3304		C	2.3
4920102	Compressed Gas, toxic, flammable, corrosive, n.o.s.	UN 3305		A	2.3
4920303	Compressed Gas, toxic, flammable, corrosive, n.o.s.	UN 3305		B	2.3
4920304	Compressed Gas, toxic, flammable, corrosive, n.o.s.	UN 3305		C	2.3
4920305	Compressed Gas, toxic, flammable, corrosive, n.o.s.	UN 3305		D	2.3
4920165	Compressed Gas, toxic, flammable, n.o.s.	UN 1953		A	2.3
4920396	Compressed Gas, toxic, flammable, n.o.s.	UN 1953		B	2.3
4920378	Compressed Gas, toxic, flammable, n.o.s.	UN 1953		C	2.3
4920379	Compressed Gas, toxic, flammable, n.o.s.	UN 1953		D	2.3
4920556	Compressed Gas, toxic, n.o.s.	UN 1955		B	2.3

HMRC	Proper Shipping Name	UN/NA#	Packing Group	Hazard Zone	Hazard Class
4920181	Compressed Gas, toxic, n.o.s.	UN 1955		A	2.3
4920570	Compressed Gas, toxic, n.o.s.	UN 1955		B	2.3
4920375	Compressed Gas, toxic, n.o.s.	UN 1955		C	2.3
4920373	Compressed Gas, toxic, n.o.s.	UN 1955		D	2.3
4920505	Compressed Gas, toxic, n.o.s.	UN 1955		C	2.3
4920517	Compressed Gas, toxic, n.o.s.	UN 1955			2.3
4920525	Compressed Gas, toxic, n.o.s.	UN 1955			2.3
4920103	Compressed Gas, toxic, oxidizing, corrosive, n.o.s.	UN 3306		A	2.3
4920306	Compressed Gas, toxic, oxidizing, corrosive, n.o.s.	UN 3306		B	2.3
4920307	Compressed Gas, toxic, oxidizing, corrosive, n.o.s.	UN 3306		C	2.3
4920308	Compressed Gas, toxic, oxidizing, corrosive, n.o.s.	UN 3306		D	2.3
4920104	Compressed gas, toxic, oxidizing, n.o.s.	UN 3303		A	2.3
4920337	Compressed gas, toxic, oxidizing, n.o.s.	UN 3303		B	2.3
4920309	Compressed gas, toxic, oxidizing, n.o.s.	UN 3303		C	2.3
4920310	Compressed gas, toxic, oxidizing, n.o.s.	UN 3303		D	2.3
4920395	Cyanogen	UN 1026		B	2.3
4920178	Cyanogen Chloride, Stabilized	UN 1589		A	2.3
4920107	Diborane	UN 1911		A	2.3
4920398	Dichlorosilane	UN 2189		B	2.3
4920174	Dinitrogen Tetroxide	UN 1067		A	2.3
4920342	Ethylene Oxide and Carbon Dioxide mixture	UN 3300		D	2.3
4920353	Ethylene Oxide or Ethylene Oxide with Nitrogen	UN 1040		D	2.3
4920180	Fluorine, Compressed	UN 1045		A	2.3
4920510	Gas Identification set	NA 9035			2.3
4920536	Gas sample, non-pressurized, toxic, n.o.s.	UN 3169			2.3
4920534	Gas sample, non-pressurized, toxic, flammable, n.o.s.	UN 3168			2.3
4920354	Germane	UN 2192		B	2.3
4920515	Hexaethyl tetraphosphate and compressed gas mixtures	UN 1612		C	2.3
4920528	Hexafluoroacetone	UN 2420		B	2.3
4920502	Hydrogen Bromide, anhydrous	UN 1048		C	2.3
4920503	Hydrogen Chloride, anhydrous	UN 1050		C	2.3
4920504	Hydrogen Chloride, refrigerated liquid	UN 2186		C	2.3
4920348	Hydrogen Iodide, anhydrous	UN 2197		C	2.3
4920122	Hydrogen Selenide, anhydrous	UN 2202		A	2.3
4920513	Hydrogen Sulfide	UN 1053		B	2.3
4920115	Insecticide gases, toxic, flammable, n.o.s.	UN 3355		A	2.3
4920302	Insecticide gases, toxic, flammable, n.o.s.	UN 3355		B	2.3
4920322	Insecticide gases, toxic, flammable, n.o.s.	UN 3355		C	2.3
4920323	Insecticide gases, toxic, flammable, n.o.s.	UN 3355		D	2.3
4920550	Insecticide gases, toxic, n.o.s.	UN 1967		C	2.3
4920105	Liquefied gas, toxic, corrosive, n.o.s.	UN 3308		A	2.3
4920311	Liquefied gas, toxic, corrosive, n.o.s.	UN 3308		B	2.3
4920313	Liquefied gas, toxic, corrosive, n.o.s.	UN 3308		C	2.3
4920315	Liquefied gas, toxic, corrosive, n.o.s.	UN 3308		D	2.3

HMRC	Proper Shipping Name	UN/NA#	Packing Group	Hazard Zone	Hazard Class
4920108	Liquefied gas, toxic, flammable, corrosive, n.o.s.	UN 3309		A	2.3
4920314	Liquefied gas, toxic, flammable, corrosive, n.o.s.	UN 3309		B	2.3
4920316	Liquefied gas, toxic, flammable, corrosive, n.o.s.	UN 3309		C	2.3
4920318	Liquefied gas, toxic, flammable, corrosive, n.o.s.	UN 3309		D	2.3
4920164	Liquefied gas, toxic, flammable, n.o.s.	UN 3160		A	2.3
4920382	Liquefied gas, toxic, flammable, n.o.s.	UN 3160		B	2.3
4920380	Liquefied gas, toxic, flammable, n.o.s.	UN 3160		C	2.3
4920381	Liquefied gas, toxic, flammable, n.o.s.	UN 3160		D	2.3
4920195	Liquefied gas, toxic, n.o.s.	UN 3162		A	2.3
4920368	Liquefied gas, toxic, n.o.s.	UN 3162		C	2.3
4920369	Liquefied gas, toxic, n.o.s.	UN 3162		D	2.3
4920383	Liquefied gas, toxic, n.o.s.	UN 3162			2.3
4920531	Liquefied gas, toxic, n.o.s.	UN 3162			2.3
4920571	Liquefied gas, toxic, n.o.s.	UN 3162		B	2.3
4920110	Liquefied gas, toxic, oxidizing, corrosive, n.o.s.	UN 3310		A	2.3
4920312	Liquefied gas, toxic, oxidizing, corrosive, n.o.s.	UN 3310		B	2.3
4920320	Liquefied gas, toxic, oxidizing, corrosive, n.o.s.	UN 3310		C	2.3
4920325	Liquefied gas, toxic, oxidizing, corrosive, n.o.s.	UN 3310		D	2.3
4920111	Liquefied gas, toxic, oxidizing, n.o.s.	UN 3307		A	2.3
4920317	Liquefied gas, toxic, oxidizing, n.o.s.	UN 3307		B	2.3
4920319	Liquefied gas, toxic, oxidizing, n.o.s.	UN 3307		C	2.3
4920321	Liquefied gas, toxic, oxidizing, n.o.s.	UN 3307		D	2.3
4920518	Methyl Bromide	UN 1062		C	2.3
4920355	Methyl Mercaptan	UN 1064		C	2.3
4920394	Methylchlorosilane	UN 2534		B	2.3
4920113	Nitric oxide and nitrogen dioxide mixtures or Nitric oxide and dinitrogen tetroxide mixtures	UN 1975		A	2.3
4920112	Nitric Oxide, Compressed	UN 1660		A	2.3
4920175	Nitrogen Trioxide	UN 2421		A	2.3
4920509	Nitrosyl Chloride	UN 1069		C	2.3
4920344	Oil Gas, Compressed	UN 1071			2.3
4920530	Organic phosphate, mixed with compressed gas or Organic phosphate compound, mixed with compressed gas or Organic phosphorus compound, mixed with compressed gas	NA 1955		C	2.3
4920173	Oxygen Difluoride, Compressed	UN 2190		A	2.3
4920535	Parathion and Compressed gas mixture	NA 1967		C	2.3
4920356	Perchloryl Fluoride	UN 3083		B	2.3
4920184	Phosgene	UN 1076		A	2.3
4920160	Phosphine	UN 2199		A	2.3
4920326	Phosphorus Pentafluoride	UN 2198		B	2.3
4920106	Selenium Hexafluoride	UN 2194		A	2.3
4920357	Silicon Tetrafluoride	UN 1859		B	2.3
4920167	Stibine	UN 2676		A	2.3
4920508	Sulfur Dioxide	UN 1079		C	2.3
4920187	Sulfur Tetrafluoride	UN 2418		A	2.3

HMRC	Proper Shipping Name	UN/NA#	Packing Group	Hazard Zone	Hazard Class
4920526	Sulfuryl Fluoride	UN 2191		D	2.3
4920188	Tellurium Hexafluoride	UN 2195		A	2.3
4920347	Trifluoroacetyl Chloride	UN 3057		B	2.3
4920346	Trifluorochloroethylene, Stabilized	UN 1082		C	2.3
4920371	Tungsten Hexafluoride	UN 2196		B	2.3
FLAMMABLE LIQUIDS, HAZARD CLASS 3					
4907434	Ethyl Isocyanate	UN 2481	I	A	3
4907409	Isobutyl Isocyanate	UN 2486	I	A	3
4909306	Isopropyl Isocyanate	UN 2483	I	A	3
4910370	Methacrylonitrile, Stabilized	UN 3079	I	B	3
4909307	Methoxymethyl Isocyanate	UN 2605	I	A	3
SPONTANEOUSLY COMBUSTIBLE, HAZARD CLASS 4.2					
4916138	Pentaborane	UN 1380	I	A	4.2
OXIDIZERS, HAZARD CLASS 5.1					
4918505	Bromine Pentafluoride	UN 1745	I	A	5.1
4918507	Bromine Trifluoride	UN 1746	I	B	5.1
4918180	Tetranitromethane	UN 1510	I	B	5.1
POISONS, HAZARD CLASS 6.1					
4921402	2-Chloroethanal	UN 2232	I	B	6.1
4921495	2-Methyl-2-Heptanethiol	UN 3023	I	B	6.1
4921741	3, 5-Dichloro-2, 4, 6-Trifluoropyridine	NA 9264	I	B	6.1
4921401	Acetone Cyanohydrin, Stabilized	UN 1541	I	B	6.1
4927007	Acrolein, Stabilized	UN 1092	I	A	6.1
4921019	Allyl Alcohol	UN 1098	I	B	6.1
4923113	Allyl Chloroformate	UN 1722	I	B	6.1
4921004	Allylamine	UN 2334	I	B	6.1
4923209	Arsenic Trichloride	UN 1560	I	B	6.1
4921727	Bromoacetone	UN 1569	II	B	6.1
4921558	Chloroacetone, Stabilized	UN 1695	I	B	6.1
4921009	Chloroacetonitrile	UN 2668	II	B	6.1
4923117	Chloroacetyl Chloride	UN 1752	I	B	6.1
4921414	Chloropicrin	UN 1580	I	B	6.1
4921746	Chloropivaloyl Chloride	NA 9263	I	B	6.1
4921248	Crotonalydehyde, Stabilized	UN 1143	I	B	6.1
4921010	Cyclohexyl Isocyanate	UN 2488	I	B	6.1
4921254	Diketene, Stabilized	UN 2521	I	B	6.1
4921405	Dimethyl Sulfate	UN 1595	I	B	6.1
4921251	Dimethylhydrazine, Symmetrical	UN 2382	I	B	6.1
4921202	Dimethylhydrazine, Unsymmetrical	UN 1163	I	B	6.1
4921020	Ethyl Chloroformate	UN 1182	I	B	6.1
4921745	Ethyl Phosphonothioic Dichloride, Anhydrous	NA 2927	I	B	6.1
4921742	Ethyl Phosphonous Dichloride, Anhydrous pyrophoric liquid	NA 2845	I	B	6.1
4921744	Ethyl Phosphorodichloridate	NA 2927	I	B	6.1
4921404	Ethyldichloroarsine	UN 1892	I	B	6.1
4921420	Ethylene Chlorohydrin	UN 1135	I	B	6.1

HMRC	Proper Shipping Name	UN/NA#	Packing Group	Hazard Zone	Hazard Class
4921497	Ethylene Dibromide	UN 1605	I	B	6.1
4927006	Ethyleneimine, Stabilized	UN 1185	I	A	6.1
4921722	Hexachlorocyclopentadiene	UN 2646	I	B	6.1
4921028	Hydrocyanic acid, aqueous solutions or Hydrogen cyanide, aqueous solutions	UN 1613	I	B	6.1
4921239	Hydrogen Cyanide, solution in alcohol	UN 3294	I	B	6.1
4927014	Hydrogen Cyanide, stabilized	UN 1051	I	A	6.1
4927004	Iron Pentacarbonyl	UN 1994	I	A	6.1
4921211	Isobutyl Chloroformate	NA 2742	I	B	6.1
4921252	Isopropyl Chloroformate	UN 2407	I	B	6.1
4921245	Methanesulfonyl Chloride	UN 3246	I	B	6.1
4921438	Methyl Bromide and Ethylene dibromide mixtures, liquid	UN 1647	I	B	6.1
4927008	Methyl Chloroformate	UN 1238	I	A	6.1
4927012	Methyl Chloromethyl Ether	UN 1239	I	A	6.1
4921304	Methyl Iodide	UN 2644	I	B	6.1
4927009	Methyl Isocyanate	UN 2480	I	A	6.1
4921487	Methyl Isothiocyanate	UN 2477	I	B	6.1
4921255	Methyl Orthosilicate	UN 2606	I	B	6.1
4921695	Methyl Phosphonic Dichloride	NA 9206	I	B	6.1
4921008	Methyl Phosphonous Dichloride	NA 2845	I	B	6.1
4927022	Methyl Vinyl Ketone, Stabilized	UN 1251	I	A	6.1
4921275	Methyldichloroarsine	NA 1556	I	B	6.1
4927011	Methylhydrazine	UN 1244	I	A	6.1
4921730	n-Butyl Chloroformate	UN 2743	I	B	6.1
4921027	n-Butyl Isocyanate	UN 2485	I	B	6.1
4927010	Nickel Carbonyl	UN 1259	I	A	6.1
4921756	n-Propyl Chloroformate	UN 2740	I	B	6.1
4927025	n-Propyl Isocyanate	UN 2482	I	A	6.1
4921473	Perchloromethyl Mercaptan	UN 1670	I	B	6.1
4921216	Phenyl Isocyanate	UN 2487	I	B	6.1
4921413	Phenyl Mercaptan	UN 2337	I	B	6.1
4921587	Phenylcarbylamine Chloride	UN 1672	I	B	6.1
4921016	Phosphorus Trichloride	UN 1809	I	B	6.1
4921207	sec-Butyl Chloroformate	NA 2742	I	B	6.1
4927026	tert-Butyl Isocyanate	UN 2484	I	A	6.1
4923298	Thiophosgene	UN 2474	II	B	6.1
4921024	Toxic by Inhalation liquid, corrosive, n.o.s.	UN 3390	I	B	6.1
4921287	Toxic by Inhalation liquid, corrosive, n.o.s.	UN 3390	I	B	6.1
4921288	Toxic by Inhalation liquid, corrosive, n.o.s.	UN 3390	I	B	6.1
4927028	Toxic by Inhalation liquid, corrosive, n.o.s.	UN 3389	I	A	6.1
4921003	Toxic by Inhalation liquid, flammable, n.o.s.	UN 3384	I	B	6.1
4921029	Toxic by Inhalation liquid, flammable, n.o.s.	UN 3384	I	B	6.1
4927019	Toxic by Inhalation liquid, flammable, n.o.s.	UN 3383	I	A	6.1
4921000	Toxic by Inhalation liquid, n.o.s.	UN 3382	I	B	6.1
4927018	Toxic by Inhalation liquid, n.o.s.	UN 3381	I	A	6.1

HMRC	Proper Shipping Name	UN/NA#	Packing Group	Hazard Zone	Hazard Class
4921023	Toxic by Inhalation liquid, oxidizing, n.o.s.	UN 3388	I	B	6.1
4927024	Toxic by Inhalation liquid, oxidizing, n.o.s.	UN 3387	I	A	6.1
4921006	Toxic by Inhalation liquid, water-reactive, n.o.s.	UN 3386	I	B	6.1
4927023	Toxic by Inhalation liquid, water-reactive, n.o.s.	UN 3385	I	A	6.1
4921213	Trimethoxysilane	NA 9269	I	B	6.1
4921063	Trimethylacetyl Chloride	UN 2438	I	B	6.1
4821019	Waste Allyl Alcohol	UN 1098	I	B	6.1
4821029	Waste Toxic by Inhalation Liquid, Flammable, n.o.s.	UN 3384	I	B	6.1
4821722	Waste Hexachlorocyclopentadiene	UN 2646	I	B	6.1
CORROSIVES, HAZARD CLASS 8					
4932010	Boron Tribromide	UN 2692	I	B	8
4936110	Bromine or Bromine Solutions	UN 1744	I	A	8
4936106	Bromine Solutions	UN 1744	I	B	8
4930204	Chlorosulfonic Acid	UN 1754	I	B	8
4933327	Ethyl Chlorothioformate	UN 2826	II	B	8
4930024	Hydrogen Fluoride, Anhydrous	UN 1052	I	C	8
4931201	Nitric Acid, red fuming	UN 2032	I	B	8
4932352	Phosphorus Oxychloride	UN 1810	II	B	8
4930050	Sulfur Trioxide, Stabilized	UN 1829	I	B	8
4930030	Sulfuric acid, fuming	UN 1831	I	B	8
4930260	Sulfuryl Chloride	UN 1834	I	A	8
4932385	Titanium Tetrachloride	UN 1838	II	B	8
4935231	Trichloroacetyl Chloride	UN 2442	II	B	8
4830030	Waste Sulfuric acid, fuming	UN 1831	I	B	8

Appendix B:
List of Poison Inhalation Hazard (PIH) or Toxic Inhalation Hazard Chemicals (TIH)
(Hazard Zone A, B, C, or D)
Sorted by Hazmat Response Code #
March 15, 2010

HMRC	Proper Shipping Name	UN/NA#	Packing Group	Hazard Zone	Hazard Class
4821019	Waste Allyl Alcohol	UN 1098	I	B	6.1
4821029	Waste Toxic by Inhalation Liquid, Flammable, n.o.s.	UN 3384	I	B	6.1
4821722	Waste Hexachlorocyclopentadiene	UN 2646	I	B	6.1
4830030	Waste Sulfuric acid, fuming	UN 1831	I	B	8
4904210	Ammonia, Anhydrous	UN 1005			2.2
4904211	Ammonia, Solution	UN 3318			2.2
4904879	Ammonia, Anhydrous	UN 1005			2.2
4907409	Isobutyl Isocyanate	UN 2486	I	A	3
4907434	Ethyl Isocyanate	UN 2481	I	A	3
4909306	Isopropyl Isocyanate	UN 2483	I	A	3
4909307	Methoxymethyl Isocyanate	UN 2605	I	A	3
4910370	Methacrylonitrile, Stabilized	UN 3079	I	B	3
4916138	Pentaborane	UN 1380	I	A	4.2
4918180	Tetranitromethane	UN 1510	I	B	5.1
4918505	Bromine Pentafluoride	UN 1745	I	A	5.1
4918507	Bromine Trifluoride	UN 1746	I	B	5.1
4920101	Compressed Gas, toxic, corrosive, n.o.s.	UN 3304		A	2.3
4920102	Compressed Gas, toxic, flammable, corrosive, n.o.s.	UN 3305		A	2.3
4920103	Compressed Gas, toxic, oxidizing, corrosive, n.o.s.	UN 3306		A	2.3
4920104	Compressed gas, toxic, oxidizing, n.o.s.	UN 3303		A	2.3
4920105	Liquefied gas, toxic, corrosive, n.o.s.	UN 3308		A	2.3
4920106	Selenium Hexafluoride	UN 2194		A	2.3
4920107	Diborane	UN 1911		A	2.3
4920108	Liquefied gas, toxic, flammable, corrosive, n.o.s.	UN 3309		A	2.3
4920110	Liquefied gas, toxic, oxidizing, corrosive, n.o.s.	UN 3310		A	2.3
4920111	Liquefied gas, toxic, oxidizing, n.o.s.	UN 3307		A	2.3
4920112	Nitric Oxide, Compressed	UN 1660		A	2.3
4920113	Nitric oxide and nitrogen dioxide mixtures or Nitric oxide and dinitrogen tetroxide mixtures	UN 1975		A	2.3
4920115	Insecticide gases, toxic, flammable, n.o.s.	UN 3355		A	2.3
4920122	Hydrogen Selenide, anhydrous	UN 2202		A	2.3
4920135	Arsine	UN 2188		A	2.3
4920160	Phosphine	UN 2199		A	2.3
4920164	Liquefied gas, toxic, flammable, n.o.s.	UN 3160		A	2.3
4920165	Compressed Gas, toxic, flammable, n.o.s.	UN 1953		A	2.3
4920167	Stibine	UN 2676		A	2.3
4920173	Oxygen Difluoride, Compressed	UN 2190		A	2.3
4920174	Dinitrogen Tetroxide	UN 1067		A	2.3
4920175	Nitrogen Trioxide	UN 2421		A	2.3

HMRC	Proper Shipping Name	UN/NA#	Packing Group	Hazard Zone	Hazard Class
4920178	Cyanogen Chloride, Stabilized	UN 1589		A	2.3
4920180	Fluorine, Compressed	UN 1045		A	2.3
4920181	Compressed Gas, toxic, n.o.s.	UN 1955		A	2.3
4920184	Phosgene	UN 1076		A	2.3
4920187	Sulfur Tetrafluoride	UN 2418		A	2.3
4920188	Tellurium Hexafluoride	UN 2195		A	2.3
4920189	Chlorine Pentafluoride	UN 2548		A	2.3
4920195	Liquefied gas, toxic, n.o.s.	UN 3162		A	2.3
4920301	Compressed Gas, toxic, corrosive, n.o.s.	UN3304		D	2.3
4920302	Insecticide gases, toxic, flammable, n.o.s.	UN 3355		B	2.3
4920303	Compressed Gas, toxic, flammable, corrosive, n.o.s.	UN 3305		B	2.3
4920304	Compressed Gas, toxic, flammable, corrosive, n.o.s.	UN 3305		C	2.3
4920305	Compressed Gas, toxic, flammable, corrosive, n.o.s.	UN 3305		D	2.3
4920306	Compressed Gas, toxic, oxidizing, corrosive, n.o.s.	UN 3306		B	2.3
4920307	Compressed Gas, toxic, oxidizing, corrosive, n.o.s.	UN 3306		C	2.3
4920308	Compressed Gas, toxic, oxidizing, corrosive, n.o.s.	UN 3306		D	2.3
4920309	Compressed gas, toxic, oxidizing, n.o.s.	UN 3303		C	2.3
4920310	Compressed gas, toxic, oxidizing, n.o.s.	UN 3303		D	2.3
4920311	Liquefied gas, toxic, corrosive, n.o.s.	UN 3308		B	2.3
4920312	Liquefied gas, toxic, oxidizing, corrosive, n.o.s.	UN 3310		B	2.3
4920313	Liquefied gas, toxic, corrosive, n.o.s.	UN 3308		C	2.3
4920314	Liquefied gas, toxic, flammable, corrosive, n.o.s.	UN 3309		B	2.3
4920315	Liquefied gas, toxic, corrosive, n.o.s.	UN 3308		D	2.3
4920316	Liquefied gas, toxic, flammable, corrosive, n.o.s.	UN 3309		C	2.3
4920317	Liquefied gas, toxic, oxidizing, n.o.s.	UN 3307		B	2.3
4920318	Liquefied gas, toxic, flammable, corrosive, n.o.s.	UN 3309		D	2.3
4920319	Liquefied gas, toxic, oxidizing, n.o.s.	UN 3307		C	2.3
4920320	Liquefied gas, toxic, oxidizing, corrosive, n.o.s.	UN 3310		C	2.3
4920321	Liquefied gas, toxic, oxidizing, n.o.s.	UN 3307		D	2.3
4920322	Insecticide gases, toxic, flammable, n.o.s.	UN 3355		C	2.3
4920323	Insecticide gases, toxic, flammable, n.o.s.	UN 3355		D	2.3
4920324	Compressed Gas, toxic, corrosive, n.o.s.	UN 3304		B	2.3
4920325	Liquefied gas, toxic, oxidizing, corrosive, n.o.s.	UN 3310		D	2.3
4920326	Phosphorus Pentafluoride	UN 2198		B	2.3
4920331	Compressed Gas, toxic, corrosive, n.o.s.	UN 3304		C	2.3
4920337	Compressed gas, toxic, oxidizing, n.o.s.	UN 3303		B	2.3
4920342	Ethylene Oxide and Carbon Dioxide mixture	UN 3300		D	2.3
4920343	Carbon Monoxide and Hydrogen mixture, Compressed	UN 2600			2.3
4920344	Oil Gas, Compressed	UN 1071			2.3
4920346	Trifluorochloroethylene, Stabilized	UN 1082		C	2.3
4920347	Trifluoroacetyl Chloride	UN 3057		B	2.3
4920348	Hydrogen Iodide, anhydrous	UN 2197		C	2.3

HMRC	Proper Shipping Name	UN/NA#	Packing Group	Hazard Zone	Hazard Class
4920349	Boron Trichloride	UN 1741		C	2.3
4920351	Carbonyl Sulfide	UN 2204		C	2.3
4920352	Chlorine Trifluoride	UN 1749		B	2.3
4920353	Ethylene Oxide or Ethylene Oxide with Nitrogen	UN 1040		D	2.3
4920354	Germane	UN 2192		B	2.3
4920355	Methyl Mercaptan	UN 1064		C	2.3
4920356	Perchloryl Fluoride	UN 3083		B	2.3
4920357	Silicon Tetrafluoride	UN 1859		B	2.3
4920359	Ammonia, Anhydrous	UN 1005		D	2.3
4920360	Ammonia, Solution	UN 3318		D	2.3
4920368	Liquefied gas, toxic, n.o.s.	UN 3162		C	2.3
4920369	Liquefied gas, toxic, n.o.s.	UN 3162		D	2.3
4920371	Tungsten Hexafluoride	UN 2196		B	2.3
4920373	Compressed Gas, toxic, n.o.s.	UN 1955		D	2.3
4920375	Compressed Gas, toxic, n.o.s.	UN 1955		C	2.3
4920378	Compressed Gas, toxic, flammable, n.o.s.	UN 1953		C	2.3
4920379	Compressed Gas, toxic, flammable, n.o.s.	UN 1953		D	2.3
4920380	Liquefied gas, toxic, flammable, n.o.s.	UN 3160		C	2.3
4920381	Liquefied gas, toxic, flammable, n.o.s.	UN 3160		D	2.3
4920382	Liquefied gas, toxic, flammable, n.o.s.	UN 3160		B	2.3
4920383	Liquefied gas, toxic, n.o.s.	UN 3162			2.3
4920392	Chloropicrin and Methyl Chloride mixtures	UN 1582		B	2.3
4920394	Methylchlorosilane	UN 2534		B	2.3
4920395	Cyanogen	UN 1026		B	2.3
4920396	Compressed Gas, toxic, flammable, n.o.s.	UN 1953		B	2.3
4920398	Dichlorosilane	UN 2189		B	2.3
4920399	Carbon Monoxide, Compressed	UN 1016		D	2.3
4920502	Hydrogen Bromide, anhydrous	UN 1048		C	2.3
4920503	Hydrogen Chloride, anhydrous	UN 1050		C	2.3
4920504	Hydrogen Chloride, refrigerated liquid	UN 2186		C	2.3
4920505	Compressed Gas, toxic, n.o.s.	UN 1955		C	2.3
4920508	Sulfur Dioxide	UN 1079		C	2.3
4920509	Nitrosyl Chloride	UN 1069		C	2.3
4920510	Gas Identification set	NA 9035			2.3
4920511	Carbon Monoxide, refrigerated liquid	NA 9202		D	2.3
4920513	Hydrogen Sulfide	UN 1053		B	2.3
4920515	Hexaethyl tetraphosphate and compressed gas mixtures	UN 1612		C	2.3
4920516	Chloropicrin and Methyl Bromide mixtures	UN 1581		B	2.3
4920517	Compressed Gas, toxic, n.o.s.	UN 1955			2.3
4920518	Methyl Bromide	UN 1062		C	2.3
4920522	Boron Trifluoride	UN 1008		B	2.3
4920523	Chlorine	UN 1017		B	2.3
4920525	Compressed Gas, toxic, n.o.s.	UN 1955			2.3
4920526	Sulfuryl Fluoride	UN 2191		D	2.3

HMRC	Proper Shipping Name	UN/NA#	Packing Group	Hazard Zone	Hazard Class
4920527	Coal Gas, Compressed	UN 1023		C	2.3
4920528	Hexafluoroacetone	UN 2420		B	2.3
4920530	Organic phosphate, mixed with compressed gas or Organic phosphate compound, mixed with compressed gas or Organic phosphorus compound, mixed with compressed gas	NA 1955		C	2.3
4920531	Liquefied gas, toxic, n.o.s.	UN 3162			2.3
4920534	Gas sample, non-pressurized, toxic, flammable, n.o.s.	UN 3168			2.3
4920535	Parathion and Compressed gas mixture	NA 1967		C	2.3
4920536	Gas sample, non-pressurized, toxic, n.o.s.	UN 3169			2.3
4920547	Chloropicrin and Methyl Bromide mixtures	UN 1581		B	2.3
4920550	Insecticide gases, toxic, n.o.s.	UN 1967		C	2.3
4920556	Compressed Gas, toxic, n.o.s.	UN 1955		B	2.3
4920559	Carbonyl Fluoride	UN 2417		B	2.3
4920570	Compressed Gas, toxic, n.o.s.	UN 1955		B	2.3
4920571	Liquefied gas, toxic, n.o.s.	UN 3162		B	2.3
4920715	Bromine Chloride	UN 2901		B	2.3
4921000	Toxic by Inhalation liquid, n.o.s.	UN 3382	I	B	6.1
4921003	Toxic by Inhalation liquid, flammable, n.o.s.	UN 3384	I	B	6.1
4921004	Allylamine	UN 2334	I	B	6.1
4921006	Toxic by Inhalation liquid, water-reactive, n.o.s.	UN 3386	I	B	6.1
4921008	Methyl Phosphonous Dichloride	NA 2845	I	B	6.1
4921009	Chloroacetonitrile	UN 2668	II	B	6.1
4921010	Cyclohexyl Isocyanate	UN 2488	I	B	6.1
4921016	Phosphorus Trichloride	UN 1809	I	B	6.1
4921019	Allyl Alcohol	UN 1098	I	B	6.1
4921020	Ethyl Chloroformate	UN 1182	I	B	6.1
4921023	Toxic by Inhalation liquid, oxidizing, n.o.s.	UN 3388	I	B	6.1
4921024	Toxic by Inhalation liquid, corrosive, n.o.s.	UN 3390	I	B	6.1
4921027	n-Butyl Isocyanate	UN 2485	I	B	6.1
4921028	Hydrocyanic acid, aqueous solutions or Hydrogen cyanide, aqueous solutions	UN 1613	I	B	6.1
4921029	Toxic by Inhalation liquid, flammable, n.o.s.	UN 3384	I	B	6.1
4921063	Trimethylacetyl Chloride	UN 2438	I	B	6.1
4921202	Dimethylhydrazine, Unsymmetrical	UN 1163	I	B	6.1
4921207	sec-Butyl Chloroformate	NA 2742	I	B	6.1
4921211	Isobutyl Chloroformate	NA 2742	I	B	6.1
4921213	Trimethoxysilane	NA 9269	I	B	6.1
4921216	Phenyl Isocyanate	UN 2487	I	B	6.1
4921239	Hydrogen Cyanide, solution in alcohol	UN 3294	I	B	6.1
4921245	Methanesulfonyl Chloride	UN 3246	I	B	6.1
4921248	Crotonalydehyde, Stabilized	UN 1143	I	B	6.1
4921251	Dimethylhydrazine, Symmetrical	UN 2382	I	B	6.1
4921252	Isopropyl Chloroformate	UN 2407	I	B	6.1
4921254	Diketene, Stabilized	UN 2521	I	B	6.1

HMRC	Proper Shipping Name	UN/NA#	Packing Group	Hazard Zone	Hazard Class
4921255	Methyl Orthosilicate	UN 2606	I	B	6.1
4921275	Methyldichloroarsine	NA 1556	I	B	6.1
4921287	Toxic by Inhalation liquid, corrosive, n.o.s.	UN 3390	I	B	6.1
4921288	Toxic by Inhalation liquid, corrosive, n.o.s.	UN 3390	I	B	6.1
4921304	Methyl Iodide	UN 2644	I	B	6.1
4921401	Acetone Cyanohydrin, Stabilized	UN 1541	I	B	6.1
4921402	2-Chloroethanal	UN 2232	I	B	6.1
4921404	Ethyldichloroarsine	UN 1892	I	B	6.1
4921405	Dimethyl Sulfate	UN 1595	I	B	6.1
4921413	Phenyl Mercaptan	UN 2337	I	B	6.1
4921414	Chloropicrin	UN 1580	I	B	6.1
4921420	Ethylene Chlorohydrin	UN 1135	I	B	6.1
4921438	Methyl Bromide and Ethylene dibromide mixtures, liquid	UN 1647	I	B	6.1
4921473	Perchloromethyl Mercaptan	UN 1670	I	B	6.1
4921487	Methyl Isothiocyanate	UN 2477	I	B	6.1
4921495	2-Methyl-2-Heptanethiol	UN 3023	I	B	6.1
4921497	Ethylene Dibromide	UN 1605	I	B	6.1
4921558	Chloroacetone, Stabilized	UN 1695	I	B	6.1
4921587	Phenylcarbylamine Chloride	UN 1672	I	B	6.1
4921695	Methyl Phosphonic Dichloride	NA 9206	I	B	6.1
4921722	Hexachlorocyclopentadiene	UN 2646	I	B	6.1
4921727	Bromoacetone	UN 1569	II	B	6.1
4921730	n-Butyl Chloroformate	UN 2743	I	B	6.1
4921741	3, 5-Dichloro-2, 4, 6-Trifluoropyridine	NA 9264	I	B	6.1
4921742	Ethyl Phosphonous Dichloride, Anhydrous pyrophoric liquid	NA 2845	I	B	6.1
4921744	Ethyl Phosphorodichloridate	NA 2927	I	B	6.1
4921745	Ethyl Phosphonothioic Dichloride, Anhydrous	NA 2927	I	B	6.1
4921746	Chloropivaloyl Chloride	NA 9263	I	B	6.1
4921756	n-Propyl Chloroformate	UN 2740	I	B	6.1
4923113	Allyl Chloroformate	UN 1722	I	B	6.1
4923117	Chloroacetyl Chloride	UN 1752	I	B	6.1
4923209	Arsenic Trichloride	UN 1560	I	B	6.1
4923298	Thiophosgene	UN 2474	II	B	6.1
4927004	Iron Pentacarbonyl	UN 1994	I	A	6.1
4927006	Ethyleneimine, Stabilized	UN 1185	I	A	6.1
4927007	Acrolein, Stabilized	UN 1092	I	A	6.1
4927008	Methyl Chloroformate	UN 1238	I	A	6.1
4927009	Methyl Isocyanate	UN 2480	I	A	6.1
4927010	Nickel Carbonyl	UN 1259	I	A	6.1
4927011	Methylhydrazine	UN 1244	I	A	6.1
4927012	Methyl Chloromethyl Ether	UN 1239	I	A	6.1
4927014	Hydrogen Cyanide, stabilized	UN 1051	I	A	6.1
4927018	Toxic by Inhalation liquid, n.o.s.	UN 3381	I	A	6.1

HMRC	Proper Shipping Name	UN/NA#	Packing Group	Hazard Zone	Hazard Class
4927019	Toxic by Inhalation liquid, flammable, n.o.s.	UN 3383	I	A	6.1
4927022	Methyl Vinyl Ketone, Stabilized	UN 1251	I	A	6.1
4927023	Toxic by Inhalation liquid, water-reactive, n.o.s.	UN 3385	I	A	6.1
4927024	Toxic by Inhalation liquid, oxidizing, n.o.s.	UN 3387	I	A	6.1
4927025	n-Propyl Isocyanate	UN 2482	I	A	6.1
4927026	tert-Butyl Isocyanate	UN 2484	I	A	6.1
4927028	Toxic by Inhalation liquid, corrosive, n.o.s.	UN 3389	I	A	6.1
4930024	Hydrogen Fluoride, Anhydrous	UN 1052	I	C	8
4930030	Sulfuric acid, fuming	UN 1831	I	B	8
4930050	Sulfur Trioxide, Stabilized	UN 1829	I	B	8
4930204	Chlorosulfonic Acid	UN 1754	I	B	8
4930260	Sulfuryl Chloride	UN 1834	I	A	8
4931201	Nitric Acid, red fuming	UN 2032	I	B	8
4932010	Boron Tribromide	UN 2692	I	B	8
4932352	Phosphorus Oxychloride	UN 1810	II	B	8
4932385	Titanium Tetrachloride	UN 1838	II	B	8
4933327	Ethyl Chlorothioformate	UN 2826	II	B	8
4935231	Trichloroacetyl Chloride	UN 2442	II	B	8
4936106	Bromine Solutions	UN 1744	I	B	8
4936110	Bromine or Bromine Solutions	UN 1744	I	A	8

Appendix C
Environmentally Sensitive Chemicals
March 15, 2010

Proper Shipping Name	Hazmat STCC
Allyl Chloride	4907412
Carbon Tetrachloride	4821831 / 4860106 / 4921830 / 4921831 / 4960115
Chlorobenzene	4909153
Chloroform	4921767 / 4921769 / 4925224 / 4925225
o-Dichlorobenzene	4915132 / 4925203
Dichloropropane (Propylene dichloride)	4909265
Dichloropropane/Dichloropropene mixture	4910234
Dichloropropene	4909255
Ethyl Chloride	4905712 / 4908129 / 4908162 /
Ethylene Dibromide (already listed as PIH)	
Ethylene Dibromide and Methyl Bromide Mixtures (already listed as PIH)	
Ethylene Dichloride	4909166 / 4912081/ 4908129 / 4910437 / 4913242 / 4913295 / 4921030
Epichlorohydrin	4921005
Methyl Chloroform (1,1,1 Trichloroethane)	4825182 / 4925182 / 4910463 / 4910475 / 4925310 / 4960205
Methylene Chloride (Dichloromethane)	4925131 / 4905764
Methylene chloride/chloroform mixture	4960150
Perchloroethylene (Tetrachlorothylene)	4825202 / 4910134 / 4925202
Perchloroethylene/Trichloroethylene mixture	4940373
Trichloroethylene	4825181 / 4925181

Appendix D
Time Sensitive Materials
July 17, 2006

Proper Shipping Name	Haz Mat STCC
20 Day	
Ethylene, refrigerated liquid	4905735
Hydrogen, refrigerated liquid	4905745
Vinyl Fluoride, stabilized	4905793
Chloroprene, stabilized	4907223
Flammable Liquid, n.o.s. (Methyl Methacrylate Monomer, uninhibited)	4907255
Hydrogen chloride, refrigerated liquid	4920504
30 day	
Styrene monomer, stabilized	4907265
Flammable Liquid, n.o.s. (Recycled styrene)	4910159
Styrene monomer, stabilized	4907235

Appendix E
Spent Nuclear Fuel (SNF) and High Level Radioactive Waste (HLRW)
March 17, 2009

HMRC	Proper Shipping Description
4929142	Radioactive Material, Type B(U) Package, Fissile
4929143	Radioactive Material, Type B(M) Package, Fissile
4929144	Radioactive Material, Transported Under Special Arrangement, Fissile
4929147	Radioactive Material, Transported Under Special Arrangement

Appendix F to
Circular OT-55

Sample Request for Hazardous Materials Commodity Flow Information

March 1, 2005

[Company LOGO]

Request for Hazardous Materials COMMODITY FLOW INFORMATION

Organization Requesting Information: ____

Contact Person: ____

Phone Number: ____

Email Address: ____

Mailing Address: ____
(Street Address)
____
(City, State, Zip)

Geographical Description of Area for study: ____

____

Preferred method to receive report: ☐ Email ☐ U.S. Mail (Mark One)

By signing below I acknowledge and agree to the terms set forth by **[RAILROAD NAME]** for use and dissemination of the **[RAILROAD'S]** Hazardous Materials Commodity Flow Information . [RAILROAD'S NAME] considers this information to be restricted information of a security sensitive nature. I thus affirm and agree that the information provided by **[RAILROAD NAME]** in this report will be used solely for and by bona fide emergency planning and response organizations for the expressed purpose of emergency and contingency planning. This information will not be distributed publicly in whole or in part without the expressed written permission of **[RAILROAD NAME]**.

____
(Signature of person requesting commodity flow information)

Return Completed Form to: [INSERT RAILROAD NAME AND ADDRESS]

- -

For [RAILROAD] Use Only

[PERSON RESPONSIBLE FOR APPROVAL]: ___Yes___ NO Date: __________

Hazardous Materials Service Support:

Date Request Received: ______________________________

Time Period Covered: ________________________________

Date Report Sent: __________________________________

Report sent via: ☐ Email ☐ U.S. Mail

Appendix B:
Thermoluminescent Dosimetry

Radiation absorbed dose is measured using different instruments, one of which is the thermoluminescent dosimeter (TLD). This is a simple explanation of how the TLD works: When ionizing radiation interacts with any material, some or all of the energy is deposited in that material. The energy interacts with the atoms in the material, causing some to lose an electron—called ionization—and results in the formation of a charged atom, called an ion.

Thermoluminescence (TL) is the ability of some materials to convert the energy from the ionizing radiation absorbed to a radiation of a different wavelength, normally in the visible light range through the application of heat to the material. Generally the materials that are used for this purpose are crystalline in form. Most crystalline materials contain impurities, thus producing irregularities within the crystal structure (lattice). The imperfections in the crystal lattice act as sites where free electrons from the ionization process can become trapped, locking them in the crystal. The crystalline materials most commonly used in TLDs are made of lithium fluoride (LiF) and calcium fluoride (CaF), although some other materials can be used for specific applications.

Heating the crystal causes the crystal lattice to release the trapped electrons, thus releasing the captured energy from ionization as light. The intensity of the light released in this way is measured using a very sensitive device based on photomultiplier tubes. The number of photons is then counted and is proportional to the amount of energy deposited in the crystal.

Sophisticated TLDs have up to four identical crystals mounted on a card with filters made of different materials (for example, plastic, aluminum, copper, etc.), and thicknesses placed in front of each of the crystals. The filters help determine the type and energy of the incident radiation since different filter material reduces the amount of ionizing radiation getting to the crystals differently. The automated reader then heats the four crystals simultaneously and light output from each crystal is read out separately. Dose calculating algorithms are applied to the readings from the crystals to calculate the radiation dose to the individual wearing the dosimeter.

For situations where a specific type of radiation is expected or the measurement of one type is more “important,” filter materials of different types and thickness can be tailored along with calibration procedures using specific sources for the type of radiation of concern to ensure the accuracy of those specific measurements. The tailoring of filter materials is also useful for estimating exposures to different parts of the body, e.g., skin and shallow tissue, lenses of the eyes, and deep body tissue doses.

The minimum reportable dose is 10 millirem for gamma radiation and x-rays. This is the smallest dose that can be measured reliably and accurately.

Once the TLD is put through the reading process, the crystals are essentially “renewed” since the absorbed energy is released by the reading process, and the TLD can be used again.