14th International Symposium on the Packaging and Transportation of Radioactive Materials (PATRAM 2004), Berlin, Germany, September 20-24, 2004

Paper # 246

Assessing Exposure to the Public from Low-Level Radioactive Waste Truck Transportation in the United States to the Nevada Test Site

Shafer, David S., Campbell, Scott, Church, Bruce W., Gray, Karen J., Holz, Barbara, and Miller, J.J.
Desert Research Institute, 755 East Flamingo Road, Las Vegas, Nevada 89119 USA

ABSTRACT

The U.S. Department of Energy's (USDOE) Nevada Test Site (NTS) is one of two regional sites in the United States where low-level radioactive waste (LLW) from approved USDOE and U.S. Department of Defense generators is disposed by shallow land burial. In fiscal year 2003, when most of the data for this study was collected, more than 91,000 m^3 of LLW were transported by truck to the NTS. USDOE and U.S. Department of Transportation (USDOT) regulations ensure that radiation exposure from truck shipments is negligible. Nevertheless, particularly in rural communities, there is perceived public risk regarding cumulative exposure, especially where LLW transportation routes and main highways running through towns are one and the same.

To address the issue of cumulative exposure, a stationary and automated array of four Reuter-Stokes, Model RSS-131, high-pressure ion chambers (PICs) was set up to monitor trucks transporting LLW before entering the NTS. PICs were positioned 1 m from the truck trailer at a height of 1.52 m to simulate conditions where exposure to a human being standing next to a truck carrying LLW is representative of the exposure to the chest area for a "Reference Man" [1]. The four PICs (two on each side of the vehicle pullout area) were used to investigate nonuniformity in the wasteload, which occurs when levels of gamma radiation from waste packages varies from side to side and from front to back in the truck trailer. Each PIC was calibrated both at the field site and in the laboratory to a source known to contain 189.2 μCi of ^{137}Cs.

Truck drivers were directed to park their trucks in a marked "footprint" within the array and record times of arrival and Waste Shipment Identification Numbers in a logbook at the vehicle pullout area. Acoustic sensors were used to produce a second record noting when a truck entered and departed the array. Values from the PICs were assessed at 5-sec intervals, whether or not a truck was present. For each 2-min interval, a maximum, minimum, and averaged 5-sec reading was recorded by each PIC and stored on a data logger. Measurements recorded when trucks were not present were used to calculate two, 12-hr background readings per each 24-hr period. Typical background conditions were reflected in the maximum background reading recorded by the 4 detectors on 6 March 2003 (stable weather with no significant barometric changes), where the average median of the maximum PIC readings was 13.4 μR/hr with an average standard deviation of 1.16 μR/hr. However, background ranged between 9–50 μR/hr. From a gross measurement collected at the array, a background reading and its standard deviation were subtracted to obtain a net exposure for the truck trailer. Automating the array provided an objective and consistent means for calculating potential exposure from each vehicle.

Because the USDOE could not contractually require truck drivers to use the array, the data set was biased toward voluntary participants. However, some trucks were measured from all the major generators that shipped to the NTS during the study period. Data on 1,012 LLW shipments were collected in 2003, and the analysis is nearing completion. A group of 436 trucks (43 percent) were measured below background thus contributing no net exposure above background. For another 37 percent (378), exposures are projected to be at or near background. Therefore, only 20 percent of the truck population would contribute to the cumulative exposure of an individual, although cumulative exposure would be dominated by the small number of trucks (54) producing net exposure values greater than 1 mR/hr at 1 m. The highest exposure measurement, if converted to dose, was less than 7.5 percent of the USDOT shipping standard at 2 m. The study was funded by the Waste Management Division of the USDOE, National Nuclear Security Administration Nevada Site Office.

INTRODUCTION

Background and Objectives

The United States Department of Energy's (USDOE) Nevada Test Site (NTS) is one of two U.S. regional sites where low-level radioactive waste (LLW) from approved USDOE and U.S. Department of Defense generators is disposed by shallow land burial. Since 1980, more than 651,558 m^3 of LLW have been disposed at the NTS. During fiscal year 2003, when most of the data for this study were collected, more than 91,000 m^3 of LLW were transported by truck to the NTS. It is anticipated that offsite generators will continue to dispose LLW at the NTS until at least 2021 [2]. The NTS is located 105 km northwest of Las Vegas, Nevada (Figure 1).

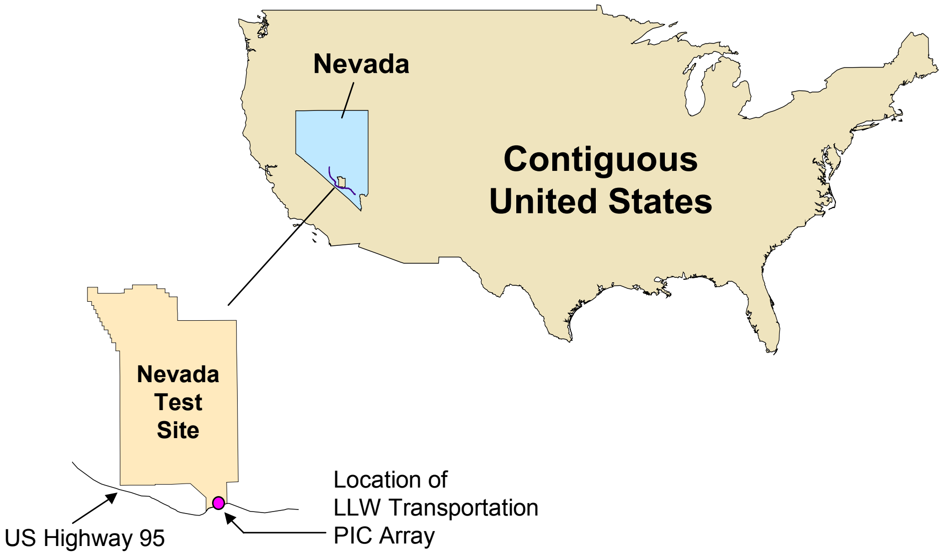

Figure 1. Location of the NTS study site in the state of Nevada in the contiguous United States.

USDOE and U.S. Department of Transportation (USDOT) regulations ensure that radiation exposure to U.S. citizens from LLW shipments is negligible. Nevertheless, public concern over the safety of LLW shipments to the NTS continues. These concerns can be broadly divided into two categories: (1) risk of vehicle accidents involving trucks transporting LLW on public highways, resulting in the release of radioactive material; and (2) possible long-term health risks due to cumulative exposure from LLW shipments to residents living along transportation routes. There is a perceived risk about cumulative exposure particularly from residents living in rural communities along transportation routes in the states of Utah and Nevada, especially when their "Main Street" and the transportation route used by LLW trucks are one and the same. Generators of LLW primarily use highways that pass through rather than around towns in rural parts of Nevada and western Utah to reach the NTS.

Previous studies on potential exposure to the public from transporting LLW to the NTS either relied on calculated exposures [3] or were based on a small population of trucks (100) where a standard deviation and relatively high-background value (50 μR/hr) were subtracted from the gross reading of the truck trailer [4]. To provide a comprehensive assessment of potential exposure from gamma radiation to the public, the Desert Research Institute (DRI) and USDOE National Nuclear Security Administration, Nevada Site Office (USDOE/NNSA/NSO) set up a stationary and automated array of four high-pressure ion chambers (PICs) in a vehicle pullout area just outside the entrance to the NTS. The PIC array was designed to simulate the conditions of a resident in a small town along the side of the road when a LLW truck was passing along one of the transportation routes to the NTS.

Voluntary Nature of the Study

The purpose in automating the system was to provide a set-up whereby potential radiation exposure from trucks transporting LLW could be objectively and consistently measured and calculated. However, USDOE/NNSA/NSO could not contractually require truck drivers to use the PIC array. Consequently, the data set is biased toward volunteers who participated in the study. In addition, because of the isolated nature of the NTS and because trucks arrive at all times throughout the day and night, it was not practical to have a person available to facilitate participation in the study. Nevertheless, between 13 February 2003 and the 31 December 2003, external gamma readings were collected from 1,012 of the approximately 2,260 trucks that delivered LLW to the NTS. All U.S. generators who ship waste to the NTS were represented in the data set. The authors are unaware of a larger data set of automated exposure readings collected from LLW trucks during transit.

METHODS

Configuring the PIC Array

The stationary and automated array of four Reuter-Stokes, Model 131, PICs was set up at an existing roadside pullout just before the entrance to the NTS. The array was designed with two PICs on each side of the driveway, allowing a semi-truck to drive into the array and center the trailer between the two pairs of PICs (Figure 2). The PICs were positioned along the driveway, so that they would be situated 1 m away from the side of a standard truck trailer and at a height of 1.52 m above the ground to simulate conditions of a human being standing next to a LLW truck on a standard two-lane highway in the United States—an exposure scenario frequently presented by the DOE/NNSA/NSO to the public in discussing LLW transportation [4]. Although determining dose or a dose rate was not an objective of the study, the array layout was designed to detect exposures that would be representative of potential exposure to the chest area for a “Reference Man” using the Snyder-Fisher model of an adult human [1]. Four PICs (two on each side) were used to evaluate nonuniformity in the wasteload, where gamma radiation levels from waste packages varied from side to side and from front to back in the truck trailer. Photoacoustic sensors (Campbell Scientific SR50 instruments), positioned on each side of the driveway between the PICs and horizontally aimed at the center of the driveway, were used to help detect when a truck entered and departed the array. Readings from the photoacoustic sensors and PICs were recorded on Campbell Scientific CR10x data loggers and later manually downloaded to a laptop computer. Lights were provided at the PIC array, so that it could be used 24 hours per day. Power to the detectors, data loggers, and related equipment was provided by solar panels and storage batteries (Figure 2).

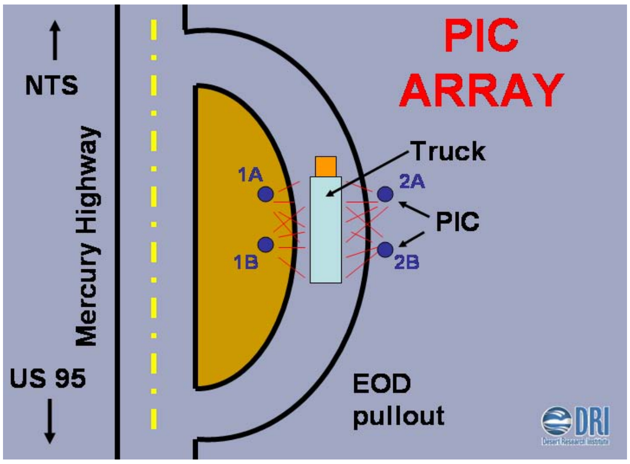

Figure 2. Plan view schematic of PIC array.

Calibrating the PIC Array

The objective in calibrating the PIC array was to examine the response of the PICs to known source strength in the same configuration that they would be placed in the field to study the potential radiation exposure of an NTS-bound load of LLW. The measurements could then be compared to the theoretical response versus distance (i.e., inverse-square law) curve and values calculated for the calibration source when the distance between the source and the PIC was increased. The PICs were permanently installed at the vehicle pullout area and positioned, so that approximately one-third of the truck trailer extended beyond the front and back of the PIC array (Figure 3). An Isotope Products Laboratories 189.2 μCi source of ^{137}Cs (Nevada State Health Division, Radioactive Material License Number 16-13-0003-07) was mounted on a tripod within a Plexiglas® framework, selected to reduce or minimize absorption and scatter of the ^{137}Cs gamma rays. A laser-light level was used to verify that the source was in the same horizontal and vertical planes as the center point of the ionization chamber in the instrument for each distance where PIC responses were measured.

Figure 3. A flatbed truck positioned in the PIC array during the setup.

Exposure rate was measured at three distances between the source and center of the instrument's ionization chamber: 0.3 m, 0.5 m, and 1.0 m. At each distance, seven gross or total gamma readings in microroentgens per hour (μR/hr) were taken at 5-sec intervals. From the averaged value for the total gamma measurements, an averaged background reading (seven measurements total) was subtracted to yield a net value. The exposure and background rates were hand-recorded and digitally recorded on a data logger. Work was temporarily halted if winds at the site exceeded approximately 16–32 km/hr.

Following the data collection phase in the field, the array was disassembled and the PICs brought back to the DRI laboratory in Las Vegas, Nevada. A similar calibration was performed on PICs 1A and 2A in the laboratory to compare with the measurements taken in the field. For each PIC, 15 measurements were taken at each of the three distances measured in the field, and net values were calculated similarly to the field calibration. PIC 2A showed a slight under response both in the field and in the laboratory as shown in Table 1. With the exception of the reading of PIC 1A at 0.3 m, all the net readings in the DRI laboratory were slightly higher than in the field, possibly because of some scatter off the floor, ceilings, and walls in the room.

Table 1. Calibration results of PICs in the field array, as well as laboratory calibrations at DRI. Background readings were subtracted from gross PIC readings to obtain net readings in microroentgens per hour (μR/hr). Parenthetical values below the three distances where PIC readings were taken (100, 50, and 30 cm) are theoretical values for the calibration source using the inverse-square law.

Field Calibration

		Net Readings (μR/hr)			
Data logger	PIC	100 cm (60.5)	50 cm (242.0)	30 cm (672.7)	Background (μR/hr)
1	1A	62.7	243.0	672.0	11.7
	1B	62.3	245.0	664.0	11.7
2	2A	57.4	225.0	614.0	11.1
	2B	61.5	235.0	654.0	11.6

DRI Laboratory Calibration

		Net Readings (μR/hr)			
Data logger	PIC	100 cm (60.5)	50 cm (242.0)	30 cm (672.7)	Background (μR/hr)
1	1A	63.6	244.8	671.4	10.6
	1B	63.8	—	—	10.9
2	2A	59.0	228.7	622.7	10.6
	2B	61.9	—	—	10.3

In addition to DRI calibrations, the PIC 1A was sent to the U.S. Department of Homeland Security, Environmental Measurement Laboratory (EML), in New York for an independent, cross-calibration check to verify accuracy and precision in the PIC array. At EML, a 1 mg traceable ^{266}Ra needle source from the National Institute of Standards and Technology was used in shadow-field geometry at a distance of 4–5 m from the PIC. At this distance, the exposure rate for the direct beam ranged from 30–45 μR/hr. The result for the direct analog output from PIC 1A was 14.1 mV per μR/hr. This calibration factor provided a room background reading of about 7 μR/hr. PIC 1A was previously calibrated by Reuter-Stokes in March 2001 with a ^{137}Cs source and produced a value of 13.68 mV per μR/hr, a 3 percent difference from the EML reading. However, this reading was within the tolerance range for a response variance in the detector energy for a PIC when comparing ^{266}Ra with a ^{137}Cs calibration source [5].

Instructions to Generators for Using PIC Array

Participation by waste generators was voluntary. However, to encourage participation, the DOE/NNSA/NSO Waste Management Division Director, E. F. DiSanza, in a letter to all approved offsite LLW waste generators, requested that transportation companies participate in the study [6]. When drivers entered the array, they were directed to park the truck trailer in a marked “footprint” within the array and enter the prescribed information in a logbook located at the vehicle pullout area. The drivers were asked to record the date and time of their arrival, location where the waste shipment originated, and the Waste Shipment Identification Number. Instructions for the drivers regarding the location of the vehicle pullout area and how to park the truck trailer in the array, as well as photographs of the site, were included in the letter [6]. The instructions were also posted at the array.

Collecting and Processing Data from the PIC Array

PIC data loggers were programmed to run continuously. PIC measurements were taken at 5-sec intervals, and at 2-min intervals, the data logger recorded the (1) maximum microroentgen (μR/hr) value collected during the 2-min period, (2) minimum value recorded, and (3), average of all 5-sec PIC readings [7]. In using these values, it is important to note that it was known when a truck passed through the PIC array during a 2-min interval. However, particularly when the minimum recorded PIC value was at background, there was ample evidence that the truck may not have remained for the entire duration of the two-minute period. In these cases, the 2-min averaged readings from the PIC would incorporate both measurements from the truck as well as background readings before the truck entered the array or after it departed. As a consequence, the maximum PIC values were the most consistent measurements of the truck. Consequently, the highest maximum value from the four PICs was selected as the gross measurement for the truck.

Readings taken when trucks were not present in the array were used to calculate two background values in a 24-hour period: from 1946 to 0744 and 0744 to 1946 hours. For consistency in using maximum exposure measurements from the trucks, the average of maximum values obtained during the 12-hr window when trucks arrived at the PIC array, plus the standard deviation, were subtracted from the gross reading to obtain net exposure values for each truck. Typical maximum background conditions at the PIC array site are represented by those occurring on 6 March 2003 (stable weather with no significant barometric changes), where the average median of maximum PIC readings was 13.4 μR/hr with an average standard deviation of 1.16 μR/hr. Overall, background readings could vary from approximately 9–40 μR/hr, although typically background ranged between 10–15 μR/hr.

Exposure Reading Greater than 800 μR/hr

Although manufacturer specifications for the Reuter-Stokes, Model RSS-131, PIC specify that this instrument will read to 1000 μR/hr, it was found that a second channel on the PIC had to be used for measurements over 800 μR/hr, and even then, per the manufacturer, the “analog sensitivity output is invalid” for measurements between 800 and 1000 μR/hr [8]. To rectify this situation, which affected 59 trucks that produced one or more PIC readings exceeding 800 μR/hr, the Waste Shipment Identification Number from the logbook was used to obtain specific waste information for that particular truck from the Radioactive Waste Management Complex (RWMC) on the NTS. Before a wasteload is accepting at this complex for disposal, radiation readings are made using a Ludlum Model 3 gamma detector to verify compliance with Title 10 US Code of Federal Regulation Part 835 (Occupation Radiation Protection) and other DOE radiation control procedures. At the RWMC, the highest spot reading on a truck trailer must be recorded. Manual measurements are made at the trailer surface or “in contact” with the truck trailer body, at 0.3 m, and at 1 m. Additional readings are taken at the truck cab or location where the driver sits.

As a check on the reliability of measurements taken at the RWMC, values at contact, 0.3 m, and 1.0 m were analyzed as a data set to evaluate the question of a determinable physical function with distance; i.e., was there an orderly decrease in the energy signal at a rate equivalent to the inverse of the square of the distance from the truck. Because “at contact” readings are actually taken on the outside surface of the truck trailer and not on the wasteload, it was estimated that these readings actually represented a measurement of approximately 0.1 m from the waste. Although these data are clearly not as precise as those collected with the stationary instruments at the PIC array, the standard deviation of the readings normalized at 1 m was estimated at ±40 percent. One check of consistency between measurements taken at the PIC array and measurements taken at the RWMC indicated that, in all but one case, trucks measured with the PIC array that produced exposure values exceeding 800 μR/hr also produced values at the RWMC that exceeded 800 μR/hr as well. Consequently, the 1 m measurements taken at the RWMC were used for the 59 trucks in the database.

RESULTS AND CONCLUSIONS

As previously stated, the primary audience for this study is the U.S public, particular citizens living in rural towns located along transportation routes through the states of Utah and Nevada that are used by

LLW truck drivers to reach the NTS. DOE/NNSA/NSO regularly provides information to the public on the number of waste shippers and identifies the generators that are shipping waste. In addition, DOE/NNSA/NSO has presented the results from limited studies [3, 4] regarding potential exposures from LLW shipments at public meetings. In describing the results of the present study, an attempt is being made to follow the format and exposure scenarios that have been used previously in presentations to the U.S. public. In addition, most meaningful to citizens in the United States are exposure values in roentgens (R) [microroentgens (µR) are used in the present study] as opposed to the International System of units in coulombs per kilogram (C/kg).

For each of the 1,012 trucks, a net exposure measurement is calculated by subtracting the averaged maximum exposure value and the standard deviation from the gross reading at the PIC array. Although the calculation of all background values has not been completed, the values that have been determined to date have been used to project the distribution of net exposures for the remaining portion of the truck population. The "net exposure" results include 436 truck trailers (43 percent of the population) that were below background (Figure 4 and Table 2) and 378 trucks having net exposure values at or near background.

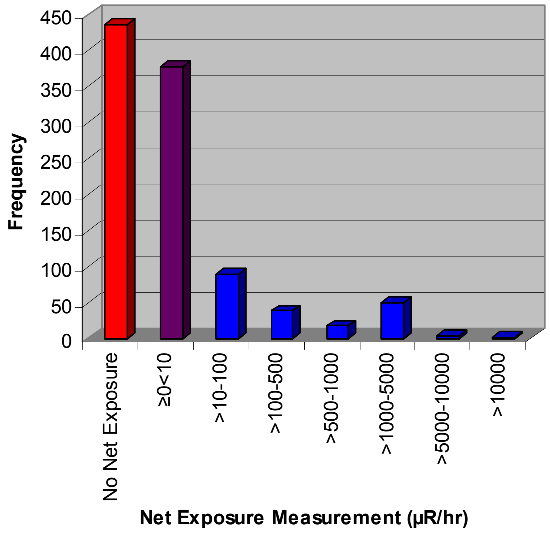

Figure 4. Distribution of net exposure readings for the 1,012 trucks measured during the present study. The far left column (red) represents trucks having no net exposures, while the second column from the left (purple) represents trucks having net exposures at or near background. The absolute number of trucks per increment of exposure is presented in Table 2.

Table 2. Number of trucks per increment of exposure per hour at 1 m.

Exposure Range	Number of Trucks
No Net Exposure	436 trucks
≥0–10 µR/hr	378 trucks
>10–100 µR/hr	89 trucks
>100–500 µR/hr	38 trucks
>500–1000 µR/hr	17 trucks
>1000–5000 µR/hr	49 trucks
>5000–10 000 µR/hr	4 trucks
>10 000 µR/hr	1 truck

According to criteria used at the NTS disposal site, where a standard 50 µR/hr background is subtracted from the highest spot reading on the truck trailer, the group of 378 trucks would have produced "no net exposure". The remaining 20 percent of the measured truck population could potentially contribute to the cumulative exposure. However, a cumulative exposure measurement (for example, the highly unlikely event of a single person being exposed to all trucks that traveled a particular shipping route) would be dominated by relatively few trucks, such as the 54 that exceeded 1000 µR/hr or 1 mR/hr. Still, even considering the truck producing the highest exposure reading, if a conservative gamma dose rate constant of 1.0 [9] is applied to convert from milli-Roentgens per hour (mR/hr) to millirems per hour (mrem/hr), and if the inverse-square law is applied, exposure from the truck would be less than 7.5 percent of the USDOT shipping standard at 2 m.

ACKNOWLEDGEMENTS

The study was funded by the Waste Management Division of the USDOE, National Nuclear Security Administration Nevada Site Office. The participation of the waste generators is appreciated.

REFERENCES

[1] Turner, J.E. 1995. Atoms, Radiation, and Radiation Protection. John Wiley and Sons, Inc.; New York.

[2] United States Department of Energy (DOE). 2002. Performance Management Plan. DOE/NV-831. U.S. DOE National Nuclear Security Administration, Nevada Operations Office, Las Vegas, Nevada.

[3] Davis, M., A.E. Hechanova and G.S. Cerefice. 2002. Doses from the transportation of radioactive waste. Presentation to the Clark County Yucca Mountain Nuclear Waste Advisory Committee, Las Vegas, Nevada.

[4] Gertz, C.P. 2001. Overview of low-level waste transportation and disposal. Presentation to the USDOE Nevada Operations Office Community Advisory Board. 32 p.

[5] Shebell, Peter. 2004. PIC calibration results for Desert Research Institute. US Department of Homeland Security, Environmental Measurements Laboratory; New York, 3 p.

[6] DiSanza, E.F. 2002. Assessing exposure to the public from transporting low-level radioactive waste (LLW) to the Nevada Test Site. Letter to approved Nevada Test Site waste generators, NNSA/NV, November 18, 2002.

[7] Campbell Scientific. 1997. CR10X Measurement and Control System Operator's Manual.

[8] Reuter-Stokes. 2001. RSS-131 User's Manual. Revision J. 155 p.

[9] Shleien, B., L.A. Slaback, Jr. and B. Birky. 1998. Handbook of Health Physics and Radiological Health. Lippinott Williams and Wilkins, 700 p.