RADIOLOGICAL CHARACTERIZATION OF SKYSHINE FROM A RETIRED LOW-LEVEL, RADIOACTIVE LIQUID EFFLUENT DISPOSAL FACILITY AT HANFORD

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ABSTRACT

The 1301-N Liquid Waste Disposal Facility, located on the Hanford Site in southeastern Washington State, received N Reactor low-level radioactive liquid process effluent from 1962 to 1985. This facility was retired in 1985 although N Reactor operated until 1987. During normal operation, sediments in the trench sections of the disposal facility became contaminated from the liquid effluent. Radiation emanating from the top of the trench sections was not significant because the sediments were normally under several meters of water, which provided the necessary shielding.

During operation, liquid effluent was present in the trench sections: the rate of percolation into the ground was offset by the rate of discharge of liquid effluent into the trench. Following retirement of the facility in 1985, the liquid normally present in the trench sections of the disposal facility percolated into the ground leaving the residual radioactively contam-inated sediments unshielded along the bottom and sides of the trench sections. The radioactive constituents of the contaminated sediments include the gamma-emitting isotopes Co-60 and Cs-137. Because of the lack of water covering, some of the gamma photons that were emitted upward above the trench sections were scattered downward due to Compton interaction of these photons with atmospheric constituents. These downward-scattered gamma rays are present at the nearby Columbia River shoreline and increase the exposure rate above the ambient background rate. This phenomenon is known as "skyshine."

A radiological characterization was required to provide guidance for determining the effectiveness of interim stabilization alternatives that would not adversely affect future Resource Conservation and Recovery Act (RCRA) (1) site closure activities, (e.g., filling in trench sections with spoils from excavation activities). A noninvasive radiological characterization of this disposal facility and the affected area of the Columbia River shoreline was conducted in 1989 and 1990. This characterization confirmed that skyshine is the cause of the elevated shoreline exposure rates and provided a model that could be used to rate the effectiveness of alternative interim stabilization measures.

INTRODUCTION

The N Reactor operated on the Hanford Site adjacent to the Columbia River as a dual-purpose production and steam-generating facility from 1962 to 1987. The 1,500 km^2 (560-mi^2) Hanford Site is located in southeastern Washington State. The 1301-N Liquid Waste Disposal Facility received N Reactor low-level radioactive liquid effluent from startup in 1962 until this facility wasretired from service in September 1985. The disposal facility consists of a 416-m (1,367 ft) trench, arranged with five sections in a zigzag fashion, covered with concrete decking to prevent animal intrusion (Fig. 1). The general direction of the trench is parallel to and approximately 500 m from the Columbia River shoreline, which has a general north-south orientation in this location.

During operation and following retirement in 1985, liquid normally present in the facility percolated into the ground leaving the residual contaminated sediments unshielded. Now, instead of being covered by several meters of water, these sediments, situated along the sides and bottom of the trench section, were exposed. This exposure provided a relatively unshielded source of gamma photons to the air space above the trench sections. Some of the gamma photons traversing the air space above the trench are scattered downward due to Compton interaction of these photons with atmospheric constituents. These downward-scattered gamma rays are present at the nearby Columbia River shoreline and increase the exposure rate above the ambient background rate. This phenomenon will be referred to as "skyshine."

To provide guidance for programmatic interim stabilization studies, a radiological characterization was required. A noninvasive radiological characterization of this liquid effluent disposal facility and the affected area of the Columbia River shoreline was conducted in 1989 and 1990. The objectives of this characterization were twofold: (1) to provide data to support the hypothesis that "skyshine" is the cause of the elevated exposure rates, and (2) to provide a model that could be used to rate the effectiveness of alternative interim stabilization measures.

RADIOLOGICAL CHARACTERIZATION

Radiological characterization consisted of the following measurements.

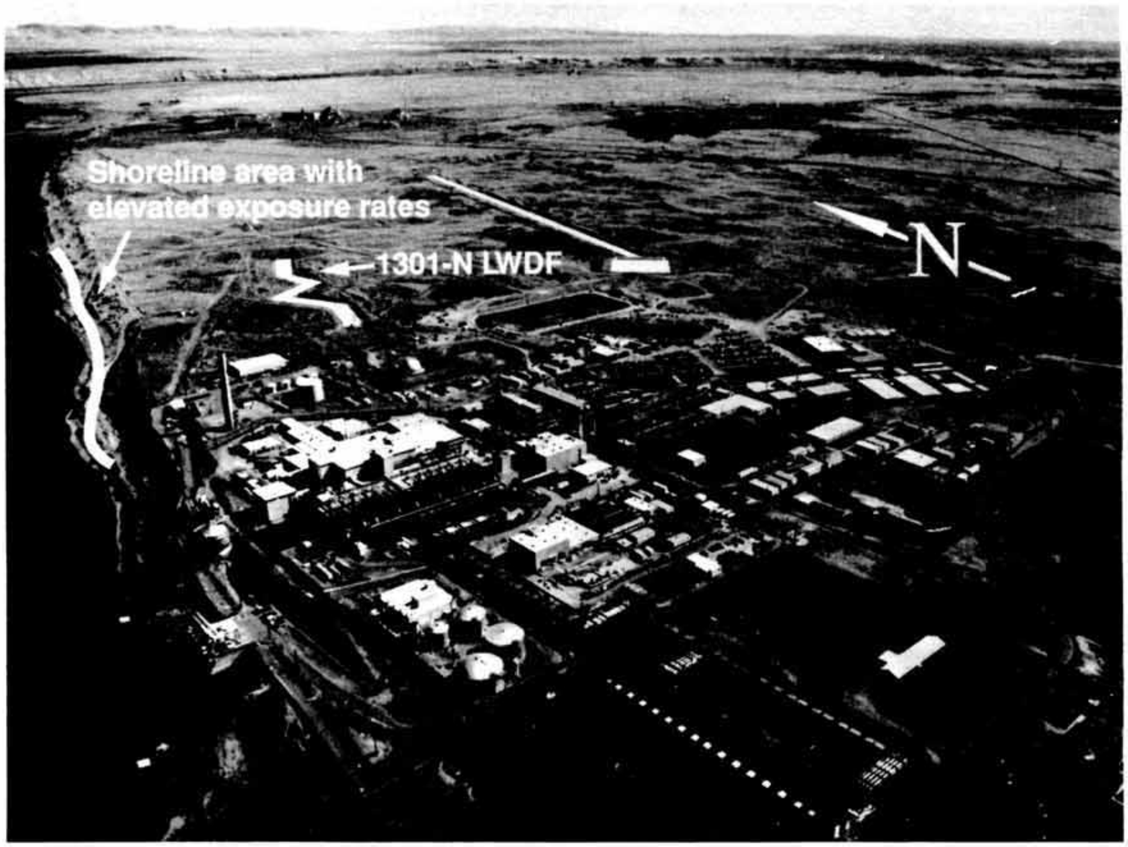

Fig. 1. Aerial view of the 100-N area with the 1301-N liquid waste disposal facility indicated.

1. Performance of a gamma energy analysis of the spectrum present at the area of concern.
2. Measurement of exposure rates along the extent of the decking-covered top of the 1301-N Liquid Waste Disposal Facility.
3. Measurement of the variation of exposure rates above the concrete decking of the disposal facility as a function of height and displacement from the centerline.
4. Measurement of the shoreline exposure rates with a pressurized ionization chamber.
5. Estimation of the inventory of radioactive materials discharged into the effluent disposal facility from effluent disposal records.

To meet the second objective of the characterization, providing a model of the skyshine phenomenon, the distribution of the radioactive sediments in the bottom of the trench had to be estimated.

Effluent disposal records provided the total activity of all radionuclides discharged into the disposal facility: 85 TBq (2,300 Ci) of Co-60, 70 TBq (1,900 Ci) of Sr-90, and 96 TBq (2,600 Ci) of Cs-137 for a total inventory of 251 TBq (6,800 Ci) corrected for decay to 1990. However, these radionuclides were distributed throughout the soil column beneath the trench sections because of the adsorption characteristics of the underlying soil. Only that portion of the contaminated sediments within a short distance from the bottom of the trench (top of the soil column) would contribute to skyshine. Therefore, the distribution of the Co-60 and Cs-137 along the top layer of the soil column was required for subsequent calculations.

The concentration of radioactive material in this top layer (bottom of the trench) and the dimensions of the layer (thickness and width) determine the gamma-ray exposure rate observed above the concrete decking covering the trench sections and comprising the source term model used. This model was prepared using data from noninvasive exposure rate measurements taken above the decking. From this model a conversion factor would then be available to convert the survey meter exposure rate readings, taken above the decking, to total activity available to cause skyshine in each section of the trench. The manner in which this conversion factor was calculated is now described.

The process of estimating the source distribution relied on the following data: (1) exposure rate measurements taken immediately above the trench (item 2), and (2) the variation in exposure rates with respect to distance above the concrete decking and distance from the trench centerline (items 3 and 5), which were then used as input to a gamma-ray shielding program.

The variation of the exposure rate above a slab source can be calculated in a number of ways: by manual means (or hand calculations), and by a number of computer shielding programs. For this radiological characterization, a microcomputer version of ISOSHLD, a gamma-ray shielding program that has been in use for more than 20 yr, was used (2,3,4).

The dimensions of the resulting modelled source slab should be the approximate dimensions of the bottom of the trench. The exposure rate above a slab source is a function of the distance above the decking, the offset distance from the centerline of the slab, the thickness and types of intervening shielding material, and the concentration of radioactive material in the slab. These are the input parameters for ISOSHLD, and they were adjusted in a systematic way until a reasonably good fit in shape and magnitude was obtained for calculated and measured exposure rates (items 2 and 3). The concentration of the radioactive material in the sediments was assumed to contain the same ratio of radionuclides as in the total inventory discharged into the facility. For purposes of the skyshine characterization, only the Co-60 and Cs-137 components were of importance.

Once the source term model was fixed, the exposure rate measurements (item 2) could then be used to estimate the concentration of radioactive materials in the sediment layer along the bottom of the trench. The estimated skyshine inventory in the trench could then be compared with the recorded total inventory as a check on the validity of the calculational process. The assumption that only the radionuclides in the top layer of the soil column would contribute to skyshine results in the skyshine inventory being some fraction of the recorded total inventory.

The final series of calculations consisted of using the source distribution in the bottom of the trench as input to the computer program MicroSkyshine* along with the pertinent distances to provide an estimate of the skyshine component along the shoreline. These calculations take the shielding effect of the sediment layer and the concrete decking into effect in the calculational process. These estimates were compared with the measurements of the exposure rates taken along the shoreline (item 4).

RESULTS AND DISCUSSION

An energy analysis of the gamma spectrum present along the shoreline was performed in 1989. The resulting spectra were a continuum of energies below the Compton back-scattered photons resulting from skyshine. No direct photopeaks from Co-60 or Cs-137 were observed. This analysis proved that no line-of-sight (unshielded) source of radiation containing Co-60 or Cs-137 was responsible for the increased exposure rate.

A radiation survey of the direct radiation emanating from the trench directly over the concrete decking was performed early in 1990. Exposure rates ranged from 0.5 to 9 mSv (50 to 900) mrem/h (Fig. 2). The purpose of this survey was to obtain data necessary to estimate the skyshine inventory of radioactive material in the sediments; i.e., those radioactive materials present close enough to the surface of the trench such that gamma rays emitted during decay could escape to the atmosphere above the trench and contribute to skyshine along the shoreline. This skyshine inventory should only be a fraction of the total inventory from effluent release records because much of the radioac-tivity was

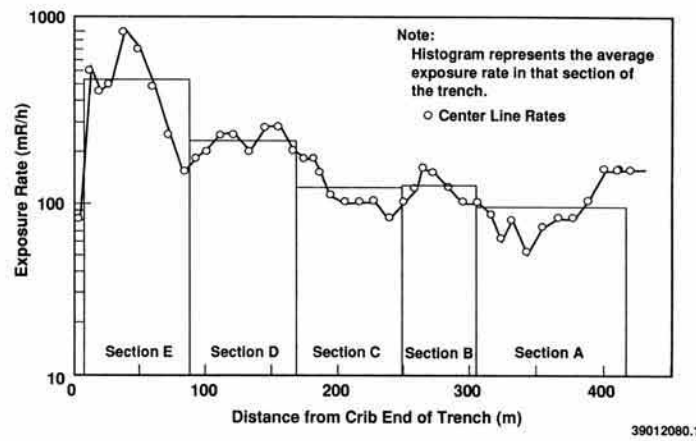

Fig. 2. Results of radiation survey along the top of the 1301-N liquid waste disposal facility trench sections.

distributed at various depths beneath the trench bottom. The gamma rays emitted from the deep locations beneath the trench would be absorbed prior to escaping to the atmosphere above the trench.

To estimate the active inventory, the radiation shielding program, ISOSHLD, was used to calculate the exposure rate above the concrete decking over the trench. The best source configuration was found to be a slab of the width of the trench bottom, 2.4 m (8 ft), 0.3-m (1 ft) thick, and an appropriate length between massive concrete support beams for the concrete decking. An implicit assumption in this analysis is that the radioactive sediments are uniformly distributed throughout the volume of the slab. The thickness of 0.3 m (1 ft) was chosen because calculations

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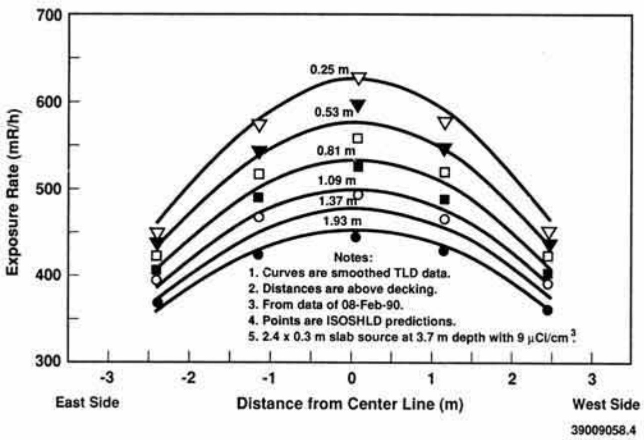

Fig. 3. Smoothed exposure rates above the 1301-N liquid waste disposal facility as compared with ISOSHLD predictions.

indicated that more than 90 percent of the exposure rate from a 0.9-m (3 ft) thick slab came from the uppermost 0.3-m (1 ft) layer.

Figure 3 indicates the manner in which the measured exposure rates above the concrete decking varied as a function of height above the decking and displacement from the centerline of the trench. The ISOSHLD calculations of the exposure rate variation show good agreement for the source geometry parameters selected: a slab of 2.4 m (8 ft) in width, 0.3-m (1 ft) thick, located 3.7 m (12 ft) below the decking with a source concentration of 0.3 TBq/m^3 (9 μCi/cm^3).

Once the source configuration was established, the exposure rate from a unit concentration of radioactive material in the sediments was calculated. This was done with the computer program, ISOSHLD, taking into account the appropriate distances, thicknesses, and densities of intervening shielding materials including the sediments and the concrete decking. Knowing the exposure rate from a unit concentration of radioactive material in the sediments, the concentration necessary to cause the measured exposure rate could be calculated. From these calculated concentrations of radioactive materials and the slab source volume, the total activity in each of the five sections of the trench could be estimated.

The principal radioactive components contributing to the skyshine were 85 TBq (2,300 Ci) of Co-60 and 96 TBq (2,600 Ci) of Cs-137 out of a total of 250 TBq (6,800 Ci) of all radionuclides known from effluent disposal records. Other radionuclides were present, but they were either at much lower activities or did not emit gamma rays during radioactive decay; as a result, they did not need to be included in these calculations.

The skyshine inventory (all radionuclides) estimated from the shielding calculation was 41 TBq (1,100 Ci), some 16 percent of the total activity known from effluent disposal records. This activity was distributed as follows: 20, 9, 4, 3, and 5 TBq from the discharge end of the trench to the following four sections, respectively. This indicates a significant fraction of the total activity discharged to the trench is carried to sediments located further into the soil column.

With a source distribution for each section of the trench, the calculation of the skyshine component of radiation at the shoreline of the Columbia River was possible. The source distribution, activity, and gamma ray energies were input to the computer program MicroSkyshine. Output from the program was the estimate of the skyshine at selected locations along the Columbia River shoreline. Fig. 4 shows the cumulative calculations from all five sections of the 1301-N Liquid Waste Disposal Facility in comparison with measurements taken along the shoreline with a pressurized ionization chamber.

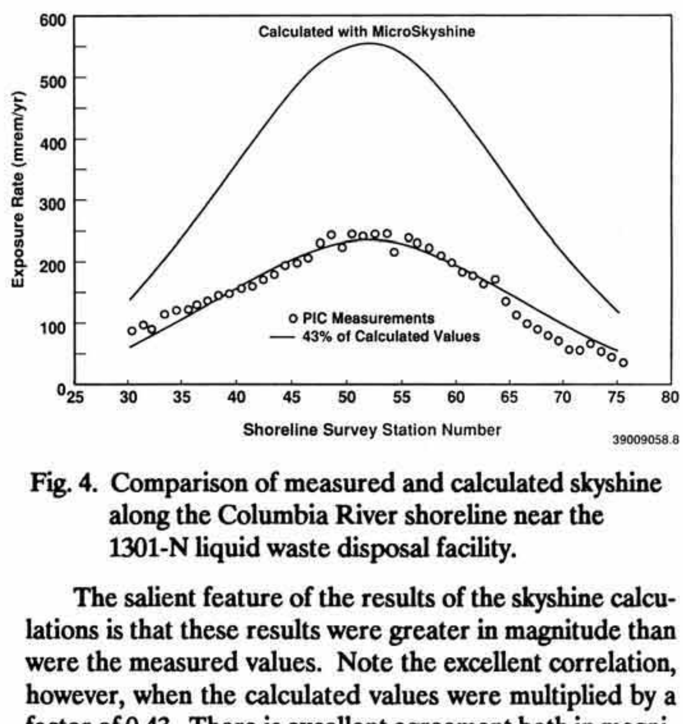

Fig. 4. Comparison of measured and calculated skyshine along the Columbia River shoreline near the 1301-N liquid waste disposal facility.

The salient feature of the results of the skyshine calculations is that these results were greater in magnitude than were the measured values. Note the excellent correlation, however, when the calculated values were multiplied by a factor of 0.43. There is excellent agreement both in magnitude and shape.

The reason for this discrepancy has not been determined, and for purposes of this characterization, there was no need to provide such a determination. For modelling, the results obtained by multiplying the calculations by 0.43 were considered adequate.

To assist in evaluating programmatic interim stabilization methods, such as filling in one or more of the trench sections, the calculations were performed with one or more sections of the trench eliminated as sources of skyshine. Figure 5 indicates that at least the two sections of the trench with the majority of the activity would have to be filled in to reduce the shoreline exposure rate to less than 1 mSv (100 mrem)/yr.

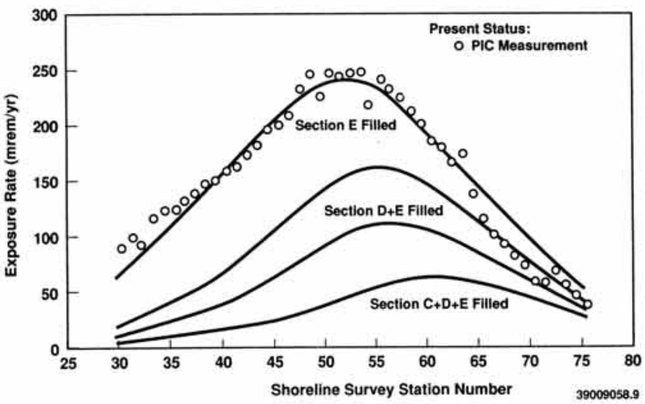

Fig. 5. Estimated effects on shoreline skyshine contributions from filling in sections of the 1301-N liquid waste disposal facility.

CONCLUSIONS

A noninvasive radiological characterization of the 1301-N Liquid Waste Disposal Facility was conducted in 1989 and 1990. This characterization had two purposes. The first was to determine if the source of the elevated environmental exposure rates along the shoreline of the Columbia River in the near vicinity of the disposal facility is in fact due to skyshine. The second was to provide modelling capability for evaluation of interim stabilization alternatives if the elevated shoreline exposure rates were due to skyshine. These objectives were met.

A series of measurements provided data to show that skyshine from the 1301-N Liquid Waste Disposal Facility was the cause of the elevated exposure rates. Further calculations with a radiation shielding program and a skyshine evaluation program provided a reasonable fit to the measured exposure rates along the shoreline.

Modelling the effects on the shoreline exposure rates from skyshine indicated that two, and possibly three, sections of the trench would have to be filled in to reduce the radiation exposure rate below 1 mSv (100 mrem)/yr or 0.01 mrem/h. By means of comparison, this increase is similar to what a person would receive from natural environmental radiation by moving from sea level to Denver, Colorado.

REFERENCES

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