RADIOLOGICAL DOSE ASSESSMENT FOR THE COMMERCIAL TREATMENT, STORAGE, AND DISPOSAL FACILITIES THAT HANDLE DEPARTMENT OF ENERGY HAZARDOUS WASTES *,**

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ABSTRACT

Radiological dose assessments were performed for 8 commercial hazardous waste treatment, storage, and disposal facilities. The purpose of these assessments was to evaluate the radiation exposure that may have been received by the onsite workers and the offsite public from the hazardous-waste shipments to these commercial treatment, storage, and disposal facilities from various Department of Energy sites from 1980 to 1991. The preliminary results indicate that the radiation exposures are extremely low. The maximal annual dose to an onsite worker ranges from 3×10^{-3} to 8×10^{-2} mrem while the maximum annual dose to a member of the general public ranges from 1×10^{-7} mrem/y to 4×10^{-3} mrem. In conclusion, treatment of Department of Energy wastes at the treatment, storage, and disposal facilities evaluated to date would have no discernible health impact on the workers or the general public.

INTRODUCTION

Department of Energy (DOE) facilities have historically disposed of their radioactive waste at DOE and, to a lesser extent, at Nuclear Regulatory Commission (NRC) or state-licensed radioactive-waste disposal sites. Nonradioactive hazardous wastes from DOE facilities have been treated and disposed of at DOE facilities and at permitted commercial treatment, storage, and disposal (TSD) facilities.

In May 1991, DOE headquarters learned that past practices at DOE field facilities resulted in the presence of minute amounts of known or likely radioactive contamination in some hazardous waste shipped from 4 DOE sites (K-25 and Y-12 in Oak Ridge, TN; Paducah Gaseous Diffusion Plant, Paducah, KY; and Portsmouth Gaseous Diffusion Plant, Portsmouth, OH) to commercial facilities not licensed to receive radioactive waste. Subsequently, the DOE Office of Environmental Restoration and Waste Management imposed a nationwide moratorium on the shipment of potentially radioactive waste from DOE sites to commercial treatment and disposal facilities. The moratorium is to remain in effect until procedures are approved by DOE headquarters that will ensure the hazardous waste contains no radioactive contamination in volume from DOE operations and meets the surface contamination guidelines of DOE Order 5400.5 (1).

To assess the radiation exposures to commercial hazardous-waste operators and the offsite public, a preliminary evaluation was made, indicating that radiation doses were extremely small. As a follow-up, DOE contracted with M. H. Chew & Associates, Inc., and Argonne National Laboratory to perform detailed site-specific dose assessments of possible radiation exposures to workers and the public due to the shipment and processing of DOE hazardous waste at commercial TSD facilities from 1980 to 1991. This preliminary report describes the process for conducting the site-specific dose assessment and the results of the assessment for the following 8 TSD facilities:

- Aptus Environmental Services, Inc., Coffeyville, KS (Aptus).
- Rollins Environmental Services, Inc., Deer Park, TX (RES–DP).
- Chemical Waste Management, Inc., Emelle, AL (CWM–Emelle).
- Chemical Waste Management, Inc., Chicago, IL (CWM–Chicago).
- Chemical Waste Management, Inc., Lake Charles, LA (CWM–Lake Charles).
- Environmental Systems Company, Inc., El Dorado, AR (ENSCO).
- S.D. Myers, Inc., Tallmadge, OH (SDM).
- LWD, Inc., Calvert City, KY (LWD).

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The evaluation of the workers' dose covers operations from the time the waste was picked up at the DOE sites until its final disposal. The evaluation of the offsite public dose considers the maximally exposed offsite individual and the general population within 50 mi (80 km) of the facility. The study also compares the calculated doses with doses due to natural background radiation and applicable federal regulatory limits, and assesses potential health effects.

METHODOLOGY

In general, the study was performed in 4 steps, which are depicted in Fig. 1 and briefly described below.

Step 1: Site Walkthrough

In most cases, assessment teams, composed of health physicists, engineers, radiological risk-assessors, and sometimes a chemist, visited the TSD facilities and performed a walkthrough. The purpose of these visits was to gather as much data as possible related to the treatment, storage, and disposal processes of the potentially contaminated waste. When a site walkthrough was not performed, data was gathered through communications with facility personnel. After the site walkthrough and data collection, the assessment teams started the evaluation of onsite worker and offsite public radiation doses.

Step 2: Onsite Worker Dose

The evaluation of the onsite worker dose was performed using the following 4 steps (see Fig. 1):

Step 2.1: Operational Analysis. Based on the site walkthrough and/or discussions with TSD facility personnel, operations that could have resulted in radiation exposure to onsite workers were identified. Information was summarized on the timeliness of these operations. The information includes: detailed steps of the operation, types of potentially contaminated sources involved in the operation, duration of the operation, distance between the worker and the source, shielding of the source, number of workers involved in the operation, and respiratory protection.

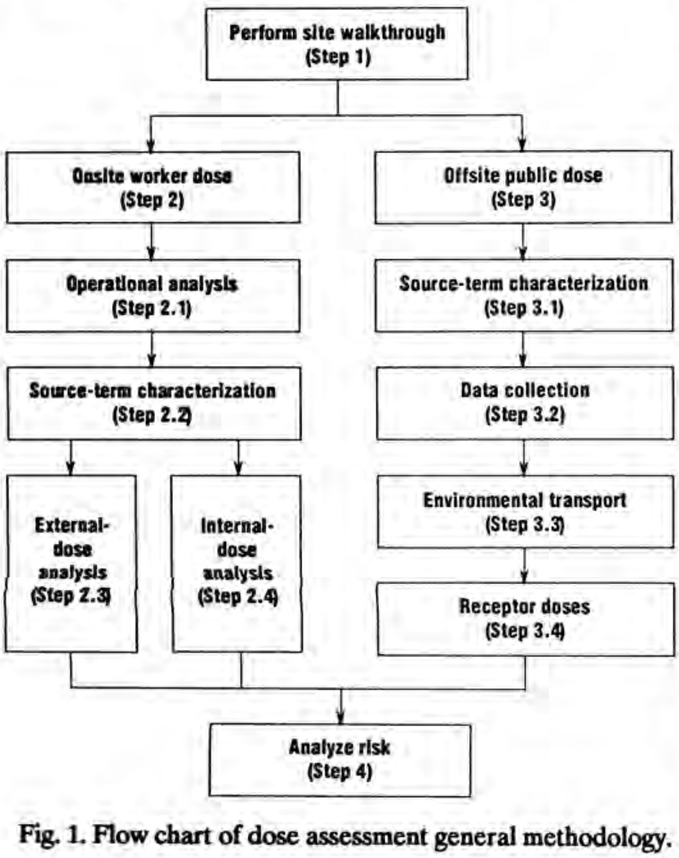

Fig. 1. Flow chart of dose assessment general methodology.

Step 2.2: Source-Term Characterization. The radioactive source terms were characterized in the Idaho National Engineering Laboratory (INEL) database (2). The waste type and weight were described in the shipping manifests. Any uncertainties in the source-term data were resolved by using conservative estimates. Such information was critical in assessing the various exposure pathways since different types of waste are handled differently at the facilities.

Step 2.3: External-Dose Analysis. The various modes of external exposure that a worker may have encountered at the facility were determined. External dose primarily depends on the source strength, source geometry, distance to the worker from the source, shielding of the source, duration of the operation, and the total number of operations conducted.

Step 2.4: Internal-Dose Analysis. Contamination can become airborne as a result of incineration, resuspension from contaminated surfaces, opening a container for sampling, or as a result of incinerator maintenance. Once airborne, the radioactive contamination is then available for inhalation and possible ingestion. Internal exposure due to ingestion is not likely for workers at the TSD facilities because of work practices (i.e., designated eating areas, change room, showers, etc.) and the use of personal protective equipment. Therefore, only inhalation was considered a credible pathway requiring evaluation.

Step 3: Offsite Public Dose

The public residing in the vicinity of the TSD facilities may have received an internal and external radiation dose due to the incinerator exhaust and/or landfill operations. The evaluation of the offsite public dose includes the analysis of the release data from incineration and landfill of the potentially contaminated DOE waste (Step 3.1); the collection of the meteorological data, the population data [within 50 mi (80 km)], and the agricultural and food-consumption data (Step 3.2); environmental transport calculations for transport of radionuclides from the point of emission at the TSD facility to places where the offsite receptors were located (Step 3.3); and calculation of receptor doses (Step 3.4).

Step 4: Risk Analysis

The potential radiation doses to onsite workers and to the general public are compared with those from natural sources and with various regulatory limits. The health-risk implications are also discussed.

Impacts are presented for the cumulative total as well as for the maximum impact year. The doses are presented in terms of the effective dose equivalent (EDE) (1) in millirem (mrem) for individuals and in person-rem for the population. The EDE includes the committed effective dose equivalent (CEDE) from internal deposition of radionuclides as described in ICRP 26 (3) and the EDE due to penetrating radiation from sources external to the body.

EVALUATION OF ONSITE WORKER DOSES

Based on the walkthroughs, 7 major operations that may contribute significantly to the worker doses at the 8 TSD facilities were identified. These operations include:

- Transport of potentially contaminated waste from DOE sites.
- Unloading, sampling, and check-in.
- Storage operations.
- Incineration, including collection of incineration residues (such as slag, ash, and filter cake).
- Landfill operations.
- Incinerator maintenance.
- Transport of incineration waste or other waste residues offsite.

The known or likely contaminated hazardous wastes shipped to the 8 TSD facilities from the various DOE sites from 1980 to 1991 contained ^{234}U, ^{235}U, ^{238}U, and ^{99}Tc. The estimated isotopic activities were provided by the INEL database (2). The specific activity of these contaminated wastes generally ranged from 0.1 pCi/g to 10 pCi/g. These wastes included dirt and debris, PCB oil, transformers, capacitors, etc. Solid wastes were usually shipped in drums while oil and liquid were shipped either in drums or in tank trucks.

The external radiation dose, D^{ex}, was calculated as follows:

$$D^{ex} = \sum D^{ex}_{ij} ,$$

$$D^{ex}_{ij} = R^{ex}_{ij} (g, d, sh) * S_i * P_j * T_j * N_j ,$$

where:

R^{ex}_{ij} = direct shine dose rate, which is calculated for a specific activity of 1 pCi/g and is dependent on the source geometry, g (e.g., a drum, a tank, a bin, etc.), the source distance, d, and the source shielding, sh.

S_i = correction factor for the source term.

P_j = process correction factor for waste processing, such as mixing with other materials (note that P = 1 for untreated waste).

T_j = duration of the operation.

N_j = number of operations performed per year.

The subscript i denotes the various isotopes (such as ^{234}U, ^{235}U, ^{238}U, and ^{99}Tc) and the subscript j denotes the various operations involved. For each individual the external dose is summed across all applicable operations.

The reference dose rate R^{ex} was calculated using the code MICROSHIELD (4), a commercial derivative of ISOSHLD (5). The code MICROSHIELD is a point kernel code used to calculate external dose rates from gamma radiation. The code includes an updated nuclides library, attenuation coefficients for various materials, various buildup factor models and coefficients, and can handle any gamma energy between 0.1 MeV to 10 MeV. This range includes the major gamma energies from the uranium isotopes except for the 0.066 MeV from ^{238}U, which was entered in the code as 0.101 MeV with an adjusted photon yield. The values of other correction factors were calculated and incorporated into a spread sheet. Note that the reference dose rate R^{ex} was calculated separately for ^{234}U, ^{235}U, and ^{238}U. Since ^{99}Tc is a pure beta emitter, it was not considered in the calculation of external doses.

TSD facility workers may have received an internal radiation exposure as a result of inhalation of contaminated air due to the handling and processing of potentially contaminated wastes. The radioactive isotopes ^{234}U, ^{235}U, ^{238}U, and ^{99}Tc contained in the potentially contaminated DOE waste could become airborne via the following scenarios:

- Normal stack releases from incineration of potentially contaminated DOE wastes.
- Sampling drums containing potentially contaminated dirt.
- Stabilization and placement of waste material and covering the waste material in the landfill.
- Maintenance of incinerator systems.

The internal exposure D^{in} due to inhalation was calculated by:

$$D^{in} = RR * X/Q * BR * T * PF * DCF ,$$

where:

RR = activity release rate (Ci/s).

X/Q = atmospheric dispersion factor (s/m^3) or an equivalent dilution factor.

BR = breathing rate (m^3/s).

T = exposure time (s).

PF = respiratory protection factor.

DCF = dose-conversion factor (rem/Ci).

In the calculations, the dose-conversion factors were those given in ICRP 30, Supplement to Part 1 (6), and the breathing rate was taken to be the standard value of 11.7×10^{-3} ft^3/s (3.33×10^{-4} m^3/s). Note that the above methodology is similar to the one used to calculate the internal dose to the offsite public.

Note that in the above equation, RR * X/Q represents the activity concentration in the air. In several cases the airborne activity concentration can also be estimated by multiplying the airborne dust concentration by the specific activity of the DOE waste. Depending on the operation in this study, the airborne dust concentration, which ranged from 1 to 10 mg/m^3, is either based on uranium oxide suspension studies by Schwendiman (7) or derived from a mass-balance equation.

EVALUATION OF OFFSITE PUBLIC DOSES

Offsite radiological impacts from the atmospheric releases from the 8 TSD facilities were calculated for the nearest resident, for the maximally exposed resident, and for the general population within 50 mi (80 km) of the facility. Releases were based on the estimated radioactive contents of the hazardous wastes shipped from the DOE sites to these facilities during 1980 to 1991 given in the INEL database (2).

Calculations were performed using Version 1.0 of the CAP88–PC computer code (8,9). CAP88–PC is a personal-computer version of the Clean Air Act Assessments Package-1988 (CAP–88), which is one of the codes specified by the U.S. Environmental Protection Agency (EPA) in 40 CFP Part 61, Subpart H, for demonstrating compliance with the National Emission Standards for Hazardous Air Pollutants (NESHAP).

CAP88–PC was developed by the EPA's Office of Radiation Programs. The computer code consists of a set of subprograms, databases, and associated utility programs that implement the mathematical model for assessing dose and risk due to radionuclide emissions to the air. The software computes the environmental transport of radionuclides released to the atmosphere and estimates health impacts from the inhalation, ingestion, air immersion, and ground-surface irradiation pathways, and tabulates impacts for maximally exposed individuals and regional populations.

The code CAP88–PC models environmental transport in a similar fashion as documented in its predecessor, AIRDOS-EPA (10), and uses a modified Gaussian plume equation to estimate the average dispersion of radionuclides released from up to 6 sources. The sources may be either elevated stacks, such as smokestacks, or uniform-area sources, such as a pile of uranium mill tailings. Plume rises can be calculated assuming either a momentum-driven or buoyancy-driven plume. Assessments are done for a circular grid within a 50-mi (80-km) radius of the facility.

CAP88–PC computes radionuclide concentrations in air, rates of deposition on ground surfaces, concentrations in food, and intake rates to people from inhalation of air and ingestion of food produced in the assessment area. The radionuclide concentrations in produce, leafy vegetables, milk, and meat consumed by humans are estimated by coupling the output of the atmospheric transport models with the U.S. Nuclear Regulatory Guide 1.109 terrestrial food-chain models (11).

Dose factors are provided in CAP88–PC for the pathways of ingestion and inhalation intake, ground-level air immersion, and ground-surface irradiation. Factors are further broken down by particle size, solubility class, and digestion transfer factors. These factors were generated using the computer program RADRISK (12,13).

A review of the TSD facilities reveals that there are several likely places in the facilities where the radionuclides contained in the DOE waste could have been released to the atmosphere: (i) an incinerator stack, (ii) an incinerator emergency vent during plant-upset conditions, and (iii) landfill operations. The release from a stack is estimated by combining the waste fed into the incinerator with a removal efficiency in the incineration system. In contrast to the normal continuous release from the stack, releases from the vent would occur intermittently and only under plant-upset conditions. Under such conditions the venting process bypasses all of the filtering equipment in the system. Offsite atmospheric releases from the landfill operations are rather limited. The most likely source of release is associated with disposal of nonstabilized wastes at the landfill. Releases from the landfill operations are assumed to be mainly from the generation of fugitive dust during the waste-dumping activities of trucks. The waste-release fraction of respirable particulates (less than 10 m in size) from dumping operations was estimated to be 3×10^{-7} based on an EPA methodology (14). Releases of radionuclides were calculated by multiplying the waste-release fraction by the activities of the contaminated wastes.

The input parameters needed to use CAP88–PC are explained in its user's guide (8). Many of the parameters are generic (e.g., breathing rate of humans), whereas others are site-specific (e.g., location of receptors). Most of the input parameters have default values assigned to them by the code developers. These default values are generally based on conservative assumptions and are recommended for use by the EPA in the absence of site-specific data. EPA (8) lists the default values used by CAP88–PC. In cases when site-specific data were not available, the generic data were used.

RESULTS AND CONCLUSIONS

Onsite worker dose and offsite public dose were calculated for the 8 commercial TSD facilities, The preliminary results are discussed below.

Onsite Worker Dose

The worker dose includes the external exposure and the inhalation dose. Maximal annual doses were extremely low, ranging from 3×10^{-3} to 8×10^{-2} mrem/y. In the absence of more specific data, cumulative worker doses were calculated on a conservative basis, i.e., assuming that each worker was engaged in the same operations for every year the DOE wastes were received onsite. These cumulative doses range from 4×10^{-3} to 1×10^{-1} mrem.

Two types of workers, inspection/sampling workers and incinerator workers, received the highest annual and cumulative doses. Doses to these workers were dominated by internal doses. Inspection/sampling worker doses were dominated by internal doses due to sampling of solid materials (i.e., dirt) and stack emission, which can result in the generation of airborne respirable particulates. Incinerator-worker doses were dominated by internal doses due to incinerator maintenance and stack emission. Because of the greater uncertainty, the estimation of internal doses was based upon more conservative assumptions than for external doses, resulting *in relatively* higher internal doses. For example, sampling data were not available to directly evaluate airborne concentrations during incinerator maintenance and sampling of solid materials. In their absence, a relatively conservative airborne dust concentration of 10 mg/m^3 was employed to model these doses. Based on both the likely particle distribution and our experience, it is probable that these values exceeded the actual respirable concentrations by 10- to 100-fold.

Offsite Public Dose

The potential radiological doses to the general public residing in the vicinity [within 50 mi (80 km)] of the TSD facilities were assessed. Based on an examination of the operations and disposition of the wastes, no credible offsite release of radioactive material to the atmosphere was identified at 2 facilities (CWM–Lake Charles and SDM). For the 6 facilities for which population doses were evaluated, maximum annual individual doses range from 1×10^{-7} mrem to 4×10^{-3} mrem. Maximum cumulative individual doses range from 2×10^{-7} to 6×10^{-3} mrem. The maximum annual collective population doses ranged from 4×10^{-7} *person-rem to* 2×10^{-2} person-rem for the maximum year, with cumulative doses ranging from 6×10^{-7} person-rem to 1×10^{-2} person-rem. The cumulative total population dose for all sites combined is 0.05 person-rem.

Comparison of Doses with Federal Standards and Regulations

Federal radiation-protection limits differ for members of the public and those exposed as a result of their occupation. Table I lists some of these standards and their applications and sources. The calculated maximum individual public radiation doses are less than 0.1% of 10 mrem/y, which is the

TABLE I
List of Radiation Protection Standards and Guidelines.

Dose limits and guidelines (mrem/y)	Source	Application	Comment
5,000[a]	DOE 5480.11	Occupational	Upper limit on dose to DOE employees and contractors
5,000[c]	10 CFR Part 20	Occupational	NRC[b] upper limit on dose to workers in the commercial sector
100a	DOE 5480.11	Occupational	Limit for unmonitored workers exposed as a result of DOE activities
2,000[c]	DOE Rad. Con. Manual	Occupational	Administrative guideline for protection of DOE workers
100c	DOE 5400.5	Public	DOE primary dose limit for radiation exposure of the public from all sources and pathways combined
100[c]	10 CFR Part 20	Public	NRC dose limit for protection of the public from NRC-licensed operations
10[c]	DOE 5400.5	Public	DOE limit for the public from exposures through the air pathway
10[c]	40 CFR Part 61	Public	EPA limit for air emissions from DOE facilities and NRC-licensed facilities
4[c]	DOE 5400.5	Public	DOE limit for radionuclides in drinking water applied at the tap. Also in EPA-proposed revision to 40 CFR Part 141

[a]Annual effective dose equivalent.
[b]Nuclear Regulatory Commission.
[c]Sum of 50-y committed effective dose equivalent and effective dose equivalent.

air-pathway limit established by the Environmental Protection Agency (15) for protection of the public. The calculated public radiation doses are less than 0.01% of 100 mrem/y, which is the DOE limit (1) for protection of the public from all sources and all pathways combined. Maximum annual doses to workers are less than 0.1% of the 100-mrem/y DOE guideline for unmonitored workers, such as those who might have been exposed at the TSD facilities.

Comparison of Doses with Background Radiation

To provide some perspective, the calculated workers doses and public doses are compared with those derived from natural background radiation. In the U.S. the average annual dose due to natural background radiation is about 300 mrem to an individual (16). In comparison, the estimated doses in any one year to a maximally exposed worker do not exceed 0.03% of the average annual dose due to background radiation. The estimated doses in any one year to a maximally exposed member of the offsite public do not exceed 0.002% of the average annual dose due to background radiation. For the entire populations within 50 mi (80 km) of the various sites, the estimated maximum population doses in any particular year do not exceed 0.00001% of the average dose from natural background radiation received by a similar population.

Health-Risk Implications

Risk assessment for radiation doses is based on the assumption that the cancer fatality rate per unit dose determined at high doses can be directly applied to extremely low doses, such as those calculated in this study. This assumption follows a policy designed for the development of regulations and guidelines for the protection of public health. Even though this assumption is not supported directly by data at these extremely low doses, a lifetime fatal cancer risk of 0.0005 (5×10^{-4}) per rem of exposure (17,18) was used to provide some conservative estimates of risks from treatment of the DOE wastes. Using this relation the cancer risks are estimated as follows:

- For the maximally exposed worker, the estimated fatal cancer risks are less than 4×10^{-8} for the year of highest exposure and 5×10^{-8} for the cumulative period of exposure during which the DOE wastes were received onsite.
- The estimated fatal cancer risks for the maximally exposed member of the general population are less than 2×10^{-9} for the year of highest exposure and 3×10^{-9} for the cumulative period of exposure during which the DOE wastes were received onsite.

The above estimated risks are extremely low compared to many risks encountered from other sources (19).

In conclusion, treatment of DOE wastes at the TSD facilities evaluated to date would have no discernible health impact on the workers or the general public.

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