GENERIC DOSE ASSESSMENT FOR DISPOSAL OF INCINERATOR ASH IN A LANDFILL

September 1994

U.S. NUCLEAR REGULATORY COMMISSION
OFFICE OF NUCLEAR MATERIAL SAFETY AND SAFEGUARDS
DIVISION OF LOW LEVEL WASTE MANAGEMENT AND DECOMMISSIONING
WASHINGTON, D.C.

NMSS/RGN-002 Attachment 1

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1. INTRODUCTION

Under provisions in 10 CFR Part 20, the Nuclear Regulatory Commission allows for different disposal options for media contaminated with radioactive materials. These provisions were promulgated to ensure proper management and safe disposal of radioactive waste. NRC requirements in Part 20 allow various options for waste disposal, including transfer to other licensed facilities, decay in storage, and release of air and liquid effluents to unrestricted areas provided that the concentrations of radioactive material in the effluents do not exceed the values specified in Appendix B, Table II of 10 CFR Part 20.

The Part 20 requirements also allow disposal of radioactive waste by incineration. Incineration may be an appropriate disposal method when the waste volume is substantially reduced through incineration and when most of the hazardous (organic or biological) constituents are nearly eliminated through thermal destruction. On the other hand, radionuclides originally present in the waste may be concentrated in the ash through incineration. NRC has allowed licensees to dispose of this ash at unlicensed facilities (e.g., municipal waste landfills) provided that radionuclide concentrations in the ash are sufficiently low.

Previously, NRC authorized disposal of incinerator ash containing radionuclides (with atomic numbers 1-83) in unlicensed disposal facilities as an ordinary waste, if radionuclide concentrations in the ash did not exceed the liquid effluent concentration values (μCi/ml) in 10 CFR Part 20, Appendix B, Table II, Column 2 (old Part 20 limits were used). In applying the liquid effluent values to solid ash, NRC equated μCi/ml to μCi/g. The technical basis for this approach was that a milliliter of water has a mass of about 1 gram. In addition, the effluent concentration values in Appendix B, Table II, Column 2 were generally established based on the assumption that a member of the public would not receive an annual whole body (or organ) dose equivalent in excess of 0.5 rem (according to the old Part 20) if that individual ingested two liters of drinking water per day with the radionuclide at the stated concentration. Using this approach, ingesting two liters drinking water per day was assumed to be roughly the equivalent of ingesting 2000 g of ash a day. Because the likelihood of such ingestion occurring was considered extremely remote, NRC believed that applying the Appendix B values for release of ash would ensure adequate protection of the public. The revised Appendix B values in the new 10 CFR Part 20 requirements have been established, using the same approach, to ensure that the annual Total Effective Dose Equivalent would not exceed 0.05 rem (TEDE) to an individual member of the public from ingesting 2 l/d of the liquid effluent.

Concentration limits for the free release (as ordinary waste) of the ash containing radioactive material, however, have not been established through regulation. Indeed, the application of the Appendix B, Table 2, Column 2 values for limiting releases of solid ash has not been supported by any generic dose assessment studies, using environmental pathway analysis, to evaluate potential risks or maximum dose to a member of the critical population group. The calculational basis for the values in Appendix B did not consider potential concentration effects that may occur in the environment due to plant uptake, bioconcentration, groundwater transport, and other mechanisms that could increase human exposure to radionuclides contained in the ash.

In the wake of the revocation of NRC's 1986 and 1990 policy statements on Below Regulatory Concern and associated public concerns, NRC staff initiated this generic dose assessment in 1992 to determine whether continued application of the Appendix B limits (Revised Part 20) ensure that the public dose remains a small fraction of the public dose limit in §20.1301(a) (100 mrem/yr) from the disposal of incinerator ash in unlicensed landfills.

Currently, there are several tens of medical and research licensees requesting authorization to dispose of incinerator ash in municipal landfills as unregulated waste. NRC withheld completion of these license amendment and renewal reviews, pending the completion of the generic dose assessment to ensure that NRC first established a sufficient technical rationale for any licensing decisions involving authorization for ash disposal.

This technical report summarizes results of the generic dose assessment for the disposal of incinerator ash in a typical landfill. The thrust of the assessment was to determine the potential radiological risks associated with landfill disposal of incinerator ash with concentrations of a wide range of radioactive materials at or below the concentration values in Part 20, Appendix B, Table 2, Column 2. The current assessment does not include the radiological impacts from the process of incineration because such impacts are already evaluated as part of the licensing review process for the incineration facility. The scope of the current dose assessment only evaluates potential doses arising from the ash transport to disposal in the landfill and the subsequent unrestricted use of the landfill site.

It should be pointed out that the results presented in this report were based on a generic approach and sets of assumptions. Potential radiological impacts will vary from generator to generator depending on the characteristics of the ash, the type of landfill, the frequency and rate (volume) of ash disposal, the distance of the landfill from the generator site, and the actual physical conditions at the landfill. The report concludes with NRC staff recommendations on how the results should be integrated with NRC's existing regulatory framework to continue to ensure protection of the public health and the environment.

2. APPROACH AND METHODOLOGY

In this study, NRC staff employed two computer codes to evaluate radiological impacts. The first code used was RESRAD code Version 5.0, *Manual for Implementing Residual Radioactive Material Guidelines* (DOE, 1989; DOE, 1993). RESRAD was used to assess the maximum reasonable projected dose to a member of the critical population group that may inhabit the landfill site at some point in the future. The second code used was the NRC's IMPACTS-BRC code Version 2.1 *De Minimis Waste Impacts Analysis Methodology* [(NUREG/CR-3585, Volume 1 (NRC, 1984) & Volume 2 (NRC, 1986), NUREG/CR-5517 (NRC, 1990), and NUREG/CR-5797 (NRC, 1991)]. The IMPACTS-BRC code was specifically used to evaluate potential doses to workers and members of the public associated with transportation of incinerator ash from the generator site to the landfill.

The methodology adopted in conducting this assessment is summarized below.

2.1 Collection of Data on Ash Characteristics

To provide some assurance that the conditions and assumptions used in the dose assessment were reasonable, NRC staff requested information from nine NRC licensees regarding their incinerator ash and the intended landfill facilities where the ash has been or would be disposed of. Questionnaires were sent to licensees requesting information on the amount of ash generated, types and characteristics of landfills, the manner in which the ash is sent to the landfill for disposal, the activity content of the ash, and other radiological survey data. Appendix A presents a summary of the responses to these questionnaires received from 8 NRC licensees. Additional information pertinent to storage of the ash before disposal was also requested. Further, NRC staff contacted the licensees regarding the following:

(a) Do landfills that have received ash in the past have on-site radiation detection systems to monitor radioactivity levels of incoming incinerator ash shipments before disposal in the landfill facility?

(b) If so, has any ash shipment been rejected by the landfills due to excessive radioactivity levels?

In addition, NRC staff conducted a computer data-base search to identify the names and types of active NRC licensees authorized to incinerate, and to identify radioactive material characteristics and quantities possessed under these licenses. This information was used to establish the generic characteristics of the landfill facilities and the radionuclide concentrations in the contaminated ash. In addition, NRC used the information in developing the dose assessment approach and in providing an independent check on radiation levels associated with projected ash concentrations.

2.2 Collection of Data on Typical Landfill Characteristics

In selecting parameters values to represent a typical municipal waste landfill that may receive the incinerator ash for disposal, NRC staff reviewed the characteristics of landfills described in *De Minimis Waste Impacts Analysis Methodology*, (NUREG/CR-3585; NRC, 1984); and the Environmental Protection Agency's (EPA's) reports on solid waste disposal *Report to Congress on Solid Waste Disposal in the United States*, Volumes I and II, Office of Solid Waste, October 1988, Report No. EPA/530-SW-88-011 (EPA, 1988a); Solid Waste Disposal Facility Criteria in 40 CFR Parts 257 and 258; Proposed Rule, Federal Register, Volume 53, No. 168, 33314-3342 (EPA, 1988b); and *Municipal Waste Combustors-Background information for Proposed Standards: 111(b) Model Plant Description and Cost*, Office of Air Quality Planning and Standards, August 1989, Report No. EPA-450-3-89-27b (EPA, 1989). NRC staff also analyzed survey data on landfills contained in NRC's contractor studies entitled *Characterization of Class-A Low-Level Radioactive Waste 1986-1990* and *Treatment and Disposal of Ordinary Industrial, Municipal, and Hazardous Waste* (Sanford Cohen and Associates, 1992).

2.3 Radiological Impact Analysis

In conducting the radiological impact analysis, NRC staff employed the following methodology:

1. Assessment of radionuclide source terms and potential mechanisms of releases;

2. Determination of points of potential human exposure;

3. Evaluation and selection of potential exposure pathways and exposure routes into humans (e.g. direct exposure or ingestion); and

4. Quantification of potential exposures using applicable dose assessment codes.

The generic methodologies of the two computer codes employed by the NRC staff in the radiological impacts analysis (RESRAD and IMPACTS-BRC) are discussed briefly below.

2.3.1 RESRAD Methodology

The RESRAD model assumes a family-farm exposure scenario (DOE, 1989 and DOE, 1993). It assumes that a family will move onto the disposal (landfill) site after the site has been released for unrestricted use. The family proceeds to raise crops and livestock on the site as a substance farm. Using this methodology, it is assumed that members of the family could conceivably be exposed through direct radiation exposure, inhalation of resuspended dust and radon, ingestion of food from crops grown in the contaminated soil, ingestion of milk and meat products from livestock raised on the contaminated landfill, ingestion of fish from a contaminated nearby pond, and ingestion of contaminated water from a well at the site. The resident family is also assumed to drill a well at the site boundary to draw water for irrigation, bathing, and watering farm animals.

NRC staff estimated doses to a maximally exposed member of the public from multiple RESRAD runs using eight potential exposure pathways: external exposure, dust inhalation, plant ingestion, meat ingestion, milk ingestion, aquatic food ingestion, drinking water, and soil ingestion. The only exposure pathway excluded was that of radon/thoron inhalation because the ash was assumed not to include elevated levels of uranium, radium, or thorium (the parent radionuclides of radon and thoron).

The computer runs were conducted for two types of landfills. The first type is the "Ramp Method" (or Progressive Slope Method) (see Section 4.2). The typical landfill of this type is assumed to have a total waste thickness of 24 ft. The second type of landfill is the "Area Method," in which the total waste thickness is assumed to be 8 ft. Dose assessments were also conducted assuming two cover options. The first option assumes a clay cover of about 2 ft thick to be placed on the top of the landfill. The second option assumes no cover on the top of the landfill.

As mentioned earlier, the annual radiological doses to the resident farm family were calculated using three different radionuclide concentration levels in the landfill. These concentration levels were based on three different scenarios for the number of waste generators (10, 5, and 1 generator) assumed to be sending their incinerator ash to the same landfill.

2.3.2 IMPACTS-BRC Methodology

The IMPACTS-BRC methodology (NRC, 1984, 1986) calculates occupational exposures, population exposures, and off-site individual exposures associated with the disposal of low activity radioactive waste, including radiological impacts associated with waste transportation, waste processing, waste disposal, and post-disposal use of the disposal site. In this dose assessment for the incinerator ash, NRC staff only used the IMPACTS-BRC code to calculate potential doses to workers from transporting the incinerator ash and total projected population dose (person-mrem/yr) to members of the public adjacent to the travel routes. Radionuclide energies and abundances are used to derive individual radionuclide dose rates. Correction factors are used in conjunction with the dose rate factors. The correction factors used by the code include a correction for geometry and finite dimensions of the transporting vehicle, build-up factors related to the thickness of the source, attenuation factors due to waste and air media attenuations, and a correction factor to account for a non-point flux source.

The IMPACTS-BRC code was only used in this analysis to calculate the radiological impacts from incinerator ash transportation. NRC staff selected this approach because the IMPACTS-BRC analysis for other exposure pathways may not be sufficiently conservative and consistent with the present NRC staff practices for assessing radiological impacts associated with residual radioactivity. This conclusion was based on the fact that the IMPACTS-BRC code does not adequately represent post-operational, onsite exposure of a site resident to irrigated agricultural products. Sandia National Laboratory has also identified limitations of the code with respect to assessing post-operational, off-site exposures of an individual or population located off-site (NUREG/CR-5797; SNL, 1991).

3. INCINERATOR ASH SURVEY DATA

There are currently about 60 NRC licensees that are authorized to incinerate wastes containing radioactive materials. Most of these licenses are academic or medical institutions. There are a small number of licensees that fall under the industrial (manufacturing and distribution) category. NRC staff surveyed nine NRC licensees in connection with incineration activities and ash generation. NRC requested information on incinerator ash volume, radiological composition, disposal method, and storage method. Appendix A summarizes the data received from 8 licensees. Additional information was also collected by NRC staff regarding the potential monitoring of incinerator ash at the landfill site before disposal (see section 2.1). The results of this survey are summarized below.

1. The mass of ash generated annually by each licensee ranges from 225 to 550,000 Kg (500-1,200,000 lbs). This corresponds, on the average, to a volume range of 0.225-550 m^3 (8-20,000 ft^3).

2. The ash is disposed of in regional, county, or private municipal landfills. The landfills process up to 500,000 tons of municipal waste annually with an area of 44 to 200 acres. In some cases, the ash is transferred to a centralized facility for storage until it is shipped for final disposal.

3. The ash is shipped to the landfills in covered roll-off containers (10-20 tons)

or compactors (dumpsters). In some instances, the ash is sent to the landfill in bulk form, using ordinary transportation vehicles or in 55-gallon fiberboard containers.

4. The most predominant radionuclides (atomic No. 1-83) reported to be present in the ash are byproduct material: H-3, C-14, Na-22, P-32, S-35, Cl-36, Ca-45, Cr-51, Mn-54, Fe-55, Co-58, Zn-65, Se-75, Sr-85, Y-90, Nb-95, Tc-99, Tc-99m, Sn-113, I-125, I-131, Ce-141, Gd-153, and Tl-201. Appendix B presents list of the common radionuclides, half-lives, type of decay, and energies of emissions for each radionuclide.

5. The concentration of each radionuclide in the ash (μCi/g) is less than the effluent concentration limits (μCi/ml) in 10 CFR Part 20 (old Part 20) Table II, Column 2.

6. The ash is typically stored, for decay and/or for accumulation, for 1 month to 2 years. The ash is shipped for disposal at a rate ranging from a maximum of one shipment every 10 days to a minimum rate of a few shipments for the entire year.

In terms of radiological monitoring of incoming waste at the landfill facilities, NRC staff contacts with licensees in Regions I and III (see section 2.1) indicated the following:

1. Some landfill facilities do monitor (at the landfill) the radiation levels of incoming incinerator ash shipments on site. Other landfill facilities do not monitor incoming waste shipments.

2. Based on the recollection of NRC staff in Regions I and III, and oral responses received from a few licensees in Regions I and III (i.e., responses to contacts, by phone, made by NRC staff), there has been no known case reported for rejection of any incinerator ash shipment from a licensee at a landfill due to elevated radiation levels.

4. TYPICAL LANDFILL CHARACTERISTICS

One of the challenging tasks in this generic assessment was the selection of appropriate parameters to represent a typical sanitary waste landfill that would be common for all licensed generators of incinerator ash. Selection of a typical landfill was necessary in order to establish the appropriate source term characteristics and other variables for the radiological impact analysis. The sanitary landfill is specifically characterized by certain parameters that significantly influence estimation of potential doses.

4.1 Landfill Area

The operating area of sanitary landfills varies over a wide range (1 to 250 acres). The typical sanitary landfill is on the average of 10 to 27 acres. EPA survey data (EPA, 1988 a,b) indicate that the typical landfill is an enclosed facility within an area of about 40 acres. The default parameters in IMPACTS-BRC assume an area of 25 acres. This analysis assumes an area of 25 acres. This landfill area was selected in order to be conservative (i.e., incorporate assumptions and parameter values that tend to overestimate potential doses) and to account for numerous landfills with smaller areas.

4.2 Mode of Operation

There are two principal variations in sanitary landfill operations, these are:

(a) The Ramp Method (or Progressive Slope Method) - this is a combination of the trench and area method. A small excavation is first made in front of the exposed face of an existing slope. The excavated soil is stockpiled. Refuse is placed on the exposed slope, compacted, and covered with compacted soil. This process is repeated at the faces of the newly created slopes so that a succession of slopes is produced across the landfill. The daily cover thickness is typically 1.5-2 ft. The result of this disposal method is a series of cells in which the refuse/soil mixture is completely surrounded by a layer of soil with a final cover emplaced and compacted at the top. EPA guidelines (40 CFR Parts 257 and 258) require that daily cover soil should be a minimum of 6 inches (15 cm) and that cells which will not have additional waste placed on them for 3 months or more should be covered with a with a minimum of 12 inches (30 cm) of soil. The final cover of the landfill should consist of at least 6 inches of clay, followed by 18 inches of additional soil, to support a vegetative cover. The waste disposed in the landfill cell will be mixed with soil and daily cover materials at a ratio of about four parts waste to one part soil.

(b) The Area Method - the waste is placed on the undisturbed existing ground surface. The top soil is occasionally removed and stockpiled for the final soil cover. After the waste has been placed, it is spread over the ground surface in a reasonably uniform layer and then compacted. The compacted layer of refuse and soil is covered with a soil cover either at the end of the day or when the deposition area is filled. This method is commonly employed when the groundwater table lies near the surface.

The "Trench Method" is another, less frequently used, disposal method employed in the disposal of municipal waste. Using the trench method, a long, narrow excavation is made and the excavated soil is stockpiled. The waste is generally deposited in a sloping manner at one end of the excavation and then compacted while being covered with a layer of soil. This method of disposal is most suitable for sites where the groundwater table is at a significant depth. The trench method was not evaluated in this analysis due to the lack of information on facilities using this disposal method. Specifically, representative information was not obtained on the depth to water table and trench dimensions for facilities using the trench method. In addition assuming the trench method of disposal could have reduced potential dose estimates by placing the contaminated waste at greater depths, thus reducing potential exposure to potential residents who may later occupy the site.

4.3 Waste Volume and Mass

The total volume of waste deposited in the landfill can be estimated from the total area of the landfill, waste depth or thickness, and the waste/soil ratio. Because this was intended to be reasonably conservative, the landfill area will be assumed to be 25 acres (see section 4.1). The depth of the landfill (waste thickness) can vary over a wide range. EPA survey data (EPA, 1988) indicate an average depth of 8 ft (2.5 m), whereas the default parameter value in IMPACTS-BRC (NRC, 1984, 1986, and 1990) is an average depth of 24 ft (8 m). In this analysis two scenarios were employed. The first assumed a waste thickness of 24 ft (8 m), whereas the second assumed a thickness of 8 ft (2.5 m). The second scenario is more conservative because mixing of ash with ordinary waste will provide less dilution, resulting in higher radionuclide concentrations in the bulk waste in the landfill. The waste/soil ratio in the landfill was assumed to be 4:1; this ratio is typical for the "Ramp" method. It was selected because the "Ramp" method is the most common method of disposal in landfill operations.

Based on above assumptions, the total bulk waste capacity of the typical landfill is calculated as follows:

$$V = A \times t \times R$$

where V is the landfill capacity (ft^3), A is the landfill area (ft^2), t is the waste thickness (ft), and R is the waste/soil ratio.

Using the parameters discussed above, the total volume of bulk waste in the landfill is calculated as:

$$V\ (ft^3) = 25\ (acre) \times 4.356 \times 10^4\ (ft^2/acre) \times 24\ (ft) \times 0.8$$

thus, $V = 20{,}900{,}000\ ft^3$ which is equivalent to $774{,}000\ yd^3$.

Assuming that the landfill operates for 20 years and for 280 days per year, the daily volume of bulk waste disposed would be 3734 ft^3 or 138 yd^3. For economic operation and to ensure stability of the landfill during operations and after closure, landfill operators must compact the waste to a minimum densities of between 800 and 1000 lb/yd^3 (0.47 - 0.59 g/cm^3). Given this density range, the average daily mass of waste that would be disposed in the landfill is 55-69 tons/d (50-62 tonnes/d).

The above figures on landfill area, thickness, bulk waste mass, and volume are significant parameters in calculating the dilution factors and radionuclide concentrations in the source term. Therefore, the above assumptions will have a significant influence on the results obtained from this generic dose assessment. For example, assuming a landfill waste thickness of 8 ft (rather than 24 ft) would increase the relative source term concentration by a factor of three.

4.4 Location of Water Intakes

The distance of the water intake (e.g., well) from the center of the landfill has a significant influence on the radionuclide intake by humans, livestock, and crops through ingestion of contaminated drinking water and through biotic uptake from contaminated irrigation and livestock water. Water intakes could be from a private well, where an individual establishes a residence on the landfill site; public well, where the current population receives their water from adjacent to the landfill site for domestic and agricultural use; or from a surface water source (e.g., river, stream, or a lake) near the landfill site. The most conservative approach is to assume that the well is located at the edge of the landfill boundary directly downgradient from the landfill. In the absence of specific information on the landfill, the distance to water intakes (from a well) is frequently estimated as being equivalent to $\sqrt{A}$ (DOE, 1989), where A is the disposal site area. Assuming an area of 25 acres (equivalent to 1,000,000 ft^2 or 101,000 m^2) for a typical landfill, the distance between the disposal facility and the water intake well would be 1043 ft (318 m).

EPA survey data (EPA, 1988) indicates that the typical distance between landfills and private wells is 1,850 m. The minimum reported distance, however, is 2 m from the site. EPA survey data (EPA, 1988) also indicated that 55% of the facilities have no wells within 2 km of the site, and only 5% have surface water bodies that are used for drinking water sources within this distance from the site. IMPACTS-BRC (NRC, 1986, 1990) assumes a default value of 56 m (for all three directions NW, SE, and SW) for the distance between the landfill and the well.

Considering EPA survey data and the relatively large size of landfills, it is likely that more than one resident could use the site in the unrestricted release scenario. Therefore, more than one well could be constructed near the landfill site. NRC staff selected a distance of 100 m from the center of the disposal facility to the well; this distance is also the default value in RESRAD analyses.

The concentration of radionuclides in the well is also dependent on the groundwater flow rate and velocity between the landfill and intake. There is a large variation in the groundwater flow rates and hence, the travel time from below the landfill to the well. EPA survey data indicated that such generally variations range from 0.01-16 ft/yr. IMPACTS-BRC default values vary from 3.3 to 33 ft/yr depending on the direction of measurements relative to groundwater flow direction.

In this analysis, the groundwater flow velocity was assumed to be 33 ft/yr (10 m/yr) for the unsaturated zone and 330 ft/yr (100 m/yr) for the saturated zone beneath the landfill.

4.5 Population Density

The population density is needed to assess potential radiological impacts associated with transporting the incinerator ash from the point of generation to the landfill. The worst case scenario, with respect to population exposures, in the survey analysis (EPA, 1988) is a population of 250,000 within a mile of the landfill. However, this case is unique and is the only known site with such a high population denisty out of 1,011 sites. In most cases, the population density within a radius of 5 miles from the site is in the range of 100-3500 per mi^2. If county populations are used as an indication of the populations within a 50-mile radius, the upper bound may be 5 to 7 million people (Cook County, Illinois and Los Angles County, California). In this analysis, using IMPACTS-BRC default assumptions, the population density around the transportation route was assumed to be 2,280 persons/mi^2.

4.6 Transportation Distances

The IMPACTS-BRC code assumes an average transportation distance of 10 miles between the location of generation and the disposal facility. In some cases incineration may take place at the landfill site. For the majority of the sites in EPA's survey (EPA, 1988), the typical transportation distance to the landfill ranges from 10 to 63 miles. The transportation distance assumed in this analysis is 10 miles. This figure was selected because most municipal landfills are located within this range.

4.7 Leachate Collection System

About 20% of the planned landfill disposal units in the 1988 survey were found to have leachate collection systems in their design. EPA (EPA, 1988 a,b and EPA,

1989) estimated that 75% of the new landfill units would require a leachate collection system under the proposed regulations (EPA, 1988 b). Where systems are already in place, the leachate is generally sent to a Publicly Owned Treatment Works (POTW). The POTW produces sludge as residue from the waste water treatment processes. The treated liquid effluent is then typically discharged to surface water bodies.

This analysis assumes that sanitary landfills (where the ash is to be disposed) do not contain leachate collection systems. This assumption was made conservatively in order to account for the 25% of landfills that are not anticipated to have such collection systems. Potential radiological impacts from the treatment of the leachate and the disposal of the resulting sludge residue is beyond the scope of this study. However, potential reconcentration of radionuclides in landfill sludges has not been identified as a problem in EPA's ongoing evaluations of the envirnmental management of municipal wastes.

4.8 Physical Parameters

The two codes employed in this analysis (RESRAD & IMPACTS-BRC) require input parameters that represent many site-specific physical and environmental conditions. Because this analysis is generic, the required parameters were selected based on the discussion presented above in connection with the typical landfill and ash characteristics, and also on conservative approaches that ensure accounting for the few upper bound actual cases. The assumptions and parameters selected in performing this dose assessment using RESRAD and IMPACTS-BRC codes are summarized in Tables 1, 2, and 3.

5. SOURCE TERM SCENARIOS

In conducting this generic radiological impact assessment, it was necessary to define and formulate an adequate source term that corresponds to most ash generators and landfill disposal facilities. The most appropriate approach was to establish different source term scenarios that corresponded to various disposal options and alternatives. Specifically, multiple scenario options selected in this generic assessment were based on different volumes and quantities of ash generated, the wide range of radiological characteristics of the source term, and various assumptions for the physical characteristics of the landfill. In this context, the following assumptions were made.

5.1 Typical Ash Generator

Based on responses to questionnaires, received from NRC licensees, the maximum volume of ash generated annually by one licensee was 550 m^3. The NRC assumed this rate of ash generation was the typical rate for NRC licensees, in spite of the fact that actual generation rates are probably much lower for most licensees.

5.2 Number of Ash Generators

Three options were considered with respect to number of ash generators disposing in the same landfill. The first option assumes 10 generators are disposing a total incinerator ash volume of 5,500 m^3 annually in a single landfill. The second option assumes five generators with a total annual ash volume of 2,750 m^3, and the third option assumes a single ash generator with a total annual ash volume of 550 m^3.

5.3 Radionuclides and Concentrations

Each of the two codes used in this assessment has its own limitations. RESRAD does not contain, in its assessment methodology, radionuclides with half-lives of less than 6 months. Further, RESRAD does not include certain radionuclides that are known to be present or may be present in the incinerator ash (e.g., Tl-201, Sn-113, Mo-99, and Sr-85). Therefore, only 25 radionuclides were considered in the generic dose assessment using the RESRAD code. These radionuclides are known to be present in the incinerator ash and include: Ag-108m, Ag-110m, Al-26, C-14, Cd-109, Ce-144, Cl-36, Co-57, Co-60, Cs-134, Cs-137, Fe-55, Gd-153, H-3, I-129, K-40, Mn-54, Na-22, Nb-94, Ni-59, Ni-63, Sr-90, Tc-99, Tl-204, and Zn-65.

Based on information received from 9 NRC licensees, and generic data reported on incinerator ash (EPA, 1989, Cohen and Associates, Inc., 1992), the above radionuclides are generally considered the dominant and most significant radionuclides present in the incinerator ash. Other short-lived radionuclides such as P-32, S-35, Tc-99m, Fe-59, and Ca-45 may also be significant radionuclides in the ash. Of these radionuclides, Ca-45 has the longest half-life at about 162.7 days. However, they were not analyzed in this analysis because they have not been included in the RESRAD code. Therefore, disposal of incinerator ash containing these radionuclides will need to be reviewed on a case-by-case basis to determine whether such disposal is acceptable in accordance with the requirements of 10 CFR Part 20.

For estimating potential doses from radionuclides in the ash, unit concentrations (1 pCi/g) of each radionuclide in the bulk landfill were assumed. Using the unit concentrations, NRC staff calculated the dose/source ratio {(mrem/yr)/(pCi/g)} for each radionuclide. This approach allows potential doses to estimated directly by multiplying actual concentrations of a radionuclide in the ash by the dose/source ratio for that radionuclide.

In calculating actual doses, radionuclide concentrations in the bulk landfill were calculated for three different scenarios as follows:

(a) 10 Generator Scenario

In this scenario, 10 generators were assumed to generate ash at a total annual rate of 5500 m^3. The ash density was assumed to be 1 ton/m^3. The annual waste capacity of the landfill disposal site was assumed to be 30,000 m^3 (39,000 yd^3). Assuming a waste/soil ratio of 4:1, the total annual capacity of the landfill was estimated to be 38,000 m^3 (50,000 yd^3). The total density of waste (municipal waste) in the landfill was assumed to be 0.60 g/cm^3. Assuming 1.6 g/cm^3 for the soil density, the bulk density of the mixture (soil, municipal waste, and ash) was assumed to be 0.8 g/cm^3. The total mass of waste (municipal waste + ash) and soil disposed annually in the landfill was calculated at 30,400 metric tons. Assuming the ash is thoroughly mixed with the municipal waste, and the waste/soil ratio (in the landfill) of 4:1, the ratio of ash to the bulk landfill material (waste & soil) for this scenario would be approximately 1:5. Thus, using this scenario, the dilution factor resulting from mixing the incinerator ash with the municipal waste and cover soil material in the landfill is 1:5.

(b) 5 Generator Scenario

In a similar fashion, the annual volume of incinerator ash to be mixed with municipal waste and landfill soil materials in this scenario is 2,750 m^3. Therefore, the dilution factor in this scenario is approximately 1:10.

(c) 1 Generator Scenario

The total annual volume of incinerator ash that will be disposed of in the landfill is 550 m^3; thus, the dilution factor in this scenario is approximately 1:50.

Based on these three source-term scenarios, NRC staff estimated radionuclide concentrations in the landfill. Using the dose/source ratio derived in RESRAD, the unit dose {i.e., (mrem/yr)/(pCi/g)} resulting from each radionuclide for each source term scenario was derived.

In the IMPACTS-BRC analysis methodology, the dose assessment approach is quite different from RESRAD. The code does not require the calculation of the dilution factor by mixing with ordinary waste. Rather, it requires input parameters corresponding to radiological waste concentration, density, and volume. Further, the code requires inputs of environmental parameters corresponding to the location of the landfill and physical parameters associated with the landfill characteristics. Since this code was designed for generic analysis rather than site specific analysis, code default values for most input parameters could be appropriately selected for the generic dose assessment. The parameters selected for the IMPACTS-BRC dose assessment are summarized in Tables 2 and 3. The IMPACTS-BRC code calculates dose impacts from different scenarios associated with transportation, incineration, disposal operation, leachate accumulation, groundwater, and anthropogenic activities after site closure (e.g., agricultural and construction activities). However, in this analysis, the code was employed only to calculate doses associated with incinerator ash transportation.

The radionuclides selected for the source term in the IMPACTS-BRC evaluation included: Ag-108, Ag-110, Ba-140, C-14, Ca-45, Cd-109, Ce-141, Ce-144, Cl-36, Co-57, Co-58, Co-60, Cr-51, Cs-134, Cs-137, Fe-55, Fe-59, I-125, I-129, I-131, Mn-54, Mo-99, Na-22, Nb-94, Nb-95, Ni-59, Ni-63, P-32, Ru-103, S-35, Sb-125, Se-75, Sn-113, Sr-85, Sr-90, Tc-99, Tc-99m, and Zn-65.

The above list of radionuclides was selected based on survey data for common radionuclides present in incinerator ash (e.g., responses to questionnaires received from 9 licensees, NRC data-base review, and EPA data in references EPA, 1988 a, b, and EPA 1989). In addition, these radionuclides are also included in the IMPACTS-BRC data base pertaining to the radiological characteristics of incinerator ash.

Radionuclide concentrations in the ash were assumed to be at the concentration limits in 10 CFR Part 20 [§§ 20.1001-20.2402], Appendix B, Table 2, Column 2. As described in the introduction of this report, the NRC staff has applied the Appendix B, Table 2, Column 2 values (converted from μCi/ml to μCi/g) in limiting the concentrations of radionuclides in the incinerator ash. The objective of this dose assessment is, in part, to evaluate potential radiological risks associated with this practice. Consequently, the Appendix B concentration values were assumed to be the source concentrations in this assessment.

In addition, the typical incinerator ash generator was assumed to produce an annual volume of 550 m^3 of ash with an average density of 1.00 g/cm^3. This assumption was based on the maximum volume of ash generated by one licensee reported in the limited survey of licensees (Appendix A).

6. RESULTS OF RADIOLOGICAL IMPACT ANALYSIS

6.1 Results of RESRAD Impact Analysis

The results of the radiological impact analysis for the disposal of incinerator ash in a typical landfill, that is not licensed for disposal of radioactive material, are summarized below.

(a) **RESRAD Dose Assessment Results for Disposal in a Landfill With a Waste Thickness of 8 m**

Using the RESRAD code, NRC staff estimated the annual total effective dose equivalent (TEDE), for each of the 25 radionuclides listed in section 5.3. It should be noted that these estimated doses correspond only to radionuclide concentrations (in the contaminated landfill) of 1 pCi/g. Dose calculations were conducted for a period of 10,000 years. Appendix C contains the details of the dose analysis for each radionuclide using the eight exposure pathways as explained above. Appendix C also contains graphs showing the variation of these doses with time. The peak dose for each radionuclide is shown along with the variation of the dose over a period of 10,000 years. The dose/source ratios {(mrem/yr)/(pCi/g)} for the peak dose for each of the 25 radionuclide {DSR(i,t_{max})} are listed in Table 4. Using the DSR values, the dose resulting from any radionuclide listed in section 5.3 for any assumed concentration level in the ash can be calculated.

The DSR results (presented in Table 4 and Appendix C) indicate that the following radionuclides tend to have relatively high DSR values.

Radionuclide	DSR Value (mrem/yr)/(pCi/g)
C-14	27.7
I-129	254.4
Cl-36	10.5
Al-26	8.3
Ag-108	7.6
Nb-94	2.8
Tl-204	2.9
Sr-90	1.5

The peak dose from all pathways for most radionuclides (e.g., Ag-108m, Al-26, C-14, Cl-36, I-129, Nb-94, Sr-90, and Tl-204) occurs within 10 years after release of the landfill for unrestricted use. The maximum total dose from all 25 radionuclide for all 8 pathways occurs at 7.38 years. This dose is equivalent to 317.3 mrem/yr per pCi/g of all 25 radionuclides. The I-129 contribution to this dose is approximately 80% and for C-14 contribution is about 8%. This contribution is based on a concentration of 1 pCi/g for each radionuclide, regardless of the concentration limits in 10 CFR Part 20, Appendix B.

However, the actual doses are controlled by the concentration limits in Appendix B of 10 CFR Part 20, (licensees have not been allowed to dispose of ash with radionuclide concentrations above these limits, except as specifically authorized by the NRC). As previously described (page 1), the NRC staff has established a licensing practice of limiting radionuclide concentrations in the ash to the limits in Appendix B, Table 2, Column 2, of 10 CFR Part 20, through changing the unit from μCi/ml to pCi/g. Radionuclide concentrations in the landfill are also controlled by the volume of ash generated by each licensee and by the number of generators disposing in the same landfill (i.e., the dilution factor) as was discussed above.

Using 10 CFR Part 20 [§§ 20.1001-20.2401], Appendix B, Table 2, Column 2 effluent concentration limits, and the three scenarios for the waste generators (i.e., three different dilution factors), NRC staff calculated a total projected dose resulting from each radionuclide. Table 4 lists all 25 radionuclides, their corresponding DSR ratios, 10 CFR Part 20 limits, the calculated concentrations in the landfill (assuming the five generator scenario), and the corresponding peak dose. Table 5 lists the annual dose (TEDE) corresponding to each radionuclide for three different concentration scenarios (i.e., 10, 5, and 1 generators (dilution factors of 1:5 to 1:50).

In the most conservative scenario (10 generators sending a large volume of ash at the concentrations listed in Appendix A to the same landfill), the following radionuclides could cause a potential dose to a residential farmer at the landfill in excess of 1 mrem/yr:

Radionuclide	Dose (mrem/yr)
Ag-108	13.4
Al-26	10.0
C-14	167.0
Cl-36	42.0
H-3	3.9
I-129	10.2
Nb-94	5.6
Tc-99	9.9
Tl-204	11.5

The major share of the estimated dose is from C-14 and Cl-36, while Ag-108, Tl-204, I-129, Al-26, and Tc-99 contributed approximately 10 mrem/yr each to the total dose. It is of interest to note that although I-129 has the highest DSR values, due to restrictions on its concentration level in the ash (Appendix B), the projected dose was reduced by a factor of 20. On the other hand, due to less restrictive limits on C-14 and Cl-36, the dose for each of these radionuclides increased by a factor of 4 to 5 times the DSR (i, t_{max}) given in Table 4. It is also interesting to note that due to the Appendix B warrant concern. Conversely, less stringent concentration restrictions on Tc-99 resulted in listing this radionuclide on the list of concern. These findings may have a significant bearing on formulating regulatory guidance to evaluate the acceptability of releasing ash for disposal in unregulated landfills.

The above results also indicate that reducing the number of incinerator ash generators that are disposing in the same landfill would substantially reduce the dose resulting from each radionuclide. For example, reducing the number of generators from 10 to 5 would reduce the potential dose by a factor of two. By assuming that only one generator disposes ash in the landfill reduces the dose by a factor of 10 compared to what it would be if 10 generators disposed of their ash in the same landfill. Table 5 compares anticipated doses for the three waste generator scenarios. It should be pointed out that this assessment assumes that each generator disposes of 550 tons of ash annually in the landfill. The dose can also be reduced in a similar fashion if the volume of ash generated by each licensee is less than 550 ton/yr. In fact, NRC's initial survey of licensees indicated that most licensees generate much less than this volume (See Appendix A). Therefore, it is anticipated that the actual dose is far less than that presented above. On the other hand, if the number of ash generators disposing in the same landfill increased, it could increase the potential dose to the public which could warrant a reassessment of the practice of allowing unregulated ash disposal using the concentration limits in 10 CFR Part 20, Appendix B.

(b) **RESRAD Dose Assessment Results for Disposal in a Landfill With a Waste Thickness of 2.5 m**

The DSR results obtained for the analysis of incinerator ash disposed in the second type of landfill (2.5 m waste thickness) are similar to those obtained in the previous landfill type (3 m waste thickness). The total dose from all 25 radionuclides (all 8 pathways) was reduced to 158.6 mrem/yr from a dose of 317.3 mrem/yr for the 8 m thick landfill. The time to reach the peak dose was also reduced from 7.4 to 5.3 years. The DSR changes varied from one radionuclide to another due to the compound effect of decreasing radionuclide inventory and changing environmental transport conditions (e.g., wind erosion, surface water erosion, groundwater transport, and soil uptake) . For example, the DSR for I-129 changed from 254.4 mrem/yr to 111.3 mrem/yr (i.e., a reduction by a factor of 56%). On the other hand, the DSR for C-14 was only reduced from 27.7 to 21.7 mrem/yr, which is a 22% decrease. In other words, the mechanism of exposure depends to a large extent on the assumed waste thickness in the landfill and this dependance varies from one radionuclide to another. Appendix D presents the details of RESRAD dose assessments of incinerator ash in an 8 ft (2.5 m) thick landfill. Appendix D also includes graphs showing the variation of radionuclide doses (from all 8 also includes graphs showing the variation of radionuclide doses (from all 8 pathways) with time. Table 6 compares the DSR values derived for the two landfill categories (i.e. 8 m and 2.5 m thick with 0.6 m cover). The concentration of each radionuclide in this landfill type will be increased by a factor of 3, compared with the concentration in the thicker landfill. This is due to a smaller waste volume capacity for this landfill type. In other words, there is less volume of municipal waste and soil available for mixing with the ash, and hence, less dilution for the disposed ash in the landfill. The bulk volume of waste (including ash) that can be contained in this landfill is approximately 7,000,000 ft^3 (200,000 m^3). Assuming the landfill operates for 20 years, with 280 days of operation for each year, the daily volume of waste to be disposed in the landfill is 36 m^3 or 47 yd^3. Assuming an average density of material in the landfill (ash + municipal waste + soil) of 0.8 g/cm^3, the bulk mass of waste, ash and soil in the landfill is approximately 8100 tons/yr. Considering the three cases of generator scenarios (i.e., 10, 5, and one generator) and assuming that one generator disposes, on the average, 550 tons of incinerator ash annually, the dilution factors would be approximately as follows:

Scenario	Dilution Factor
10 Generators	2:3
5 Generators	1:3
1 Generator	1:15

These dilution factors are nearly 3 times less than those calculated for the other (thicker) landfill category. Thus, radionuclide concentrations would be nearly three times higher for each corresponding scenario. The anticipated concentrations and the corresponding doses were calculated for each scenario and are presented in Table 7.

(c) Influence of Landfill Cover On RESRAD Dose Assessment Results

In the above RESRAD dose analysis, a 0.6 m thick cover of uncontaminated soil was assumed to be placed on the top of the landfill. Additional RESRAD runs were conducted, assuming no cover is placed at the top of the landfill. The results (Appendix E) indicate that the DSR values for beta emitters either remain the same or increase slightly. On the other hand, for gamma emitting radionuclides, the DSR increased by a factor of several orders of magnitude. For example, the DSR for Cs-137 for a landfill with 0.6 m thick cover was 0.15 (mrem/yr)/(pCi/g), whereas the DSR value for the same radionuclide, using a landfill scenario without a cover, was 2.55 (mrem/yr)/(pCi/g). Table 8 presents a comparison of DSR values for the 25 radionuclides for landfill with a 0.6 m thick cover and landfill without a cover. The total peak dose reached at 7.38 years. For a landfill without cover the peak dose was 339.8 mrem/yr, and the peak dose was reached at the same time (7.38 years). It is apparent from Table 8 that the additional 22.5 mrem/yr was due to excess direct gamma dose resulting from the lack of a cover at the surface of the landfill. This additional gamma dose also resulted from more active air and surface water erosion of the upper surface of the landfill.

6.2 Results of IMPACTS-BRC Analysis

NRC staff estimated the potential doses from the transportation of incinerator ash (550 ton/yr), containing 39 radionuclides, from the ash generator location to a landfill at an average haul distance of 10 miles. All radionuclides considered in this analysis are listed in section 5.3. Input parameters are listed in Tables 2 & 3. Assumptions and scenarios are discussed in sections 5 and 6. Details of the IMPACTS-BRC dose assessment results are given in Appendix F. The occupational and population doses for the 1-Generator Scenario (i.e., total ash mass 550 ton/year) resulting from transportation of incinerator ash are given in Table 9 and summarized below.

1. The projected maximum TEDE to a maximally exposed individual worker (e.g., workers involved in transporting the incinerator ash) from hauling all of the incinerator ash generated in a year by a single facility is 26.6 mrem/yr. The contribution of each radionuclide to the transportation dose is presented in Table 9. The major radionuclides contributing to the dose (mrem/yr), in descending order, are: Tc-99m (5.5), Mn-54 (2.2), Nb-95 (2.1), Sr-85 (1.9), Co-58 (1.7), Ag-108 (1.5), Nb-94 (1.4), Ru-103 (1.4), Cr-51 (1.3), Na-22 (1.2) and Sb-125 (1.2).

2. If two workers are assumed to accompany each shipment of ash for disposal (NRC, 1984, 1986), the total transportation-occupational dose was 0.05 person-rem/yr.

3. The population dose due to ash transportation was estimated to be 0.13 person-rem/yr. The population density along the transportation route (10 miles) was assumed to be 2,280 person/mi^2 (NRC, 1984, 1986).

4. Most of the occupational dose is due to direct gamma exposure. Because this dose was based on the radiological inventory in the ash produced by one generator, the total occupational dose will be much greater if the same workers also dispose of incinerator ash produced by more than one generator. For example, if workers transport and dispose of the ash produced by ten generators (5,550 tons/yr), and assuming that workers spend 10 times as much time as in the one generator case the occupational dose would be 10 times greater than the occupational dose derived in the one-generator

times greater than the occupational dose derived in the one-generator scenario. Naturally, the total occupational dose will depend on the time avaiable to the worker (a maximum of 2,000 hours per year) to carry out the transport and disposal activities associated with the incinerator ash.

7. DISCUSSION OF RESULTS

The results of this generic dose analysis indicate that certain radionuclides, if present in incinerator ash at concentration levels equivalent to the limits in 10 CFR Part 20, Appendix B, Table II, Column 2, could cause an individual member of the critical population group to receive a dose that is a large fraction of the 100 mrem/yr public dose limit in 10 CFR Part 20, assuming human intrusion into the landfill. These radionuclides include: C-14, Cl-36, Tl-204, Ag-108m, Al-26, Tc-99, Nb-94, H-3, and I-129. There could also be other radionuclides of concern that were not included among the suite of radionuclides evaluated in this dose assessment, due to nature of the generic assessment, availability of information, and computer code limitation. The current analysis did not account for all the radionuclides of the elements with atomic numbers 1-83. Selection of radionuclides in the current assessment was based on an evaluation of limited available information (e.g., from responses received from 9 licensees, and from a generic literature analysis of radiological characteristics of incinerator ash) and from review of the NRC data base pertaining to NRC licensees that are authorized to incinerate waste.

In addition to the assumed characteristics of potential exposure to potential future residents of the landfill site, the projected doses associated with each radionuclide depend to a large extent on one or more of the following three factors:

1. The radionuclide concentration in the ash;

2. The total volume of the ash disposed at the landfill; and

3. The type of landfill and method of its disposal operation.

4. Human intrusion into the landfill, including farming of the landfill.

The estimated dose from the disposal of 550 tons/yr of incinerator ash containing C-14 at a concentration of 30 pCi/g (i.e., 10 CFR part 20, Appendix B, value) in a typical landfill (25 acres) would be about 16.7 mrem/yr. This dose could be increased by a factor of 20, or more, if the volume of contaminated ash increased to 5,550 tons/yr (10 generator scenario) while the concentration of the ash remained constant, and if the landfill thickness decreased to 2.5 m. Thus, the estimated C-14 dose under such conditions could be as high as 434 mrem/yr. Nevertheless, such elevated doses are highly unlikely because of the low probability that assumed characteristics and doses when multiple generators send ash to the same landfill.

The remaining radionuclides pose lower dose impacts. On the other hand, under certain conditions (e.g., more than one generator disposing in the same landfill, and landfill capacity much less than the typical landfill discussed in section 4), the combined dose from radionuclides in the ash could approach the dose limit in 10 CFR 20.1301. For example, the dose from Cl-36 using the one-generator scenario could be as low as 4.2 mrem/yr, whereas for the 10-generator scenario it could reach 42 mrem/yr, assuming all licensed facilities released the same volume of ash and all the ash contained Cl-36 at the Appendix B concentrations. This dose could also increase with less dilution of the ash in the landfill due to mixing with ordinary waste. Comparisons of doses for all 25 radionuclides employed in this generic assessment under different disposal conditions are given in Tables 5, 6, and 7.

NRC staff analyzed the sources and environmental routes for exposure to the maximally exposed individuals of the critical population group. As was discussed earlier in section 2, the doses were calculated using the RESRAD family farm scenario. The major exposure routes vary from one radionuclide to another. From our analysis of the dose data presented in Appendices C, D, and E, it is apparent that the water-dependent environmental pathways are the most predominant routes of individual exposure. Specifically, the ingestion of drinking water, fish, meat, and milk are the major pathways that transport radionuclides in the ash to humans. The major environmental routes for the transfer of C-14 to humans were the ingestion of contaminated drinking water and fish. Conversely, the opposite trend was observed for Cl-36, which could reach humans through multiple routes from water-independent pathways such as ingestion of contaminated plants, meat, and milk as well as from water dependent pathways such as ingestion of contaminated drinking water, meat, and milk associated with use of contaminated groundwater.

Most of the remaining radionuclides showed similar dose distributions between the two extremes of C-14 and Cl-36. In other words, water-dependent pathways were the major environmental routes of exposure and ingestion of contaminated drinking water, fish, meat and milk were the major sub-routes (pathways) causing the dose impacts. For tritium (H-3), the case was different. Nearly 100% of the dose came from the ingestion of contaminated drinking water. Table 10 shows the distribution of the dose (dose fraction) among the different environmental pathways. It is interesting to note that direct gamma exposure was nearly negligible for the scenario which assumes a cover thickness of 0.6 m on the top of the landfill. Considering the scenario for the same landfill without a cover, the direct gamma (ground) contribution became significant, accounting for up to 20% of the total dose.

Although the dose estimates may approach a significant fraction of the public dose limit in Part 20, the conservative assumptions made in this analysis probably resulted in overestimating the doses that might actually occur at the landfills. One of the most

Although the dose estimates may approach a significant fraction of the public dose limit in Part 20, the conservative assumptions made in this analysis probably resulted in overestimating the doses that might actually occur at the landfills. One of the most conservative assumptions made in this analysis was the location of the intruder well. In most cases the intruder would withdraw water from public well at a far distance from the site, rather from the well 100 m away from the center of the landfill facility. In addition, it is a remote possibility that future residents would raise crops and livestock on a municipal waste landfill site. Further, there are, and will likely continue to be, institutional controls placed on the landfill sites, which should be somewhat effective in preventing the public from having access to the site over the next several decades. If, however, these controls fail, an individual drilling a well into a municipal waste landfill would most likely realize that this was a waste disposal site and would discontinue drilling. The concentrations of radionuclides in groundwater at a well off-site would be further decreased due to dispersion and retardation that would occur between the cell and the well.

Therefore, potential doses to off-site individuals would be expected to be much less than the estimated doses in this assessment. In addition, anyone digging into the waste would probably recognize that the site was previously used for municipal waste disposal and would move away from the site. The analysis also did not consider the protective effects of any liners, leachate collection systems, or engineered barriers that are known to retard and reduce groundwater contamination. Although these retardation factors cannot be assumed to remain intact indefinitely, there will be some retardation and reduction in the migration rate of radiological contamination. Since no credit was given for any type of barrier or collection system in this analysis, the estimated doses are likely to be overestimated. Further, the municipal waste itself may be somewhat effective in retarding the migration of radionuclides into groundwater beneath the landfill.

The projected dose associated with the transportation of the ash (maximum individual dose of 26.6 mrem/yr to a hauler) may also account for a significant fraction of the public dose for individual members of the public, particularly if the volume of ash increased and the same workers were employed to transport the ash. The major radionuclide contributing to the transportation dose is Tc-99m. Typically, this radionuclide is not disposed directly in the landfill. Instead, most licensees store the waste prior to combustion and the ash after combustion for decay (at least for 60 hours). Due to the short half-life (6 hours) of Tc-99m, the actual transportation doses would be expected to be much less than the value calculated in this assessment. Other gamma-emitting radionuclides are also of relatively short half-lives. Thus, the total transportation dose could be actually far less than anticipated in this assessment. This expectation is partially confirmed by the anecdotal information collected by NRC that no incidents have occurred where incinerator ash from licensed facilities has been rejected by solid waste management facilities because of excessive radiation levels.

8. CONCLUSIONS & RECOMMENDATIONS

8.1 Conclusions

The current generic dose assessment for the disposal of incinerator ash as ordinary waste in a municipal landfill indicates that, in general, the existing NRC staff practice of releasing ash at the Appendix B concentrations provides adequate protection of members of the public who may be exposed to the ash after disposal. However, because this conclusion is based on a variety of generic assumptions, licensees and NRC may need to consider the potential radiological risk of such disposal on human exposure, depending on site conditions for a limited suite of radionuclides that may be present in the ash. Specifically, NRC staff reached the following generic conclusions:

1. Certain radionuclides in the incinerator ash may represent a significant radiological risk to the public under the assumptions made in this assessment. Associated doses may approach the public dose limit in 10 CFR 20.1301. These radionuclides include: C-14, Cl-36, Tl-204, Ag-108m, Al-26, Tc-99, Nb-94, H-3, and I-129. They may also include P-32, S-35, Tc-99m, Fe-59, and Ca-45 depending upon disposal and exposure characteristics.

2. In addition to the assumed conditions of exposure (i.e., exposure scenario), projected doses associated with the disposal of the incinerator ash will depend significantly on the total volume of the ash disposed, the concentration of the radionuclide in the ash, and the method of disposal (e.g., depth) and annual capacity of the landfill.

3. Most of the anticipated dose from the ash results from the water dependent environmental pathways, specifically including ingestion of contaminated drinking water and contaminated food such as meat, fish, and milk. Projected doses would be expected to be far less where these pathways are not viable or likely.

4. Occupational radiological impacts due to transportation of the incinerator ash from the generator location to the landfill could be significant if no time were allowed for decay of the waste prior to and after incineration. However, radioactive decay is generally sufficient to quickly and significantly reduce any direct gamma exposures to workers and members of the public from the incinerator ash.

8.2 Recommendations

In order to control the potential risk and radiological impacts to the public in accordance with NRC's radiation protection requirements in 10 CFR Part 20, NRC staff recommends the following approach to evaluating the acceptability of incinerator ash disposal in solid waste landfills:

1. Allow the disposal of incinerator ash, containing radionuclides other than those listed below, in landfills provided their concentrations remain at or below the values in Table II, Column 2 of 10 CFR, Part 20, Appendix B (converting μCi/ml to μCi/g and assuming that 1 ml of water is equivalent to 1 g of ash). In applying the Appendix B values, the sum of the fractions approach should be employed to ensure that total dose from all radionuclides remains suitably low.

2. For the following radionuclides, the permissible concentrations in the ash should be no greater than one-tenth (1/10) of the Appendix B values, unless site-specific radiological analysis demonstrates that ash with higher concentrations will not result in doses that are a significant fraction of the public dose limit in 10 CFR 20.1301 when the ash is disposal of in a solid waste landfill. These radionuclides include: C-14, Cl-36, Tl-204, Ag-108m, Al-26, Tc-99, Nb-94, H-3, and I-129.

   Although the calculations in this dose assessment are reasonably conservative, the NRC staff proposes that the release limits in incinerator ash be reduced by an order of magnitude (i.e., 10 times) for these radionuclides to provide confidence that the dose to a maximally exposed individual who may reside on the landfill at some time in the future will remain a small fraction of the public dose limit. Reasonable efforts should be taken by the licensees to ensure that the concentrations of these radionuclides in the ash are as low as is reasonably achievable in accordance with Part 20.

3. In addition, licensees should demonstrate that disposal of ash containing P-32, S-35, Tc-99m, Fe-59, or Ca-45 in solid waste landfills will not result in doses that are a significant fraction of the public dose limit in 10 CFR 20.1301 when the ash is disposal of in a solid waste landfill. This is necessary because disposal of these radionuclides and the associated potential doses was not assessed by the NRC staff in this analysis.

4. When items 1-3 appear too restrictive based on ash and environmental characteristics, licensees should be allowed to develop facility specific release limits on the basis of site-specific dose assessments. The calculations and assumptions in this generic assessment may be used, and the results maybe compared with the facility specific assessments to determine whether

alternative approaches are justified. The assessment should also evaluate the maximum volume of incinerator ash that can be disposed in the landfill based on the physical characteristics of the landfill and the mode of disposal operation. Such assessments should also consider the likelihood and potential dose consequences of multiple generators disposing of the ash in the same solid waste landfill.

5. Many of the gamma-emitting radionuclides that may be contained in the ash readily decay within days or weeks. Licensees should be encouraged to store incinerator ash to allow for decay of certain gamma-emitting radionuclides in order to reduce worker exposure.

6. NRC should document the above approach and analysis in the form of a staff technical position as a draft guidance. The guidance would identify the approach recommended above as an acceptable means for demonstrating compliance with 10 CFR 20.2002 for disposal of incinerator ash containing radioactive material as ordinary municipal waste. The draft guidance should be circulated to other Federal and State agencies, Conference of Radiation Control Program Directors, solid waste management authorities, national and regional solid waste management associations, licensees, professional societies, and other interested parties for comments. After review, the technical position should be revised as appropriate and distributed to licensees and other concerned parties.

7. Disposal of incinerator ash should be coordinated between NRC, State authorities, licensees, and landfill owners, to ensure solid waste operators are properly informed that the incinerator ash may contain elevated levels of radionuclides. In addition, landfill operators should be discouraged, as part of this notification process, from concentrating all of the incinerator ash in an isolated portion of the disposal cell to provide added assurances that the potential future doses will remain very low and reduce any potential worker exposures.

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TABLE 1

Important Site Parameters Used In RESRAD Model For The Typical Landfill

PARAMETER	VALUE AND UNIT
- Length Parallel to Aquifer	100.00 m
- Cover Depth	0.6m
- Density of Contaminated Zone	0.60 g/cm^3
- Cont. Zone porosity	0.40
- Cont. Zone Effective Porosity	0.20
- Cont. Zone Hydraulic Conductivity	10.00 m/yr
- Precipitation Rate	1.00 m/yr
- Irrigation Rate	0.2 m/yr
- Runoff Coefficient	0.20
- Watershed Area	1.0 km^2
- Unsat/Uncont. Zone Hydraulic Conductivity	10.00 m/yr
- Density of Saturated Zone	1.6 g/cm^3
- Sat. Zone Total Porosity	0.4
- Sat. Zone Effective Porosity	0.20
- Sat. Zone Hydraulic Conductivity	100 m/yr
- Sat. Zone Hydraulic Gradient	0.02
- Drinking Water Intake	730 l/yr
- Drinking Water Fraction	1
- Livestock Water Fraction	1
- Irrigation Fraction From a Well	1
- Water Table Drop Rate	0 m/yr

TABLE 2

Important Parameters For Treatment/Disposal Options And Waste Stream Characteristics for Typical Landfill Using IMPACTS-BRC Model (TAPE5.DAT)

PARAMETER	VALUE AND UNIT
- Region Index	NE
- Data Index	Def.
- Disposal Facility Index	Sanitary Landfill
- No. of Waste Streams	1
- Facility Population Index	Urban
- Disposal Facility Life	20
- Institutional Control	30
- Leachate Collection System	No, Yes
- Mass of Waste Stream (Ash only from one generator)	550 tons
- Density of the Waste Stream (Ash only)	1.00 g/cm^3
- Volume of Waste Stream (Ash Only)	550 m^3
- Mass of Waste Stream (Ash + Ordinary Waste)	360,000 m^3
- Density of Waste Stream (Ash + Ordinary Waste)	0.60 g/cm^3
- Volume of the Waste Stream (Ash + Ordinary Waste)	600,000 m^3
- Dispersibility	Severe
- Processing Index	Ordinary Waste
- First Packaging Index	Not Packaged
- Processing Index	Disposal Only
- Distribution Index	1
- No. of Disposal Facilities	1
- Weight Percentage of Combustible materials	Def.
- Weight Percentage of Metal Materials	Def.
- Distribution Index 2 (% of vehicle load that contain ash)	100%
- Distribution Index 3 (No. of processing facilities)	1

TABLE 2

Important Parameters For Treatment/Disposal Options And Waste Stream Characteristics for Typical Landfill Using IMPACTS-BRC Model (TAPE5.DAT)

PARAMETER	VALUE AND UNIT
- Region Index	NE
- Data Index	Def.
- Disposal Facility Index	Sanitary Landfill
- No. of Waste Streams	1
- Facility Population Index	Urban
- Disposal Facility Life	20
- Institutional Control	30
- Leachate Collection System	No, Yes
- Mass of Waste Stream (Ash only from one generator)	550 tons
- Density of the Waste Stream (Ash only)	1.00 g/cm^3
- Volume of Waste Stream (Ash Only)	550 m^3
- Mass of Waste Stream (Ash + Ordinary Waste)	360,000 m^3
- Density of Waste Stream (Ash + Ordinary Waste)	0.60 g/cm^3
- Volume of the Waste Stream (Ash + Ordinary Waste)	600,000 m^3
- Dispersibility	Severe
- Processing Index	Ordinary Waste
- First Packaging Index	Not Packaged
- Processing Index	Disposal Only
- Distribution Index	1
- No. of Disposal Facilities	1
- Weight Percentage of Combustible materials	Def.
- Weight Percentage of Metal Materials	Def.
- Distribution Index 2 (% of vehicle load that contain ash)	100%
- Distribution Index 3 (No. of processing facilities)	1

TABLE 3

Important Site Environmental Parameters Used In IMPACTS-BRC Model For The Typical Landfill (TAPE2.DAT)

PARAMETER	VALUE AND UNIT
- Average Infiltration Rate	7.4E-02 (m/yr)
- Contact Time Between Waste and Percolation	1 (100%)
- Incremental GW Travel Time Between Sectors of Facility (Landfill is assumed to have 10 Sectors)	34 yr
- GW Travel Time From Facility to Intruder Well	1.8E+01 m/yr
- GW Travel Time From Facility to Population Well	5.0E+02 m/yr
- GW Travel Time From Facility to Surface Water(Stream)	1.0E+03 m/Yr
- Soil-To-Air Transfer Factor for Intruder Construction (the dust particles generated by various mechanical forces that are available for inhalation)	9.18E-02
- Soil-To-Air Transfer Factor for Intruder Agriculture (natural suspension from waste/soil mixture)	2.96E-011
- GW Dilution Factor for Intruder Well (pumping rate)	7.7E+03 m^3/yr
- GW Dilution Factor for Population Well	2.0E+05 m^3/yr
- GW Dilution Factor for Surface Water (a stream flowing cf/sec)	4.5E+06 m^3/yr
- Population Factor for Airborne Exposed Waste (Operations/Intrusion)	5.05E-10 person-yr/m^3
- Population Factor for Airborne Exposed Waste (Erosion)	1.51E-09 person-yr/m^3
- Site Selection factor for Waterborne Waste (Erosion/Intrusion)	1.11×10^{-7} yr/m^3
- Population Density Around Transportation Route	2.28E+03 persons/$mile^2$
- Dose Factor for Transportation Population (lower boundary for the exposure distance is 30 ft for NE and SE regions and 100 ft for the SW region)	7.06E-05 (mi^2/ft^2)
- Average Wind Speed at Site	4.61E+0 (m/sec)

TABLE 3 (Continued)

PARAMETER	VALUE AND UNIT
- Accident Atmospheric Dispersion Factor (individual is located 100 m from a ground level release that has a duration of 1 second Accident happens once/yr)	9.68E-11 yr/m^3
- Dust Mobilization rate due to ambient wind conditions	5.53E-07 g/m^2-sec
- Dust Mobilization rate for erosion Exposed Waste	5.53E-07 g/m^2-sec
- Dust Mobilization rate for Intruder Exposed Waste	2.03E-06 g/m^2.sec
- Soil Retardation Index	(NUREG/CR-3585)
- Transportation Distance to Facility	10 mi
- Transportation velocity to facility	20 mi/hr
- Annual Volume of Non-BRC Waste	2.54E+04 m^3/yr
- Off-Site Atmospheric Dispersion Factor (Elevated release of 200 ft, individuals at a distance of 300 m)	9.1E-01 yr/m^3
- Exposure Duration Factor for Incineration (wind blown in one direction 1/3 of the time individuals always located at the center of the plume)	3.33E-01
- Average density of the Waste During Shipment and Incineration.	1.00 g/cm^3
- Annual Volume of Non-BRC Waste Disposed	2.96E+04 m^3
- Offsite Atmospheric Dispersion Factor (Ground Level release)	9.10E-11 yr/m^3
- Exposure Duration Factor for Disposal Operation (fraction of the year the individual is considered to be exposed to suspended dust)	3.33E-01
- Avg. Density of the Waste During Disposal	0.59 g/cm^3
- Waste to Air Transfer factor for Incinerator operation (Low, Med, and High)	1.0E-10
- Waste to Air Transfer factor for Disposal Operations (Low, Med, and High)	2.0E-10
- Daily Exposed Area of the Disposal Facility (for offsite releases, equipment operation at landfill, unpackaged waste, and personnel)	86 m^2

TABLE 3 (Continued)

PARAMETER	VALUE AND UNIT
- Cover Mixing Efficiency (fraction of volume that consist of soil/water mixture)	0.59
- Waste Emplacement Efficiency (Ratio of volume of waste disposed to the total volume of available space)	0.8
- Volumetric Disposal Efficiency	7.31 m^3/m^2
- Erosion delay Time	1.0E+03 yr
- On-Site Incinerator Weight reduction factor	2
- On-Site Operational Dust Loading factor	5.0E-05 g/m^3

TABLE 4

Results of RESRAD Dose Calculations For Each Individual Radionuclide Assuming Five Generators Scenario

Nuclide	DSR(i,tmax)*	Pt.20**	Conc. L.Fill***	Dose****
Ag-108m	7.60E+00	9.00	0.90	6.84E+00
Ag-110m	6.56E-03	6.00	0.60	4.00E-03
Al-26	8.31E+00	6.00	0.60	4.99E+00
C-14	2.77E+01	30.00	3.00	8.31E+01
Cd-109	1.34E-01	6.00	0.60	8.00E-02
Ce-144	2.09E-06	3.00	0.30	6.30E-07
Cl-36	1.05E+01	20.00	2.00	2.10E+01
Co-57	5.54E-06	60.00	6.00	3.32E-05
Co-60	5.75E-02	3.00	0.30	1.73E-02
Cs-134	2.20E-02	0.90	0.09	1.98E-03
Cs-137	1.49E-01	1.00	0.10	1.49E-02
Fe-55	5.13E-06	100.00	10.00	5.13E-05
Gd-153	4.00E-08	60.00	6.00	2.40E-07
H-3	1.95E-02	1000.00	100.00	1.95E+00
I-129	2.54E+02	0.200	0.02	5.08E+00
K-40	3.59E-01	4.00	0.40	1.44E-01
Mn-54	7.45E-05	30.00	3.00	2.24E-04
Na-22	1.83E-02	6.00	0.6	1.10E-02
Nb-94	2.80E+00	10.00	1.00	2.80E+00
Ni-59	7.15E-04	300.00	30.00	2.15E-02
Ni-63	1.84E-03	100.00	10.00	1.84E-02
Sr-90	1.54E+00	0.500	0.05	7.70E-02
Tc-99	7.54E-01	60.00	6.00	4.52E+00
Tl-204	2.87E+00	20.00	2.00	5.74E+00
Zn-65	1.50E-02	5.00	0.50	7.50E-03

* Dose/Source ratio {(mrem/yr) per 1 pCi/g} of radionuclide present in the ash/municipal landfill mixture. Dose is the maximum in 10,000 years.

** 10 CFR Part 20 [20.1001-20.2402], Table 2, Column 2, Effluent Concentration Limits in Water (μCi/ml).

*** Calculated Concentration of radionuclide in the landfill assuming five ash generators are disposing in the same landfill at an annual rate of 550 m^3 each.

**** RESRAD calculated dose (mrem/yr) for the radionuclide in the landfill.

TABLE 5

Results of RESRAD Dose Calculations For Each Individual Radionuclide Assuming Three Scenarios: 10-Generator, 5-Generator, and one-Generator (Each Generator Is Assumed To Dispose Annually 550 m³ Of Ash)

Nuclide	Dose 1*	Dose 2**	Dose 3***
Ag-108m	1.34E+01	6.84E+00	1.34E+00
Ag-110m	8.00E-03	4.00E-03	8.00E-04
Al-26	1.00E+01	4.99E+00	1.00E+00
C-14	1.67E+02	8.31E+01	1.67E+01
Cd-109	1.60E-01	8.00E-02	1.60E-02
Ce-144	1.26E-06	6.30E-07	1.26E-07
Cl-36	4.20E+01	2.10E+01	4.20E+00
Co-57	6.63E-05	3.32E-05	6.63E-06
Co-60	3.45E-02	1.73E-02	3.45E-03
Cs-134	3.96E-03	1.98E-03	3.96E-04
Cs-137	2.98E-02	1.49E-02	2.98E-03
Fe-55	1.02E-04	5.13E-05	1.02E-05
Gd-153	4.80E-07	2.40E-07	4.80E-08
H-3	3.90E+00	1.95E+00	3.90E-01
I-129	1.02E+01	5.08E+00	1.02E+00
K-40	2.88E-01	1.44E-01	2.88E-02
Mn-54	4.48E-04	2.24E-04	4.48E-05
Na-22	2.20E-02	1.10E-02	2.20E-03
Nb-94	5.60E+00	2.80E+00	5.60E-01
Ni-59	4.30E-02	2.15E-02	4.30E-03
Ni-63	3.68E-02	1.84E-02	3.68E-03
Sr-90	1.54E-01	7.70E-02	1.54E-02
Tc-99	9.94E-00	4.52E+00	9.94E-01
Tl-204	1.15E+01	5.74E+00	1.15E+00
Zn-65	1.50E-02	7.50E-03	1.50E-03

* Total annual dose (TEDE) in mrem/yr for scenario #1 (10 generators).

** Total annual dose (TEDE) in mrem/yr for scenario #2 (5 generators).

*** Total annual dose (TEDE) in mrem/yr for scenario #3 (one generator).

Table 6

Comparison Of DSR Values For The Landfill Categories

Radionuclide	DSR for 8 m Landfill	DSR for 2.5 m Landfill
Ag-108m	7.60E+00	6.11E+00
Ag-110m	6.56E-03	4.36E-02
Al-26	8.31E+00	6.62E+00
C-14	2.77E+01	2.17E+01
Cd-109	1.34E-01	3.34E-01
Ce-144	2.09E-06	1.33E-05
Cl-36	1.05E+01	3.96E+00
Co-57	5.54E-06	3.90E-05
Co-60	5.75E-02	7.50E-02
Cs-134	2.20E-02	4.41E-02
Cs-137	1.49E-01	1.55E-01
Fe-55	5.13E-06	8.74E-06
Gd-153	4.00E-08	3.55E-07
H-3	1.95E-02	1.71E-01
I-129	2.54E+02	1.11E+02
K-40	3.59E-01	3.02E-01
Mn-54	7.45E-05	4.01E-04
Na-22	1.83E-02	2.89E+02
Nb-94	2.80E+00	2.23E+00
Ni-59	7.15E-04	7.10E-04
Ni-63	1.84E-03	1.85E-03
Sr-90	1.54E+00	1.56E+00
Tc-99	7.54E-01	5.68E-01
Tl-204	2.87E+00	3.36E+00
Zn-65	1.50E-02	1.05E-01

Table 7
Radionuclide Concentration and Corresponding Doses for Disposal In a Landfill With Waste Thickness Of 2.5 m (Concentrations are in pCi/g and doses are in mrem/y)

Nuclide	10 Generators		5 Generators		One Generator	
	Conc.	Dose	Conc.	Dose	Conc	Dose
Ag-108m	6.0	36.65	3.0	18.32	0.6	3.7
Ag-110m	4.0	0.17	2.0	0.09	0.4	0.017
Al-26	4.0	26.46	2.0	13.23	0.4	2.65
C-14	20.0	434.40	10.0	217.20	2.0	43.44
Cd-109	4.0	1.34	2.0	0.66	0.4	0.13
Ce-144	2.0	2.6E-05	1.0	1.3E-05	0.2	2.6E-06
Cl-36	13.3	52.70	6.7	26.35	1.3	5.27
Co-57	40.0	0.002	20.0	0.001	4.0	0.0002
Co-60	2.0	0.15	1.0	0.08	0.2	0.015
Cs-134	0.6	0.026	0.3	0.013	0.06	0.003
Cs-137	0.7	0.11	0.4	0.055	0.07	0.01
Fe-55	66.7	5.8E-04	33.4	2.9E-04	6.7	5.8E-05
Gd-153	40.0	1.4E-05	20.0	7.0E-06	4.0	1.4E-06
H-3	666.7	11.40	333.4	5.57	66.7	1.14
I-129	0.1	11.10	0.05	5.51	0.01	1.11
K-40	2.7	0.82	1.4	0.41	0.3	0.08
Mn-54	20.0	0.008	10.0	0.004	2.0	0.0008
Na-22	4.0	0.12	2.0	0.06	0.4	0.012
Nb-94	6.7	14.92	3.4	7.46	0.67	1.50
Ni-59	200.0	0.14	100.0	0.07	20	0.014
Ni-63	66.7	0.12	33.4	0.06	6.7	0.012
Sr-90	0.3	0.47	0.2	0.24	0.03	0.05
Tc-99	40.0	22.72	20.0	11.36	4.0	2.27
Tl-204	13.3	97.85	6.7	48.93	1.3	9.78
Zn-65	3.3	0.35	1.7	0.17	0.3	0.035

Table 8

Comparison of DSR Values For Two Landfill With Cover (0.6 m thick) and Without Cover

Radionuclide	DSR Landfill With Cover	DSR for Landfill Without Cover
Ag-108m	7.60E+00	8.90E+00
Ag-110m	6.56E-03	7.82E-03
Al-26	8.31E+00	1.06E+01
C-14	2.77E+01	2.71E+01
Cd-109	1.34E-01	1.35E-01
Ce-144	2.09E-06	2.16E-04
Cl-36	1.05E+01	1.58E+01
Co-57	5.54E-06	2.62E-04
Co-60	5.75E-02	4.32E+00
Cs-134	2.20E-02	5.08E-01
Cs-137	1.49E-01	2.55E-00
Fe-55	5.13E-06	7.28E-05
Gd-153	4.00E-08	4.56E-05
H-3	1.95E-02	1.94E-02
I-129	2.54E+02	2.55E+02
K-40	3.59E-01	1.58E+00
Mn-54	7.45E-05	7.36E-03
Na-22	1.83E-02	1.03E+00
Nb-94	2.80E+00	4.43E+00
Ni-59	7.15E-04	2.32E-03
Ni-63	1.84E-03	5.94E-03
Sr-90	1.54E+00	4.55E+00
Tc-99	7.54E-01	8.48E-01
Tl-204	2.87E+00	2.87E+00
Zn-65	1.50E-02	1.54E-02

Table 9

Summary of IMPACTS-BRC Dose Calculations For Transportation of Incinerator Ash Using One-Generator Scenario.

Radionuclide	Dose To Maximum Individual (mrem/yr)
H-3	0.000E+00
C-14	0.000E+00
Na-22	1.184E+00
P-32	0.000E+00
S-35	0.000E+00
Cl-36	0.000E+00
Ca-45	0.000E+00
Cr-51	1.260E+00
Mn-54	2.212E+00
Fe-55	0.000E+00
Fe-59	1.033E+00
Co-57	2.994E-01
Co-58	1.745E+00
Co-60	6.554E-01
Ni-59	0.000E+00
Ni-63	0.000E+00
Zn-65	2.551E-01
Se-75	1.755E-01
Sr-85	1.921E+00
Sr-90	0.000E+00
Nb-94	1.415E+00
Nb-95	2.100E+00
Mo-99	2.681E-01
Tc-99	0.000E+00
Tc-99m	5.486E+00
Ru-103	1.367E+00
Ag-108	1.363E+00
Ag-110	1.504E+00
Cd-109	8.713E-04
Sn-113	6.963E-01

Table 9 (Continued)

Radionuclide	Dose To Maximum Individual (mrem/yr)
Sb-125	1.166E+00
I-125	7.795E-03
I-129	3.997E-05
I-131	3.289E-02
Cs-134	1.296E-01
Cs-137	5.710E-02
Ba-140	1.36-E-01
Ce-141	1.102E-01
Ce-144	1.054E-02

Table 10

Distribution of Dose Fractions Among Different Environmental Pathways For Radionuclides On the List of Concern

Nuclide	Water Independent Pathways			Water Dependent Pathways				
	Plant	Meat	Milk	Water	Fish	Plant	Meat	Milk
C-14	0.012	0.060	-	0.032	0.910	0.020	0.006	0.012
Tl-204	-	-	-	0.125	0.836	-	-	-
Cl-36	0.050	0.150	0.060	0.150	0.080	0.007	0.270	0.170
Ag-108m	-	-	-	0.420	0.030	0.030	0.030	0.490
Al-26	-	-	-	0.690	0.240	0.050	-	-
Tc-99	-	-	-	0.760	-	0.133	-	0.030
Nb-94	-	-	-	0.800	0.135	0.070	-	-
H-3	-	-	-	1.000	-	-	-	-
I-129	-	-	-	0.580	0.012	0.040	0.080	0.270

APPENDIX A

SUMMARY OF RESPONSES TO QUESTIONNAIRES ON INCINERATOR ASH RECEIVED FROM 8 NRC LICENSEES.

APPENDIX A

Responses To Questionnaires (Incinerator Ash and Landfill Sources): Incinerator Ash & Landfill Information Survey

Code No.	Amount of Ash	Type of Landfill	Method of Transport	Radio-nuclide & Activity Content	Ash Storage
1	3600 lbs (90 ft^3)	Regional Landfill	Card Boxes (5/month) of capacity 1.5 ft^3 lined with PE.	I-125, S-35, P-32, H-3, and C-14.	L PE bags inside a 55 gallon drum.
2	2-3 drums/yr of 55-gallon (225 lbs per drum)	All ash generated is stored for decay. If allowed, private landfill	Strong cardboard drums	Na-22, Sn-113	1-2 years of storage Radioactive ash is stored for decay (<90 days).
3	720 Yd^3 (550 m^3)/yr 862 LB/YD^3) or 620,642 lbs/yr or 281,517	County Owned Ash Landfill It covers 18 acres, and designed to hold 1,103,500 Yd^3 or 20,000Yd^3/y	Transported in 20 Yd^3 covered roll off container which are emptied in the landfill	Ash is surveyed at least once per week	Ash is not stored prior to shipment, when the roll off is filled, it is transported to the ash landfill once every 10 days.
4	180 Yd^3 of ash per yr. Only 0.5 Yd^3 of radioactive ash is generated per yr.	Landfill, 140 acres site which receives 7000 tons/week. The ash is handled as special waste, and placed in a special disposal landfill cell with clay top and bottom, double polyliner and leachate collection system..	The ash is placed in fiberboard 55 gallon containers.	No available data	The ash is accumulated in a containerized state for at most a month.
5	of ash (75 ft^3). The radioactive waste is commingled with other waste . The total ash output is 2,025 ft^3.	Municipal waste area landfill with onsite cover. The landfill is double-lined with Pe and equipped with leachate detection and collection system, as well as GW monitoring system. The landfill process 425,000 tons of waste/yr. The site is permitted for 44 acres and currently has 30 acres in operation	The ash is shipped to a landfill 5 times a year in a dedicated 20 ton containerized roll off compactor.	The weekly ash concentration is less than the MPC_w. Weekly grab samples are collected and analyzed by gamma spectroscopy , gross alpha and gross beta.	The ash is accumulated in a dedicated 20 ton pull-off containerized compactor. Ash is shipped for disposal every 2-3 months.

Code No.	Amount of Ash	Type of Landfill	Method of Transport	Radio-nuclide & Activity Content	Ash Storage
6	1000 lbs of ash is estimated to be generated based on volume reduction by a factor of 10. The amount of ash generated from incineration of animal tissues containing less than 0.05 μCi/g is approximately 2000 lbs/yr. Incineration is done with other waste.	Centralized transfer facility. Unable to identify which approved facility would be used for disposal of the incinerator ash.	The ash is shipped off-site in a covered 15 Yd^3 "roll-off" dumpster.	Ash is assayed for residual radioactivity. LS is used for monitoring H-3 and C-14. If necessary NaI is used to monitor gamma emitting radionuclides.	The ash is stored in a covered 15 Yd^3 "roll-off" dumpster. On average, the ash is accumulated for three to four months prior to shipment . There are three to four ash shipments per yr. The ash is no longer boxed.
7	2.6 tons of ash in 27.8 m^3 were disposed in 1992. H-3, C-14, P-32, S-35, Ca-45, Y-90, Cr-51, Mn-54, Zn-65, Se-75, Tc-99^m, I-125, I-131, Tl-201	The ash is disposed of in a County landfill. The size of the landfill is 207 acres and receives 505,000 tons of waste annually.	The ash is sent to the landfill in bulk using ordinary trash transportation vehicles	Ash is sampled and analyzed for gamma activity using low-energy HPGe coaxial detectors. Gross Beta analysis is done , however for more accuracy beta spectroscopy using LSC is performed. . They proposed to use modification of the TCLP procedure on the incinerator ash to reproduce a liquid fraction which upon filtration will be analyzed by LSC technique.	The ash is stored in dumpsters, after sampling and analysis to confirm ash concentrate-ions are acceptable (Part 20 limits) the ash is transferred to a general waste transportation vehicle and disposed of as ordinary refuse in the County landfill. The disposal is made weekly at a rate of 1-2 dumpsters per week.
8	500 lbs/d or 10-15 ft^3/d (5.7x10^6 g/yr)	Municipal Solid Waste Landfill. 18 acres of this site have been set to receive ash	Ash is stored in wheeled hoppers until cool for one day, then it is added to the other institutional waste in a 40 yard closed compactor-dumpster. On daily basis these dumpsters are hauled by private company to a regional incineration facility. All of the ash from this operation is shipped to the municipal landfill.	This licensee incinerated: 26,126 μCi of H-3; 4,004 μCi of C-14; 4μCi of Cr-51 (in 1991 it was 291μCi) 12 μCi of Co-58 (in 1991 it was 185 μCi); 1μCi of Sr-85; 5μCi of Nb-95 (in 1991 it was 67 μCi); 1μCi of Ce-141; and 7μCi of Gd-153 in 1991. The licensee assumed that all activity remains in the ash and 10 CFR Part 20 Table II limits are still satisfied.	The ash is collected in 55 gallon steel drums (DOT 6J or 7H) and as appropriate stored for 10 half-lives and disposed of as not radioactive or shipped for disposal as radioactive waste.

APPENDIX B

COMMON RADIONUCLIDES PRESENT IN INCINERATOR ASH (HALF-LIFE, TYPE OF EMISSION, AND ENERGIES)

APPENDIX B

Radionuclides Present In Incinerator Ash: Half-life, Type of Decay, and Energies (Shleien, 1992)

Radionuclide	Half life	Type of Emission & Energies
*H-3	1.23 E+1y	Betas (0.018601-0.005685)
*C-14	5.73 E+3y	Betas (0.15648-0.049470)
*Na-22	2.6 E+00y	Positrons (0.54520-0.21554) Electrons (0.000820) Gammas& X-Rays (1.2745
*P-32	1.43E+01d	Betas(1.7104-0.6949)
*S-35	8.74E+01d	Betas (0.16747-0.04883)
*Cl-36	3.01E+5y	Betas (0.700-0.900)
*Ca-45	1.63E+02d	Betas (0.100-0.300)
*Cr-51	2.77E+01d	Electrons (0.0043, 0.0005) Gamma (0.0.0049, 0.32, 0.0054)
Mn-54	3.12E+02d	Electrons (0.0048, 0.0005) Gamma 0.835, 0.006)
Co-57	2.71E+02d	Electrons(0.00067, 0.006) Gammas (0.122, 0.136, 0.0064)
Co-58	7.1E+01d	Positrons (0.47504-0.2012) Electrons (0.0006, 0.0056) Gammas (0.81, 0.511, 0.006)
*Co-60	5.27E+00y	Betas (0.318-0.096) Gammas (1.332, 1.173)
Fe-55	2.7 E+01y	Electrons (0.0006, 0.005) Gammas (0.0058, 0.0065)
Fe-59	4.46E+01d	Betas (0.081, 0.149, 0.614) Gammas (1.099, 1.29, 0.192)
Ni-59	7.5EE+04y	Electrons (0.00075, 0.006) Gammas (0.0069, 0.0076)
Ni-63	1.00E+02y	Betas (0.06587-0.017)
*Zn-65	2.44E+02d	Positrons (0.33-0.143) Electrons(0.0009, 0.007) Gammas (1.115, 0.008, 0.511)
Se-75	1.19E+02d	Electrons (0.009-0.267) Gammas (0.264, 0.28, 0.136

APPENDIX B (Continued)

Radionuclide	Half life	Type of Emission & Energies
*Sr-85	6.5E+01d	Electrons (0.0016, 0.011)
		Gammas (0.513, 0.0133, 0.015)
*Sr-90	2.86E+01y	Betas (0.546-0.196)
*Nb-95m	8.66E+01h	Betas (o.335, 0.43, 1.16)
		Electrons (0.2167, 0.233, 0.014, 0.002)
		Gammas (0.235, 0.0167, 0.0165)
*Tc-99m	6.02E+00h	Electrons (0.0016, 0.002)
		Gammas (0.1405, 0.018)
*Tc-99	2.13E+05y	Betas (0.293-0.085)
		Gammas(0.089)
Ag-110m	2.5E+02d	Electrons (0.0005-0.631)
		Betas (0.08-0.53)
		Gammas (0.656, 0.937, 1.38)
Ru-103	3.94E+01d	Electrons (0.0023-0.474)
		Betas (0.113-0.723)
		Gammas (0.497, 0.61)
Ru-106	3.68E+02d	Betas (0.0394-0.01)
*Sn-113	1.15E+01d	Gamma(0.255)
I-125	6.0E+01d	Electrons (0.3-0.03)
		Gamma (0.319, 0.31)
*I-129	1.57 E+7y	Electrons (0.034-0.038)
		Beta (0.152-0.041)
		Gamma (0.029-0.033)
I-131	8.04 E+00d	Electrons (0.04-0.36)
		Betas (0.61-0.24)
		Gamma (0.364,0.64)
Sb-125	2.77E+0y	Electrons (0.003-0.0145)
		Beta (0.938-0.347)
		Gamma (0.027, 0.427, 0.600)
*Cs-137	3.17E+01	Gamma, 0.664, 89.98%
*Gd-153	2.41E+02d	Gamma (0.097, 0.103)

* Radionuclides frequently present in incinerator ash

APPENDIX B (Continued)

Radionuclide	Half life	Type of Emission & Energies
*Sr-85	6.5E+01d	Electrons (0.0016, 0.011) Gammas (0.513, 0.0133, 0.015)
*Sr-90	2.86E+01y	Betas (0.546-0.196)
*Nb-95m	8.66E+01h	Betas (o.335, 0.43, 1.16) Electrons (0.2167, 0.233, 0.014, 0.002) Gammas (0.235, 0.0167, 0.0165)
*Tc-99m	6.02E+00h	Electrons (0.0016, 0.002) Gammas (0.1405, 0.018)
*Tc-99	2.13E+05y	Betas (0.293-0.085) Gammas(0.089)
Ag-110m	2.5E+02d	Electrons (0.0005-0.631) Betas (0.08-0.53) Gammas (0.656, 0.937, 1.38)
Ru-103	3.94E+01d	Electrons (0.0023-0.474) Betas (0.113-0.723) Gammas (0.497, 0.61)
Ru-106	3.68E+02d	Betas (0.0394-0.01)
*Sn-113	1.15E+01d	Gamma(0.255)
I-125	6.0E+01d	Electrons (0.3-0.03) Gamma (0.319, 0.31)
*I-129	1.57 E+7y	Electrons (0.034-0.038) Beta (0.152-0.041) Gamma (0.029-0.033)
I-131	8.04 E+00d	Electrons (0.04-0.36) Betas (0.61-0.24) Gamma (0.364,0.64)
Sb-125	2.77E+0y	Electrons (0.003-0.0145) Beta (0.938-0.347) Gamma (0.027, 0.427, 0.600)
*Cs-137	3.17E+01	Gamma, 0.664, 89.98%
*Gd-153	2.41E+02d	Gamma (0.097, 0.103)

* Radionuclides frequently present in incinerator ash