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Authorized Limits for Disposal of PCB Capacitors from Buildings 361 and 391 at Argonne National Laboratory, Argonne, Illinois

Version 2

Environmental Science Division

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by
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TABLES

ACRONYM LIST

ALARA	as low as reasonably achievable
ANSI	American National Standards Institute
ARDC	airborne respirable dust concentration
Co-57	cobalt 57
Co-60	cobalt 60
Cs-137	cesium 137
D&D	decontamination and decommissioning
DCF	dose conversion factor
DOE	U.S. Department of Energy
EPA	U.S. Environmental Protection Agency
HPS	Health Physics Society
IAEA	International Atomic Energy Agency
IPNS	Intense Pulsed Neutron Source
K-40	potassium 40
LLD	lowest limits of detection
linac	linear accelerator
LLRW	low-level radioactive waste
Mn-54	manganese 54
Na-22	sodium 22
NRC	U.S. Nuclear Regulatory Commission
Pb-212	lead 212
Pb-214	lead 214
Rn-220	radon 220
Rn-222	radon 222
RCRA	Resource Conservation and Recovery Act of 1976
RCS	rapid cycling synchrotron
RPF	respirator protection factor

ACRONYM LIST (cont.)

TEDE	total effective dose equivalent
TSCA	Toxic Substances Control Act
TSDF	treatment, storage, and disposal facility

UNITS OF MEASURE

cm^3	cubic centimeter
ft	foot
ft^3	cubic foot
g	gram
gal	gallon
hr	hour
in.	inch
kg	kilogram
km	kilometer
km^2	square kilometer
lb	pound
m	meter
m^3	cubic meter
MeV	million electron volts
mi	mile
µCi	microcurie
mg	milligram
mrem	millirem
nCi	nanocurie
pCi	picocurie
yr	year

EXECUTIVE SUMMARY

This report contains data and analyses to support the approval of authorized release limits for the clearance from radiological control of polychlorinated biphenyl (PCB) capacitors in Buildings 361 and 391 at Argonne National Laboratory, Argonne, Illinois. These capacitors contain PCB oil that must be treated and disposed of as hazardous waste under the Toxic Substances Control Act (TSCA). However, they had been located in radiological control areas where the potential for neutron activation existed; therefore, direct release of these capacitors to a commercial facility for PCB treatment and landfill disposal is not allowable unless authorized release has been approved.

Radiological characterization found no loose contamination on the exterior surface of the PCB capacitors; gamma spectroscopy analysis also showed the radioactivity levels of the capacitors were either at or slightly above ambient background levels. As such, conservative assumptions were used to expedite the analyses conducted to evaluate the potential radiation exposures of workers and the general public resulting from authorized release of the capacitors; for example, the maximum averaged radioactivity levels measured for capacitors nearest to the beam lines were assumed for the entire batch of capacitors. This approach overestimated the total activity of individual radionuclide identified in radiological characterization by a factor ranging from 1.4 to 640. On the basis of this conservative assumption, the capacitors were assumed to be shipped from Argonne to the Clean Harbors facility, located in Deer Park, Texas, for incineration and disposal. The Clean Harbors facility is a state-permitted TSCA facility for treatment and disposal of hazardous materials. At this facility, the capacitors are to be shredded and incinerated with the resulting incineration residue buried in a nearby landfill owned by the company. A variety of receptors that have the potential of receiving radiation exposures were analyzed. Based on the dose assessment results, it is indicated that, if the disposition activities are completed within a year, the maximum individual dose would be about 0.021 mrem/yr, which is about 0.02% of the primary dose limit of 100 mrem/yr set by U.S. Department of Energy (DOE) for members of the public. The maximum individual dose was associated with a conservative and unlikely scenario involving a hypothetical farmer who intruded the landfill area to set up a subsistence living above the disposal area 30 years after burial of the incineration residue. Potential collective dose for worker and the general public combined was estimated to be less than 4×10^{-4} person-rem/yr, about 0.004% of the DOE authorized release objective of 10 person-rem/yr for collective exposure. In reality, the actual radiation doses incurred by workers and the general public are expected to be at least two orders of magnitude lower than the estimated values.

To follow the ALARA (as low as reasonably achievable) principle of reducing potential radiation exposures associated with authorized release of the PCB capacitors, a dose constraint of 1 mrem/yr, corresponding to a small fraction of the 25 mrem/yr limit set by DOE, was initially used as a reference to derive the authorized release limits. On the basis of the dose assessment results, the following authorized release limits are proposed − 0.6 pCi/g for Mn-54, 0.6 pCi/g for Na-22, 0.1 pCi/g for Co-57, and 2.3 pCi/g for Co-60, with a corresponding maximum individual dose of 0.21 mrem/yr. This maximum dose, about 0.2% of the DOE primary dose limit of 100

mrem/yr for members of the public from all sources and exposure pathways, was then selected as the final dose constraint for releasing the PCB capacitors through the authorized process.

The proposed authorized release limits would satisfy the DOE requirements for the release of non-real properties to a commercial treatment and disposal facility. In addition, due to the relatively short half-lives (< 5.27 years) of radionuclides of concern, there will be no long-term buildup of doses either in groundwater or through other exposure pathways associated with this particular release action. Contact with Clean Harbors and the State of Texas has been initiated. The radioactivity levels in the PCB capacitors meet the State of Texas radiological exemption limits and would be accepted by Clean Harbors, subject to the approval by DOE for the authorized release process.

Cost benefit analysis shows that authorized release of the PCB capacitors would provide significant cost saving over the low-level radioactive waste (LLRW) disposition alternative, i.e. sending the PCB capacitors to a certified LLRW facility for treatment and disposal, and would not cause a significantly different impact in terms of human health protection. Therefore, authorized release is determined to be the preferred alternative for the disposition of Argonne PCB capacitors.

1 INTRODUCTION

PCB capacitors in Buildings 361 and 391 of Argonne National Laboratory have the potential of being activated by neutrons because they are located in radiological controlled areas when the Intense Pulsed Neutron Source (IPNS) facility operated (Butala and Brumwell 2009). These polychlorinated biphenyl (PCB) capacitors are given a priority for disposal in order to complete deactivation of the IPNS facility and place it in a safe mode prior to decontamination and decommissioning (D&D) activities. A total of 344 large capacitors are located in Building 391, outside the 450-MeV rapid cycling synchrotron (RCS) concrete shielding, and approximately 72 large capacitors are located in Building 361, adjacent to the 50-MeV linear accelerator (linac).

Steel bolts and brass nuts from the large capacitors seated on the shelves closest to the RCS were removed for radiological characterization. In addition to these small parts, several capacitors that were judged to have the highest activation were also dismounted from racks for radiological characterization as a whole. Smear samples indicated no removable radioactive contamination on the exterior surface of these capacitors. Gamma spectroscopy results indicated the radioactivity levels are either at ambient background levels or slightly above background levels. The radionuclides identified are Mn-54, Na-22, Co-57, and Co-60. Co-60 exists only in the small parts and is not found in the steel bulk of the capacitors due to the unique metallic composition in the brass nuts (70% copper and 30% zinc) that produces Co-60 upon activation by neutrons (Butala and Brumwell 2009). Additionally, K-40 and Cs-137 were identified. K-40 is a naturally occurring radionuclide, and Cs-137 is found in all post-World War II manufactured metal items because of fallout from atmospheric nuclear weapon testing. K-40 and Cs-137 are not neutron activation products. The PCB oil samples taken from the capacitors were found to contain no measurable radioactivity (Brachmann 2009a).

Because of the low radioactivity levels, Argonne National Laboratory is evaluating the feasibility of releasing the PCB capacitors from radiological controls through the authorized release process. This report contains data and analyses needed to support the authorized release option. It presents estimates of radioactivity in the PCB capacitors through radiological characterization (Section 2); discusses disposition alternatives under consideration (Section 3); describes U.S. Department of Energy (DOE) guidance and requirements for authorized release of non-real properties (Section 4); and evaluates potential radiation exposures associated with releasing the PCB capacitors for treatment and disposal at a commercial facility, develops authorized release limits in accordance with the ALARA (as low as reasonably achievable) principle, and compares costs associated with non-authorized versus authorized release alternatives (Section 5). Last, the report demonstrates that the authorized release process undertaken by Argonne National Laboratory is consistent with DOE guidance and that the developed authorized release limits satisfy the DOE requirements to limit human radiation exposures to a small fraction of the radiation dose limit, protect the groundwater, and prevent future remediation requirement of the disposal facility (Section 6). Section 7 provides conclusions for the analyses, and Section 8 lists citations of documents referenced in this report. Detailed discussions on the input parameters used in the dose assessment are provided in the appendixes.

2 WASTE STREAM CHRACTERIZATION

The IPNS facility began operation in 1981 and was permanently shut down in December 2007. A large number of electrical capacitors at this facility contain PCB oil that must be disposed as hazardous waste. However, because some of the capacitors had been located in radiological control area where the potential for neutron activation existed, direct release of these capacitors to a commercial incinerator for treatment and landfill disposal would not be allowed unless authorized release has been approved. Characterizations of the PCB capacitors began in March 2009 and continued through September 2009. The results indicated the radioactivity levels in the capacitors are either below instrument detection limits or just slightly above detection limits.

A total of 344 large capacitors, each weighing 126 lb, had been located in Building 391 outside the proton accelerator shield in a radiation area. A preliminary radiological evaluation was made by analyzing the small parts associated with these capacitors. Steel bolts and brass nuts were removed for gamma spectroscopy analysis from three capacitors that are closest to the RCS beam line and have the highest potential for neutron activation. The analysis revealed three isotopes, Mn-54, Co-57, and Co-60, known to be activation products. The measured average concentrations in March 2009 were 0.016, 0.018, and 0.243 pCi/g, respectively. Adjusted for radioactive decay, the average concentrations would reduce to 0.010, 0.011, and 0.226 pCi/g for Mn-54, Co-57, and Co-60, respectively, by September 30, 2009. It is noted that the existence of Co-60 is unique for the brass nuts and is not found in the steel bulk of the capacitors, due to the unique metallic composition of brass, which is 70% copper and 30% zinc (Butala and Brumwell 2009). A fourth isotope, Cs-137, identified in the analysis is not a potential neutron activation product but is considered to exist in the environment because of fallout from atmospheric nuclear weapon testing.

When the capacitors are shipped off-site for disposal, two nuts and two brass retaining washers will remain on each capacitor because they retain a cable attached to the terminals that prevents accumulation of electrical charge and risk of accidental discharge. The two steel bolts that hold each capacitor to the rack, however, will not be shipped. The total weight of the two nuts and two brass was estimated to be about 142 g, constituting only 0.25% the weight of the capacitor (57.2 kg, 126 lb). Assuming all the radioactivity is concentrated in the nuts and brass washers, on the basis of the measurement data, the total radioactivity associated with Mn-54, Co-57, and Co-60 in the small parts that will be shipped off-site along with the capacitors was estimated to be about 12.07 nCi.

Two large capacitors that had sat on the floor closest to the two dominant neutron sources for the entire period of time that the RCS operated were judged to have the highest potential for neutron activation in Building 391 and were retrieved for gamma spectroscopy characterization (Butula and Brumwell 2009). The measurements, conducted on July 16, 2009, identified two activation products, Na-22 and Mn-54, in the bulk of the capacitors, with an average concentration of 0.0397 and 0.0669 pCi/g, respectively. Adjusted for radioactive decay, the average concentrations would be 0.038 and 0.057 pCi/g, respectively, on September 30, 2009. The measurements also identified the existence of K-40, Cs-137, as well as Pb-212 and Pb-214;

all were deemed to be not activation products associated with the accelerator. Cs-137 is an atmospheric fallout product, as mentioned previously. K-40 is a naturally occurring radionuclide found in soil and likely in iron ore used to manufacture the capacitors. Pb-212 is a decay product of Rn-222, and Pb-214 is a decay product of thoron, Rn-220. Both are short-lived, naturally occurring isotopes that attach to dust particles, which subsequently plated out on the exterior surfaces of the capacitors. Assuming, conservatively, that all other capacitors have the same radioactivity levels as the two retrieved ones, a total radioactivity of 1.87 μCi was estimated for the Mn-54 and Na-22 contained in the bulk of the capacitors. In reality, the total radioactivity would be much lower than the estimated value because the other capacitors are further from the beam line and thus are either not activated or less activated.

A total of 72 PCB capacitors are located on the floor in Building 361 adjacent to the 50-MeV linac. The potential for neutron activation is much lower for these capacitors because of the lower energy of the proton beam in this stage of the accelerator system. This is verified by the gamma spectroscopy analysis results, which showed no measurable radioactivity in the hardware removed from these capacitors and bulk radioactivity concentration less than the lowest limits of detection (LLD) of the instrument. To estimate the total radioactivity, the LLD (0.06 pCi/g) was used for the bulk concentration; this resulted in an estimate of 152 nCi for Mn-54 and for Na-22.

Table 2-1 summarizes the measured radioactivity concentrations in each type of capacitor. In addition to the concentrations, the total activities of these capacitors that are considered for authorized release are listed. The sums of the total activities are used for comparison with the exemption limits established by the State of Texas and the concentrations form the basis of the ALARA dose assessment detailed in Section 5 of this report. More information on the radiological characterization results is provided in the Butula and Brumwell report (2009).

TABLE 2.1 Summary of Radioactivity Concentrations and Total Inventory in PCB Capacitors

Capacitor Location/Type	Unit Weight (kg)	Number of Units	Total Weight (kg)	Activity Concentration (pCi/g)[a]				Total Activity (nCi)			
				Mn-54	Na-22	Co-57	Co-60	Mn-54	Na-22	Co-57	Co-60
Building 391 large capacitors (brass and nut)	0.142	344	49	0.01	ND[b]	0.011	0.226	0.49	ND[b]	0.54	11.04
Building 391 large capacitors (bulk)	57.2	344	19,677	0.057	0.038	ND[b]	ND[b]	1,121.58	747.72	ND[b]	ND[b]
Building 361 large capacitors[c]	63.5 (for 40 capacitors)	72	3,145	0.06	0.06	ND[b]	ND[b]	188.70	188.70	ND[b]	ND[b]
Sum			22,871					1,310.77	936.42	0.54	11.04

[a] Activity concentrations are estimates based on measurement data, with adjustment for radioactive decay to September 30, 2009.

[b] ND = not detected.

[c] There are 40 large capacitors, each weighing 63.5 kg, in Building 361. The other 32 capacitors are of different types and weights. Their total weight is estimated to be about 605 kg.

3 DISPOSTION ALTERNATIVES

Two disposition alternatives are considered for the PCB capacitors. The first alternative treats the PCB capacitors as radioactively contaminated wastes that require special treatment and disposal in a U.S. Nuclear Regulatory Commission (NRC)-licensed facility in accordance with the regulatory requirements for low-level radioactive waste (LLRW). An LLRW disposal facility, which is also approved for disposal of TSCA regulated waste, located in Clive, Utah, and owned by EnergySolutions is considered as the destination for the PCB capacitors[1]. EnergySolutions has been contracted by Argonne for accepting and disposing the LLRW it generates through various research activities.

The second alternative presumes the approval of authorized release of the PCB capacitors, so that they can be released from radiological control to a commercial facility as nonradioactive hazardous wastes for treatment and disposal. Clean Harbors was contacted about acceptance, treatment, and disposal of the PCB capacitors, subject to approval for authorized release. Clean Harbors owns an incinerator and landfill near Deer Park, Texas, which is permitted by the U.S. Environmental Protection Agency (EPA) for handling hazardous wastes. The same incinerator was used by Portsmouth Gaseous Diffusion Plant for disposition of PCB dielectric fluid after it was approved for authorized release by DOE in March 2009 (DOE 2008).

Under both alternatives, the PCB capacitors would be shipped by trucks from Argonne to the designated facility. At the EnergySolutions facility, the capacitors would be shredded and thermally treated to destroy the PCB oils; the condensate/residue would then be retrieved and disposed of at an on-site LLRW facility. Note that EnergySolutions is permitted to accept and store the PCB capacitors for up to 1 year, but has not yet been approved by EPA for shredding and treating the large capacitors. However, the modification of its permit to shred large capacitors is being processed, and its thermal desorption system for destroying PCB oils has been tested. Currently, EnergySolutions is waiting for EPA to schedule a demonstration of the thermal system. In this report, it is assumed that a permit for EnergySolutions to shred and treat the PCB capacitors is anticipated within a year; otherwise, there would be no feasible disposition alternative for the PCB capacitors other than the authorized release alternative.

At the Clean Harbors facility, the capacitors would be incinerated and disposed of in a Resource Conversation and Recovery Act (RCRA) Subtitle C landfill. With the approval of authorized release by DOE, Clean Harbors does not require another permit to shred and incinerate the PCB capacitors, as long as the total radioactivity inventories in the PCB capacitors meet the State of Texas exemption limits.

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[1] EnergySolutions is permitted to accept waste on-site in anticipating of a permit to shred and treat large PCB containing capacitors. Contractor currently is not approved for the treatment process.

4 REQUIREMENTS FOR DOE AUTHORIZED RELEASE

In accordance with DOE Implementation Guide G 441.1-XX (DOE 2002), the principal requirements for release of property containing residual radioactivity, as presented in Chapter II and IV of DOE Order 5400.5 (DOE 1990), are intended to achieve the following goals:

- Property is evaluated, radiologically characterized, and, where appropriate, decontaminated before release.
- The level of residual radioactive material in property to be released is as near background levels as is reasonably practical, as determined through DOE ALARA process requirements, and meets DOE authorized release limits.
- All property releases are appropriately certified, verified, documented, and reported; public involvement and notifications needs are addressed; and processes are in place to appropriately maintain records.

Specifically, DOE procedures for release of real or non-real property include the determination of appropriate authorized limits and radiation survey/analysis to ensure that materials being released are below the authorized limits. DOE must ensure that any personal property, including waste, released from DOE control does not contain quantities of radioactive materials subject to licensing requirements of the NRC or Agreement States. For the release of waste for disposal at a facility that is not an authorized LLRW disposal facility, the authorized limits must meet the following requirements (DOE 2002):

- Authorized limits for release of the waste must ensure that doses to the public from all sources are less than the primary dose limit for all sources (100 mrem/year).
- Authorized limits for release of the waste must be developed and approved by DOE consistent with the ALARA process. Appropriate protocols for survey and review of the clearance of such property must accompany the approval of the authorized limits. These limits will be based on a documented finding that they are as low as practicable as determined through the ALARA process, with a goal of maintaining individual doses low in comparison to background (e.g., a few mrem/year or less). In any case, the limits must be a fraction of the primary dose limit for the public (e.g., one-fourth, or 25 mrem/yr or less). The ALARA analysis should be consistent with DOE ALARA guidance (DOE 1997c).
- Authorized limits for clearance of the waste from DOE control should be coordinated with the NRC or with appropriate Agreement State representatives to ensure that DOE clearances do not violate NRC licensing requirements.

The all-sources requirement may be assumed to be satisfied if the ALARA criterion and its associated dose constraint and goals are adequately addressed.

DOE G 441.1-XX provides additional requirements specific to the clearance of waste to a non-DOE off-site landfill or to a hazardous waste treatment, storage, and disposal facility (TSDF) permitted for the management of RCRA- and Toxic Substance Control Act (TSCA)-regulated materials (DOE 1997a). These same requirements would apply to the release of the PCB capacitors considered in this report to Clean Harbors for incineration and disposal at its Deer Park facility. In addition to meeting the criteria described above for the release of property, authorized limits and authorized release protocols must meet waste acceptance criteria of the disposal facility and must be coordinated with regulatory authorities for the facility. To ensure that these requirements and goals are met, authorized limits for release of waste must be as follows:

- Selected and approved by DOE based on an assessment under the ALARA process to optimize the balance between risks and benefits (e.g., collective doses and costs) and to ensure that individual doses to the public are less than 25 mrem/yr with a goal of a few mrem/yr or less.

- Evaluated to ensure that groundwater will be protected consistent with the objectives of the applicable state regulations and guidelines.

- Assessed to ensure that future clearance of the TSDF would not be expected to require remediation under DOE Order 5400.5 or other applicable requirements for clearance of property containing residual radioactive material as a result of DOE disposals.

- Coordinated with and acceptable to the TSDF authority (e.g., municipal or private operator) implementing the waste acceptance criteria, and with state representatives responsible for implementing waste regulations, to ensure that DOE clearances do not violate radiological protection requirements applicable to the facility.

The following sections demonstrate compliance with each of the requirements listed above. Based on the successful completion of these requirements, the PCB capacitors at Argonne National Laboratory are proposed for release from control under the Atomic Energy Act for disposal at the Clean Harbors' Deer Park facility.

5 DOSE ASSESSMENT AND ALARA ANALYSIS

5.1 APPROACH AND ASSUMPTIONS

5.1.1 ALARA Process and Considerations

An ALARA analysis was conducted in the assessment of the two disposition alternatives (Section 3) considered for the Argonne PCB capacitors. The analysis results support the selection of the authorized release option.

For the ALARA analysis, potential human radiation exposures associated with the release of the PCB capacitors were evaluated; then a dose constraint, which is a small fraction of the primary dose limit of 25 mrem/yr, was selected to derive authorized release limits, which are to be used as criteria for comparison with radiological survey data before the actual release of the PCB capacitors. The evaluation of a comprehensive list of receptors and the selection of a small fraction of the primary dose limit as the dose constraint are consistent with the DOE ALARA process for protection of the public and environment (DOE 1997c).

5.1.2 Dose Limits and Dose Constraints

Dose Limits. As required by DOE, the primary dose limit for any member of the general public is 100 mrem total effective dose equivalent (TEDE) in a year. This limit applies to the sum of internal and external doses resulting from all modes of exposure to all radiation sources other than background radiation and doses received as a patient from medical sources [DOE 1990, 5400.5, II.1.a.(3)(a)].

Dose Constraints. Because the primary dose limit is for all sources, a dose constraint of one quarter of the primary dose limit (i.e., 25 mrem/yr) is applied to each DOE source or practice. Therefore, authorized limits for annual dose from the release of property should be *as far below 25 mrem as is practicable*. This dose constraint represents an upper bound, or cap, for ALARA-based authorized limits for release of property containing residual radioactive material. This dose constraint ensures DOE real property releases are consistent with dose requirements in 10 CFR 20, "Standards for Protection Against Radiation," subpart E, "Radiological Criteria for License Termination." Additionally, depending on circumstances, DOE 5400.5 either permits or requires use of concentration-based constraints as well.

Selected Dose Constraint. In keeping with DOE's ALARA process and considerations, the dose constraint of *1 mrem/yr* is selected for the release of the PCB capacitors at Argonne National Laboratory for treatment and disposal at the Clean Harbors facilities at Deer Park, Texas. This dose level is used as an upper limit for demonstration of compliance for meeting the requirements of the DOE authorized release process.

5.1.3 Waste Disposition Alternatives

Two alternatives (see Section 3) are considered for the disposition of the PCB capacitors at Argonne National Laboratory. The preferred alternative is to transport the capacitors to the Clean Harbors facility located at Deer Park, Texas, for incineration followed by disposal of the incineration residue. The Clean Harbors facility is an EPA- and TSCA-authorized commercial PCB storage and incineration facility. The alternative is to transport the PCB capacitors to the EnergySolutions facility at Clive, Utah, for treatment and disposal. The EnergySolutions facility is a LLRW facility licensed by the State of Utah as an NRC Agreement State.

5.1.4 Exposure Scenarios

All activities involved in handling, transport, treatment, and disposal of the PCB capacitors are outside of the radiological control areas and thus the potentially exposed personnel are assumed to be nonoccupational (or nonbadged) personnel. These include workers surveying the capacitors prior to the shipment, workers loading and securing the waste packages to a truck for shipment, truck drivers transporting the waste packages from Argonne to the incineration facility owned by Clean Harbors (at Deer Park, Texas), workers receiving and placing the capacitors in storage at the incineration facility, workers handling the capacitors for shredding and incineration, and workers handling and disposing the incineration residue at the landfill.

Members of the general public who have the potential of incurring radiation exposures are the drivers of vehicles that share the road with the waste trucks when they are en route to the treatment and disposal facility (on-link population); the passengers at stops when the waste trucks are parked for maintenance, refueling, food, and rest (stop population); as well as residents living on each side of the transportation route (off-link population). People who live close to the incineration facility could also incur radiation exposure to the flue gas and dust particles released during the incineration of the PCB capacitors. Because of the much longer exposure distance and shorter exposure time for the general public, their individual dose is expected to be much lower than that for the individual worker; however, the general public populations would be much larger than the worker population.

In addition to radiation exposures incurred before and during the disposition of the PCB capacitors, potential exposure after the disposition of the PCB capacitors was also analyzed. The analysis involved the consideration of a future farmer who unknowingly intrudes the landfill and sets up living above the waste disposal area. It is conservatively assumed that the landfill will be closed immediately after the disposition, followed by an institutional control period of 30 years, a common practice for RCRA landfills. After 30 years, a farmer is assumed to build a house, dig a well, plant crops, and raise livestock to live a subsistence life above the landfill area. The consideration of a subsistence farmer is very conservative in that it would encompass the most exposure pathways and the longest exposure duration. In reality, it is very unlikely that such a scenario would occur; nevertheless, the estimate of the corresponding exposure would provide the upper limit that bounds the exposures associated with any other scenario that is more likely to occur after the disposition of the PCB capacitors.

5.1.5 Uncertainty and Other Considerations

Since there could be uncertainties involved in the assessment conducted in this report, the strategy for mitigating the nature of such uncertainties is added conservatism (i.e., toward maximizing the potential doses) whenever such uncertainties may arise. The conservatism incorporated in the dose assessments and the derivation of authorized release limits include but are not limited to the followings –

(1) A conservative dose constraint of 1 mrem/yr for the maximally exposed individuals was used as an upper limit for deriving the authorized release limit, which is 4% of the DOE individual dose constraint (25 mrem/year) for authorized release, and 1% of the DOE primary dose limit (100 mrem/year) for members of the public.

(2) The maximal averaged concentration of each radionuclide obtained from radiological characterization was assumed to distribute homogeneously in the entire batch of the PCB capacitors. In reality, most of the PCB capacitors have radionuclide concentrations below or near the minimum detection limits. This is especially true concerning the distribution of Co-57 and Co-60, which were found to exist only in the small parts (nuts and brass) and not in the bulk of the B.391 capacitors, and these small parts account for less than 0.25% of the weight of each capacitor. With the homogeneous distribution assumption, the total radioactivity of each individual radionuclide was overestimated by a factor of 1.4 to 640 in the dose assessment.

(3) Conservative exposure scenarios were considered for dose calculation. Potential radiation exposure after disposition of the PCB capacitors was estimated with a subsistence farmer scenario that would yield the highest radiation dose but is very unlikely to occur. The potential dose associated with the subsistence farmer scenario provided an upper bound to the exposures associated with any other scenario that is more likely to occur in real situation.

(4) Shorter exposure distances, longer exposure durations, and in the case of assessing population exposures, higher population densities were used to obtain higher radiation dose results. For example, it was assumed to take 45 hours to ship the PCB capacitors from Argonne to Deer Park, Texas. In reality, the transportation time is more likely to be less than 30 hours. Therefore, with this assumption, the potential dose incurred by the truck driver was overestimated by 50% to 100%.

(5) For incineration treatment, although the filtering system of the incinerator has an efficiency of 97% to 99% retaining particles in the baghouse (Brachmann 2009 b), the lowest efficiency was assumed to yield the highest radionuclide releases through the emission stack. As a result, the radiation dose of the general public living near the incinerator could be overestimated by 300%. On the other hand, the radioactivity remaining in the incineration residue was assumed to be 100% to maximize the radiation exposures after closure of the disposal facility. This could result in overestimate of the potential dose slightly, about 3%.

(6) In the assessment of the intruder (subsistence farmer) exposure, the landfill cover was assumed to be completely removed during the construction of a residency, so that the entire incineration residue was exposed to the ground surface and resulted in the highest external radiation and inhalation exposures. If the cover remains intact, the potential radiation exposure would be essentially zero. Furthermore, any engineered design, e.g. liners, incorporated into the landfill to prevent leaching of radionuclides from the disposal area, was neglected, so that leaching of radionuclides could be overestimated, resulting in higher radiation doses for the groundwater-related pathways. Should the engineered designs be considered, leaching of radionuclides would not occur for at least 100 years; as a result, radioactivity in the incineration residue would be reduced to minimum by radioactive decay.

(7) Intrusion to the disposal area was assumed to occur 30 years after the burial of the incineration residue; while in reality, it is likely that the disposal facility would be operated for some time after the disposal, and after the closure of the disposal facility, institutional control of the disposal site could last for more than 30 years. Decay of radioactivity in the incineration residue would be less with the shorter time period of 30 years assumed for dose assessment, which would result in a higher radiation dose being estimated for the intruder. Otherwise, radioactivity could decay away completely and pose no threat of radiation exposure to any future receptor.

Despite the conservative approach taken, compliance with the DOE authorized release requirements is fully demonstrated, as presented in the following sections.

5.2 DOSE ASSESSMENT

5.2.1 Methodology for Dose Calculations

5.2.1.1 Source Term

Two shipments are required to transport the PCB capacitors to the incinerator at Deer Park, Texas. The first shipment would contain 14 wire baskets, each holding 16 large capacitors. The total weight is estimated to be about 30,000 lb (13,620 kg). The second shipment would contain 11 wire baskets, each with 16 large capacitors (and two to four 55-gal drums loaded with capacitors of various sizes). The total weight of the second shipment is estimated to be about 27,300 lb (12,400 kg).

For the dose assessment, two shipments, each loaded with 15,000 kg of capacitors, were assumed. The radioactivity concentrations in the capacitors were assumed to be 0.011, 0.06, 0.06, and 0.226 pCi/g for Co-57, Mn-54, Na-22, and Co-60, respectively, which are the maximal averaged concentrations obtained from recent characterization efforts (see Table 2-1). Note that Co-57 and Co-60 were not observed in the bulk of the capacitors. They exist only in nuts, washers, and wire hardware of the B.391 capacitors, and constitute a small fraction of the total weight of the capacitors. Furthermore, only the capacitors closest to the neutron beams and judged to have the highest activation were characterized. Even so, the radioactivity levels in some of the characterized capacitors were below the lowest detection limits. Therefore, the assumptions used to determine the source term for dose assessments are very conservative; they overestimate the total activity of Co-57 and Co-60 by at least two orders of magnitude.

5.2.1.2 Exposure Pathways

The radiation exposures of workers were analyzed for the external radiation and inhalation pathways. Exposures for the ingestion pathway were not analyzed. They were considered to be very small compared with exposures from the other two pathways, either because there was no removable contamination on the exterior surface of the capacitors or because workers would handle the shredded capacitors or the incineration residue with equipment and would not touch them directly. In reality, the workers would probably wear protective gloves while handling the shredded capacitors or incineration residue; thereby the possibility of ingestion exposure is greatly reduced. Inhalation exposures of workers were considered to result from dispersion of sawdust generated by shredding the capacitors and from release of airborne particles entrapped in the flue gas during incineration.

Exposures of the general public were analyzed for the external radiation pathway during transport of the PCB capacitors. During waste treatment, radiation exposure of the general public living close to the incineration facility was considered to result from release of the flue gas, through air submersion, inhalation, and external radiation to the particles entrapped in the flue gas and subsequently deposited to the ground surface at downwind locations. After disposal of the incineration residue, the general public could incur radiation exposure as a result of (1) leaching of radionuclides from the disposal area to the underlying groundwater and (2) exhumation of the buried incineration residue by digging a well or building a foundation directly into the disposal area. A resident farmer scenario was assumed to evaluate the potential radiation exposures from both mechanisms. The farmer was assumed to unknowingly intrude the landfill after its closure and set up living above the disposal area. The cover material shielding the buried residue was assumed to be removed, exposing the underlying residue to the ground surface; at the same time, precipitation and irrigation water flowed through the waste area, causing radionuclides in the residue to leach to groundwater. Radiation exposure pathways considered for the farmer scenario included external radiation, inhalation and direct ingestion of dust particles, ingestion of groundwater, ingestion of crops grown in the disposal area and irrigated with the groundwater, and ingestion of meat and milk produced by livestock fed with the groundwater and fodder grown in the disposal area.

5.2.1.3 Computer Models

The radiation doses incurred by workers were calculated with the TSD-DOSE model (Pfingston et al. 1998), which was designed specifically to consider radiation exposures resulting from the transportation, storage, treatment, and disposal of wastes containing radioactive materials. The RADTRAN model (Weiner et al. 2006; Neuhauser et al. 2000), which performs detailed analyses of radiation exposures of the general public along the transportation route, was used to assess population radiation exposure from shipping the PCB capacitors from Argonne to the incineration facility. Routing information for the shipment was obtained with TRAGIS (Johnson and Michelhaugh, 2000), which is a routing analysis tool with an extensive database of highways, railways, and waterways, as well as traffic load and population density. Information generated by TRAGIS was entered into RADTRAN for the calculation of collective radiation exposure resulting from waste transportation. The radiation dose incurred by the farmer intruding the landfill was calculated with the RESRAD code, version 6.21 (Yu et al. 2001), which is a multiple exposure pathways model for analyzing radiation exposure resulting from residual soil contamination.

Detailed discussions on input parameters used for the dose modeling are provided in Appendixes A and B.

5.2.2 Dose Assessment Results

5.2.2.1 Worker Doses

Table 5-1 lists the estimated worker doses associated with the PCB capacitors loaded in one truck shipment from Argonne to Deer Park, Texas. Although some activities may be conducted by one worker, two primary workers were assumed for each type of activity to obtain more conservative estimates of collective exposure. The average exposure distance for each type of activity was either the default value in TSD-DOSE or determined on the basis of empirical experience. The exposure durations were also intentionally chosen to be more conservative to yield higher radiation dose results.

Assuming all the activities involved in disposition of the PCB capacitors occur within one year, then according to the estimated dose results, the incineration worker would receive the highest radiation exposure, about 0.0043 mrem/yr from handling a truckload of capacitors. The radiation dose received by the truck drivers was a little lower, 0.0032 mrem/yr. Radiation exposures received by the surveying workers, riggers, receiving workers, and landfill workers were all lower than 0.001 mrem/yr per shipment of PCB capacitors. Because two shipments are required for the entire inventory of PCB capacitors, the maximum worker dose would be 0.0086 (2×0.0043) mrem/yr, which is less than 1% of the 1-mrem/yr dose constraint selected as a reference for deriving the authorized release limits.

5.2.2.2 General Public Doses

Table 5-2 lists the estimated radiation doses to the general public resulting from one shipment of the PCB capacitors from Argonne to Deer Park, Texas. Potential exposures could result during the shipment, during the incineration treatment, and after disposal of the capacitors.

TABLE 5-1 Potential Radiation Exposures of Workers Resulting from Shipping, Treating, and Disposing of the PCB Capacitors — Results Associated with the Capacitors in One Shipment

Worker Category	Worker Activity	No. of Workers Involved in Each Type of Activity	Average Exposure Distance (ft)	Exposure Duration per Shipment (hr)	Individual Dose from the Specific Activity (mrem)	Individual Dose of Each Worker (mrem)	Collective Worker Exposure (person-rem)
Inspector	Survey waste packages prior to shipment	2	0.5	4	2.90E-03	2.90E-03	1.74E-05
Rigger	Load/secure waste packages for shipment	2	2	3	5.10E-04	5.10E-04	
Driver	Transport waste packages to Deer Park, Texas	2	2–7	45	3.20E-03	3.20E-03	
Receiving worker	Unload waste packages and put them into storage	2	2	3	2.80E-04	4.60E-04	
	Move waste packages to the shredding area	2	3	2	1.80E-04		
Incineration worker	Shred capacitors	2	3	30	2.80E-03	4.31E-03	
	Incinerate shredded capacitors	2	3	10	9.40E-04		
	Collect incineration residue and prepare for disposal	2	2	0.75	5.70E-04		
Landfill worker	Unload, mix, and dispose of the residues	2	5–10	1.25	1.30E-04	1.30E-04	

TABLE 5-2 Potential Radiation Exposures of the General Public from Shipping, Treating, and Disposing of the PCB Capacitors — Results Associated with the Capacitors in One Shipment

Receptor Category	Maximum Individual Dose (mrem)	Collective Population Dose (person-rem)
In transit, on-link population	3.18E-09	1.63E-06
In transit, off-link population		2.52E-07
In transit, stop population		3.75E-06
Off-site population of the incineration facility	3.40E-06	1.70E-04
Intruder to the landfill	1.07E-02	Not applicable

During shipment of the PCB capacitors, the maximal individual dose would be incurred by a person who happened to be at the same stop where the waste truck was parked for rest, refueling, or maintenance. The estimated individual dose was 3.18×10^{-9} mrem/yr. Compared with the maximum worker dose, the maximum public dose was six orders of magnitude lower because of the much greater distance to the waste packages and the much shorter duration of exposure. The collective dose for the stop population was estimated to be 3.75×10^{-6} person-rem/yr, based on the assumptions of 25 persons at each stop, an average distance of 10 m to the waste truck, and a total stop time of 18 hours. The collective dose estimated for the on-link population was 1.63×10^{-6} person-rem/yr, based on the assumption that one-way traffic counts in rural, suburban, and urban areas were 470, 780, and 2,800 vehicles/hr, respectively, and two people were in each vehicle sharing the same route. For the off-link population that lived within 800 m on each side of the transportation route, the estimated collective dose was 2.52×10^{-7} person-rem/yr. This estimate was based on the assumption that the average population densities along the transportation route were 14.2, 301.7, and 2338.4 people/km^2 for the rural, suburban, and urban section, respectively. These population densities were estimated by TRAGIS, which also estimated the total mileage traveled in each area (1272.3 km in rural area, 574.4 km in suburban area, and 49.9 km in urban area).

During the incineration process, 3% of the radionuclides in the capacitors were assumed to escape with the flue gas. This would result in a maximal individual dose of 3.4×10^{-6} mrem/yr among the general public that lived within a 50-mile radius of the incineration facility. The collective exposure of the population was estimated to be 1.7×10^{-4} person-rem/yr, based on an urban population density.

Of the radionuclides in the PCB capacitors, 100% were assumed to remain in the residue after incineration. According to Clean Harbors, the weight reduction after incineration was about 20:1 (Brachmann 2009b). Given an average density of 1.5 g/cm^3 (Brachmann 2009b) for the incinearation residue, the residue volume for one truckload of the PCB capacitors would be less than 0.5 m^3. For estimating the potential radiation exposure of an intruder, the residue was assumed to be mixed with other wastes and buried in the landfill within a volume of 25 m^3 (5 m × 5 m × 1 m for length, width, and height, respectively). Then 30 years after the disposal of the PCB capacitors, a farmer intrudes the landfill and sets up living above the disposal area. The potential radiation dose of the farmer, estimated with RESRAD, was a peak dose of about 0.011 mrem/yr, primarily from external radiation. Because of the short half-lives of the radionuclides of concern, the radioactivity would decay away before reaching the groundwater table. As a result, there would be no groundwater contamination problem caused by disposition of the PCB capacitors.

5.3 AUTHORIZED RELEASE LIMITS

On the basis of the dose assessment results presented in Tables 5-1 and 5-2, the maximal individual dose associated with releasing the PCB capacitors at Argonne National Laboratory to the Clean Harbors facility located at Deer Park, Texas, was estimated to be 0.021 mrem/yr (2 × 0.0107 to account for two shipments) for a future farmer intruding the landfill area after closure of the disposal facility. This dose estimate was obtained by assuming homogeneous distribution of radionuclides throughout the PCB capacitors with a concentration of the maximal averaged level measured for each radionuclide. Although intrusion to the landfill by a farmer is very unlikely, the selection of the intruder scenario as the critical scenario for developing the authorized release limits is a conservative approach and is consistent with the ALARA principle to reduce potential radiation exposure.

To target a small fraction of 1 mrem/yr (the upper bound of the dose constraint selected for authorized release) for the critical scenario, authorized release limits of 0.6 pCi/g for Mn-54, 0.6 pCi/g for Na-22, 0.1 pCi/g for Co-57, and 2.3 pCi/g for Co-60 (each is 10 times the maximal averaged concentration) are proposed. These limits would result in a radiation dose of about 0.21 mrem/yr for the critical scenario. On the basis of the estimated collective doses for the general public, as shown in Tables 5-1 and 5-2, the collective population doses corresponding to the proposed authorized release limits would be far below the DOE objective of 10 person-rem/yr for collective exposure.

6 DEMONSTRATION OF COMPLIANCE

6.1 COMPARISON OF THE DERIVED AUTHORIZED RELEASE LIMITS WITH THE STATE OF TEXAS EXEMPTION LEVELS AND OTHER STANDARDS

Table 6-1 compares the proposed authorized release limits derived through dose assessments with the State of Texas exemption levels (Texas Department of State Health Services 2009), the American National Standards Institute (ANSI)/Health Physics Society (HPS) screening levels, and the International Atomic Energy Agency (IAEA) screening standards for clearance of non-real properties from radiological control. Both the proposed authorized release limits and the estimated total radioactivity in the PCB capacitors are much lower than the respective State of Texas exemption levels. The proposed authorized release limits are also lower than the screening levels developed by ANSI/HPS and screening standards developed by IAEA, which were calculated on the basis of a dose limit of 1 mrem/yr.

6.2 COST BENEFIT ANALYSIS

Contrast to the authorized release alternative, the LLRW alternative treats the PCB capacitors as radioactive waste, so they were considered to be shipped to EnergySolutions' facility at Clive, Utah, for treatment and disposal. The total cost for this LLRW disposition alternative was estimated to be about $1,009,000 based on quotes from the existing contract between Argonne and EnergySolutions. The contract lists a disposition charge based on waste volume, $\$1,330/ft^3$. Assuming the inside volume of each wire basket holding 16 large capacitors is 30.35 ft^3, the cost for the large capacitors in the first shipment would be about $565,000, and the cost for the capacitors in the second shipment would be about $444,000.

The cost associated with the authorized release alternative by shipping the PCB capacitors to Clean Harbor's facility in Deer Park, Texas, is estimated to be about $57,000. This estimate is based on the charge per unit weight, $ 0.7975/lb, and the minimum charge per shipment, $28,710 (corresponding to a net weight of 36,000 lb), quoted by Clean Harbors. Because the weight of each shipment is expected to be less than 36,000 lb, the minimum charge per shipment is applied to obtain the cost estimate.

The costs associated with the two disposition alternatives are compared in Table 6-2. The saving of the authorized release alternative is estimated to be about $950,000 over the LLRW disposition alternative.

Although the dose assessments discussed in Section 5.2 were conducted to evaluate the authorized release alternative, the potential dose to workers and the general public associated with the LLRW disposition alternative would not be significantly different. For both alternatives, the PCB capacitors would be shipped from Argonne to the designated facility where they would be shredded and treated to destroy the PCB content, and the solid residue from the treatment would then be disposed of at an on-site disposal facility. The waste treatment methods employed

TABLE 6-1 Comparison of the Derived Authorized Release Limits, Exemption Levels Prescribed by State of Texas, and National and International Standards for Clearance of Non-real Properties

			State of Texas Exemption Level[b]			
Radionuclide	Authorized Release Limit (pCi/g)	Estimated Total Radioactivity[a] (nCi)	Total Radioactivity (nCi)	Concentration (pCi/g)	ANSI/HPS Screening Level[c] (pCi/g)	IAEA Clearance Leveld (pCi/g)
Mn-54	0.6	1.27E+03	1.00E+04	1,000	30	2.7
Na-22	0.6	9.00E+02	1.00E+04	Not available	30	2.7
Co-57	0.1	5.37E-01	1.00E+05	5,000	Not available	27
Co-60	2.3	1.10E+01	1.00E+03	500	30	2.7

[a] The total radioactivity in the PCB capacitors was estimated based on the characterization data (Butala and Brumwell 2009) listed in Table 2-1.

[b] Texas Administrative Code, Title 25 Part 1, Chapter 289, Subchapter F, Rule § 289.251. Available at http://info.sos.state.tx.us/fids/25_0289_0251-13.html.

[c] Information extracted from ANSI/HPS (1999).

[d] Information extracted from IAEA Safety Guide No. RS-G-1.7 (IAEA 2004).

TABLE 6-2 Comparison of Costs Associated with the Two Disposition Alternatives Considered for the PCB Capacitors

Disposition Alternative	Description of Alternative	Vendor and Location of Disposal Facility	Treatment and Disposal Process	Limitations	Assumption for Cost Estimate	Process Quote per Unit	Estimated Cost per Shipment	Total Cost
LLRW release	PCB capacitors will be released as LLRW and shipped to Clive, Utah, for treatment and disposal.	Energy Solutions at Clive, Utah	Shredding of capacitor carcass, thermal treatment of capacitors, and disposition of condensate	Contractor is permitted to accept waste on-site in anticipation of a permit to shred and treat large capacitors. Contractor currently is not approved for the treatment process.	Disposal required for 25 wire baskets each with an inside volume of 30.35 ft^3.	Quote based on existing contract for waste at $1330/ft^3$	Shipment 1, $565,117 Shipment 2 , $444,020	$1,009,137
Authorized release	PCB capacitors will be authorized released as non-rad materials under DOE 5400.5 and will be shipped to Deer Park, Texas, for treatment and disposal.	Clean Harbors at Deer Park, Texas	Shredding of capacitors, incineration of capacitor carcass and oil, landfill disposal of residue	Contractor has permit to treat PCB waste and expects to receive approval from the State of Texas to treat and dispose waste with radioactivity levels below the exemption limits.	Total weight of packaged capacitors assumed to be 52,232 lb for capacitors and ~100 lb per containers.	$0.7975/lb Minimum charge of 36,000 net lb shall apply; each shipment cost assumes minimum charge.	Shipment 1 - $28,710 Shipment 2 - $28,710	$57,420

by EnergySolutions and Clean Harbors to destroy the PCB content may not be the same; however, it is expected that rigorous emission control technologies would be implemented at both facilities to minimize potential releases to the environment. Both disposal facilities would incorporate engineered designs to minimize leaching; institutional control and deed restriction would also be in place to prevent future intrusion. Therefore, the dose estimates presented in Section 5.2 are considered to be conservative for both disposal facilities. Either disposition alternative would satisfy the DOE requirement to maintain all radiation exposures as low as reasonably achievable (ALARA).

6.3 GROUNDWATER PROTECTION

Clearance of the PCB capacitors at Argonne National Laboratory from radiological control to off-site commercial incineration and disposal would not result in groundwater contamination at the off-site location. As demonstrated in Section 5.2, the RESRAD analysis of the future intruder scenario shows no radiation dose associated with the use of groundwater. The radionuclides identified for the PCB capacitors all have short half-lives (2.6, 0.86, 0.74, and 5.27 years for Na-22, Mn-54, Co-57, and Co-60, respectively); therefore, even if the radionuclides leach out from the waste disposal area, their radioactivity would decay away before they reach the groundwater table. Although the dose assessment was conducted by assuming the incineration residue would be buried in Deer Park, Texas, the conclusion of no potential groundwater contamination applies if the LLRW disposition alternative is chosen and the residue from thermal treatment is buried at the LLRW facility at Clive, Utah.

6.4 FUTURE REMEDIATION REQUIREMENTS

Release of the PCB capacitors for commercial incineration and disposal at an off-site facility would pose no potential for future remediation requirements at the off-site location. The radionuclides of concern are all short-lived (with half-life less than 5.27 years) and will substantiallydecay (by at least 100 times) during the institutional control period (estimated to be 30 years or more).. This is verified in Section 5.2 with the RESRAD analysis of the future intruder scenario. In that analysis, the buried incineration residue, containing all the radioactivity in the PCB capacitors, was assumed to be exhumed entirely by construction activities and exposed at the ground surface level. The intruder, who was assumed to be a farmer, then lived above the disposal area and planted crops and raised livestock for subsistence living. The consideration of a farmer intruding the waste disposal site 30 years after closure of the disposal facility is very conservative in that it allows less decay of radioactivity before the intrusion occurs (as longer institutional control is likely), encompasses all possible exposure pathways, and requires the use of longer exposure duration, all of which would result in dose estimates that bound the radiation exposures associated with more likely scenarios. Given all the conservative assumptions, the potential radiation dose estimated by RESRAD for the intruder is still very low, 0.021 mrem/yr, which is less than 0.1% of the 25 mrem/yr dose limit set by DOE for deriving cleanup guidelines for radioactively contaminated sites.

6.5 REPORTING REQUIREMENTS

Appropriate records of the cleared materials will be maintained consistent with the requirements of DOE Order 5400.5 and other applicable DOE directives. Copies of this report and characterization data (Butala,and Brumwell, 2009) will be made publicly available. The Annual Site Environmental Report will be updated to reflect the removal of the PCB capacitors from Argonne National Laboratory. Survey and measurement results will be reported consistent with the data-reporting guidelines in DOE radiological survey guidance (DOE 1997b) and DOE/EH-173T (DOE 1991).

6.6 COORDINATION WITH THE TSDF OPERATOR AND STATE REGULATOR

In accordance with DOE G 441.1-XX (DOE 2002), Argonne has coordinated with Clean Harbors, the owner/operator of the commercial incineration and disposal facilities at Deer Park, Texas, to confirm that PCB capacitors from Buildings 361 and 391 meet all waste acceptance criteria of the facilities. Clean Harbors Environmental Services Inc. has reviewed the radiological characterization report of this waste stream and indicated that it is acceptable for processing at their facilities. The vendor has provided a formal cost proposal to Argonne for processing this waste. In addition, the vendor has also submitted a request to the State of Texas regulatory authority responsible for implementing waste regulations under which the facilities are operated to ensure that the Argonne release does not violate radiation control criteria applicable to the facilities. The State of Texas regulatory authority has agreed that this waste stream is exempt from the radioactive material regulation under the Texas Administrative Code.

7 CONCLUSIONS

Authorized release limits are proposed for the disposition of the 416 capacitors at Buildings 361 and 391 of Argonne National Laboratory. The release limits were developed on the basis of conservative dose assessment results and are in compliance with the DOE ALARA principle of minimizing potential human radiation exposure. The proposed authorized release limits are 0.6, 0.6, 0.1, and 2.3 pCi/g for Mn-54, Na-22, Co-57, and Co-60, respectively, which were identified through radiological characterization of the PCB capacitors. The maximal individual dose associated with the proposed authorized release limits was estimated to be 0.21 mrem/yr, which meets the dose constraint upper bound (1 mrem/yr) selected by Argonne for the authorized release. The associated collective exposure was estimated to be about 0.004 person-rem, three orders of magnitude lower than the collective dose objective of 10 person-rem. The authorized release limits will be used for comparison with the survey data of the PCB capacitors before they can be shipped to a commercial facility for treatment and disposal.

The dose assessment results presented in this report indicate that the PCB capacitors can be safely released from radiological control for commercial incineration and disposal in compliance with the requirements specified in DOE guidance for authorized release of DOE wastes (DOE 1995, 1997a, 2002):

- The individual dose to a maximally exposed worker associated with the authorized release is estimated at about 0.0086 mrem; the maximum individual dose to a member of the general public is estimated at 0.021 mrem/yr. Collective population exposure for workers and the general public combined is estimated at about 3.8×10^{-4} person-rem. The resulting dose estimates are multiple orders of magnitude below the DOE dose limit for authorized release. They were obtained with the conservative assumption that the entire waste stream has the maximal measured concentration for each radionuclide.

- No adverse impact on groundwater is predicted. Dose assessment indicated that there would be no groundwater contamination problem at the site where the commercial disposal facility is located. Because the decay half-lives of the radionuclides contained in the PCB capacitors are short, the radioactivity would have long decayed away before the radionuclides reach the groundwater table.

- Release of the PCB capacitors to a commercial facility for treatment and disposal would not result in remediation requirement in the future at that off-site location. Potential radiation dose estimated for a very unlikely intruder, a subsistent farmer, to the disposal area was 0.021 mrem/yr, which is less than 0.1% of the dose limit (25 mrem/yr) set by DOE for developing cleanup criteria for radioactively contaminated sites.

- The PCB capacitors have been evaluated by Clean Harbors to meet the applicable waste acceptance criteria and regulatory requirements under which its facilities at Deer Park, Texas, are operated. Both the total radioactivity and concentration of each radionuclide identified for the PCB capacitors meet the State of Texas exemption limits.

Finally, cost benefit analysis shows that authorized release of the PCB capacitors would provide significant cost saving over the LLRW disposition alternative; the associated radiation exposures are not significantly different from those associated with the LLRW disposition alternative.

Based on the above reasons, authorized release is selected as the preferred alternative for the disposition of the Argonne PCB capacitors.

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APPENDIX A: EVALUATION OF WORKER DOSES WITH TSD-DOSE

The TSD-DOSE computer model (Pfingston et al. 1998) was developed by Argonne National Laboratory specifically to consider radiation exposures resulting from transportation, storage, treatment, and disposal of wastes containing radioactive materials. It is used in this report to evaluate potential radiation exposures associated with releasing the PCB capacitors from radiological control to a commercial facility near Deer Park, Texas, for treatment and disposal. Radiation doses were calculated with TSD-DOSE for the following receptors: (1) workers surveying the capacitors prior to the shipment, (2) workers loading and securing the waste packages to a truck for shipment, (3) truck drivers transporting the waste packages from Argonne to the incineration facility, (4) workers receiving and placing the capacitors in storage and retrieving the capacitors from storage for shredding at the incineration facility, (5) workers handling the capacitors for shredding and incineration, and (6) workers handling and disposing the incineration residue at the landfill.

Two shipments of the PCB capacitors would be required. In the dose modeling, it was assumed that each shipment carried 15 wire baskets of capacitors (a total of 240 capacitors) that weighed 15,000 kg (~33,000 lb). The TSD-DOSE default cargo dimensions were considered representative for the capacitors and used in the dose modeling. Based on the weight and dimensions, a bulk density of 1.41 g/cm^3 was calculated. Table A.1 lists the radioactivity inventory and the assumption for the release fraction during incineration.

TABLE A-1 Radionuclide Inventory per Shipment and Waste Characteristics Used in TSD-DOSE

Radionuclide amount (Ci)	1.65E-7 for Co-57 3.39E-6 for Co-60 9.00E-7 for Mn-54 9.00E-7 for Na-22
Stack release fraction	0.03 for all radionuclides
Weight percentage , solid	100%
Weight percentage, liquid	0%

Potential doses incurred by the inspection workers were modeled by using the "inspect and sample drums" step under the "receiving and sampling" process in TSD-DOSE. Because the input for exposure time is based on each drum, the time needed to inspect each basket was calculated and used as the input value. A total of 4 hours was assumed to be needed to inspect the capacitors in one shipment; with 15 baskets in one shipment, the time needed to inspect one basket was 0.267 hr. Furthermore, because there is no loose contaminant on the exterior of the capacitors, there would be no inhalation exposure. A small value of 0.0001 mg/m^3 was used as the value for airborne respirable dust concentration (ARDC) to minimize the dose from the inhalation pathway.

TABLE A-2 Worker Categories and Activities and the TSD-DOSE Processes and Steps That Were Used to Calculate the Corresponding Doses

Worker Category	Worker Activity	TSD-DOSE Analysis: Process	Source Term Parameter		Step	Exposure Parameter	
Inspector	Survey waste packages prior to shipment	Receiving and sampling	Density	1.41 g/cm^3	Inspect and sample drums	Time/drum	0.267 hr
						Distance	0.5 ft
						ARDC[1]	0.0001 mg/m^3
						RPF[2]	1
Rigger	Load/secure waste packages for shipment	Transport to TSD facility	Waste density	1.41 g/cm^3	Load and secure shipment	Time	3 hr
			Cargo dimensions			Shielding	0.0625 in.
			Length	18.4 ft		Distance	2 ft
			Width	7.3 ft			
			Height	2.8 ft			
Driver	Transport waste packages to Deer Park, Texas	Transport to TSD facility	Waste density	1.41 g/cm^3	Drive	Time	28 hr
			Cargo dimensions			Shielding	0.125 in.
			Length	18.4 ft		Distance	7 ft
			Width	7.3 ft	Rest	Time	16 hr
			Height	2.8 ft		Shielding	0.125 in.
						Distance	2 ft
					In route maintenance	Time	2 hrs
						Shielding	0.0625 in
						Distance	3 ft
Receiviing worker	Unload waste packages to the storage area	Receiving and sampling	Density	1.41 g/cm^3	Unload drums	Time/drum	0.2 hr
						Distance	3 ft
	Move waste packages to the shredding area	Storage	Density	1.41 g/cm^3	Transfer solids out	Time/drum	0.13 hr
						Distance	3 ft
Incineration worker	Shred capacitors	Receiving and sampling	Density	1.41 g/cm^3	Inspect and sample drums	Time/drum	2 hr
						Distance	3 ft
						ARDC[a]	10 mg/m^3
						RPF[b]	10

TABLE A-2 (Cont.)

Worker Category	Worker Activity	TSD-DOSE Aanalysis					
		Process	**Source Term Parameter**		**Step**	**Exposure Parameter**	
Incineration worker	Incinerate shredded capacitors	Receiving and sampling	Density	1.41 g/cm^3	Inspect and sample drums	Time/drum	0.67
						Distance	3 ft
						ARDC[1]	10 mg/m^3
						RPF[2]	10
	Collect incineration residue and prepare for disposal	Incineration	Density	1.41 g/cm^3	Collect residue in bin	Time/bin	0.25 hr
			Bin dimensions			Distance	2 ft
			Length	3 ft	Transport bin to storage area	Time/bin	0.25 hr
			Width	5 ft		Distance	2 ft
			Height	3 ft	Transport bin from storage area	Time/bin	0.25 hr
			Shielding	0.125 in.		Distance	2 ft
Landfill worker	Unload, mix, and dispose of the residue	Onsite landfill	Density	1.41 g/cm^3	Unload waste to mixing pit	Duration	0.25 hr
			Dump truck bed dimensions			Distance	5 ft
			Length	25 ft		ARDC[1]	1 mg/m^3
			Width	6 ft		RPF[2]	1
			Height	3 ft			
			Shielding	0.125 in.			
			Mixing pit dimensions		Mix waste in mixing pit	Duration	0.5 hr
			Length	10 ft		Distance	10 ft
			Width	10 ft			
			Height	10 ft			
			Cover thickness	2 in			
					Load truck and transport to landfill	Duration	0.25 hr
						Distance	5 ft
					Unload truck at landfill	Duration	0.25 hr
						Distance	5 ft

[a] ARDC = Airborne respirable dust concentration.

[b] RPF = Respirator protection factor

Transportation of the PCB capacitors from Argonne to Deer Park, Texas, was assumed to take 46 hr, including driving for 28 hr, resting for 16 hr, and in route maintenance for 2 hr. These were the TSD-DOSE default values and were longer than the times actually would be taken; therefore, the total dose calculated for each driver was more conservative than the actual exposure.

Unloading waste packages to the storage area was assumed to take a total of 3 hours, which was equivalent to 0.2 hr per basket. Similarly, moving the waste packages to the shredding area was assumed to take 2 hr, so, on average, moving one basket took 0.13 hr.

Shredding the capacitors was estimated to take about 60 hr in total (0.25 hr × 16 capacitors/basket × 15 baskets/shipment) (Brachmann 2009). If two workers worked independently to shred the capacitors, each worker would need to work 30 hr to finish the shredding. This converted to 2 hr per basket as an input value to TSD-DOSE. The default ARDC of 10 mg/m^3 and the respirator protection factor (RPF) of 10 were used to consider potential inhalation dose caused by the sawdust generated in shredding.

The incineration was assumed to take 20 hr (5 min × 15 baskets × 16 capacitors/basket) (Brachmann 2009), including feeding the capacitors and monitoring the incineration process. Two workers. each working 10 hr, were required. Radiation exposure was assumed to result mainly from feeding the incinerator; during incineration, the workers would stay in a control room with a much greater distance from the incinerator. The potential radiation dose was calculated by using the “inspect and sample drums” step under the “receiving and sampling” process in TSD-DOSE. The exposure duration was calculated to be 0.67 hr per basket (10 hr/15 baskets). Default ARDC and RPF values were used to calculate the inhalation dose.

Collecting incineration residue and preparing for disposal was assumed to take a total of 0.75 hr and was divided into three steps according to TSD-DOSE. Unloading, mixing, and disposing of the residue would take a total of 1 hr with four different steps involved. The TSD-DOSE default values for exposure parameters were assumed for dose calculation.

An off-site individual at the location of maximum downwind air concentration was specified to get the maximum off-site individual dose. The off-site collective dose was obtained by using an urban population density. The actual collective dose was expected to be lower than that calculated by TSD-DOSE.

APPENDIX B: EVALUATION OF DOSES ASSOCIATED WITH THE INTRUDER SCENARIO USING RESRAD

The Radiation dose incurred by the intruder scenario after closure of the landfill facility was calculated with the RESRAD computer code, version 6.21 (Yu et al. 2001), which is a multiple exposure pathways model for analyzing radiation exposure resulting from residual soil contamination. Of the radioactivity in the PCB capacitors, 100% was assumed to remain in the residue after incineration, which was mixed with other materials and buried underground within a volume of 25 m^3 (5 m × 5 m × 1 m) in a landfill. Thirty years later, a farmer was assumed to unknowingly build a house and set up a subsistence living above the disposal area. To maximize the potential radiation dose, the cover layer above the residue was assumed to be excavated by construction activities and the residue exposed to the ground surface.

The farmer was assumed to drill a well located at the edge of the disposal area and use well water as the sole source for farming and household activities. Potential radiation exposures were estimated to result from the following pathways: (1) external radiation, (2) inhalation of dust particles, (3) direct ingestion of soil, (4) ingestion of well water, (5) ingestion of plant food grown in the disposal area and irrigated with groundwater, (6) ingestion of meat, and (7) ingestion of milk obtained from livestock grazing above the disposal area and fed with groundwater. To be consistent with TSD-DOSE, the dose conversion factors (DCFs) based on EPA Federal Guidance Report No. 11 and 12 (EPA 1988, 1993) were used in the dose calculations.

Radioactivity inventory in the PCB capacitors was decayed for 30 years to form the source term for RESRAD modeling. The decayed inventory was then distributed homogeneously within a volume of 25 m^3 to give the initial concentrations in the contaminated zone. Only two radionuclides remained after 30 years, Co-60 and Na-22, with a concentration of 1.9×10^{-3} and 9.4×10^{-6} pCi/g, respectively. Mn-54 and Co-57 would decay away after 30 yr. The modeling was carried out for a time period of 1,000 years. However, because of the short half-lives of Co-60 and Na-22, no groundwater contamination was observed during the considered time frame.

Table B-1 lists the radionuclide-specific input parameters used for the modeling. Table B-2 lists the other parameters.

TABLE B-1 Radionuclide-Specific Input Parameters Used in the RESRAD Modeling

		Soil/Water Distribution Coefficient			
Radionuclide	Soil Concentration (pCi/g)	Contaminated Zone (cm^3/g)	Unsaturated Zone (cm^3/g)	Unsaturated Zone (cm^3/g)	Saturated zone (cm^3/g)
Cs-137	1.9E-3	1000	1000	1000	1000
Co-60	9.4E-6	10	10	10	10

TABLE B-2 Other Input Parameters Used in the RESRAD Modeling for the Intruder Scenario

Parameter	Value	Comment
Contaminated zone		
Area of contamination zone (m^2)	25	Assumed disposal area
Thickness of contaminated zone (m)	1	Assumed thickness
Length parallel to aquifer flow (m)	5	Square root of area
Cover and contaminated zone hydrological data		
Cover depth (m)	0	Incineration residue was exposed to ground surface by construction activities
Density of contaminated zone (g/cm3)	1.5	Average density of incineration residue (Brachmann 2009)
Contaminated zone erosion rate (cm/yr)	0	No erosion assumed
Contaminated zone total porosity	0.4	Void space of ARW
Contaminated zone field capacity	0.2	RESRAD default
Contaminated zone hydraulic conductivity	10	RESRAD default
Contaminated zone b-parameter	5.3	RESRAD default
Wind speed (m/s)	3.487	Site-specific value (Brachmann 2009)
Precipitation (m/yr)	1.3	Site-specific value (Brachmann 2009)
Irrigation (m/yr)	0.2	RESRAD default
Runoff coefficient	0	No runoff was assumed to give higher dose result
Evapotranspiration coefficient	0.9	To give an evapotranspiration rate of 1.14 m/yr, a site-specific value (Brachmann 2009)
Accuracy for water/soil computations	0.001	RESRAD default
Saturated zone		
Density of saturated zone (g/cm3)	1.5	RESRAD default
Saturated zone total porosity	0.4	RESRAD default
Saturated zone effective porosity	0.2	RESRAD default
Saturated zone field capacity	0.2	RESRAD default
Saturated zone hydraulic conductivity	100	RESRAD default
Saturated zone hydraulic gradient	0.02	RESRAD default
Saturated zone b-parameter	5.3	RESRAD default
Water table drop rate (m/yr)	0.001	RESRAD default
Well pump intake depth below water table (m)	10	RESRAD default
Model for water transport parameter	Non-dispersive	A well was assumed at the edge of the disposal area
Well pumping rate (m3/yr)	250	RESRAD default

TABLE B-2 (Cont.)

Parameter	Value	Comment
Unsaturated zone 1		
Thickness (m)	3	Within the site-specific range of 8-25 ft (Brachmann 2009)
Density of uncontaminated zone (g/cm3)	1.5	RESRAD default
Uncontaminated zone total porosity	0.4	RESRAD default
Uncontaminated zone effective porosity	0.2	RESRAD default
Uncontaminated zone field capacity	0.3	RESRAD default
Uncontaminated zone hydraulic conductivity	10	RESRAD default
Uncontaminated zone b-parameter	5.3	RESRAD default
Occupancy, inhalation, and external gamma data		
Inhalation rate (m^3/yr)	8400	RESRAD default
Mass loading for inhalation (g/m^3)	0.0001	RESRAD default
Exposure duration (yr)	30	RESRAD default
Indoor dust filtration factor	0.4	RESRAD default
External gamma shielding factor	0.7	RESRAD default
Indoor time fraction	0.5	RESRAD default
Outdoor time fraction	0.25	RESRAD default
Shape of the contaminated zone	circular	RESRAD default
Ingestion dietary		
Fruit, vegetable, and grain consumption (kg/yr)	160	RESRAD default
Leafy vegetable consumption (kg/yr)	14	RESRAD default
Milk consumption (L/yr)	92	RESRAD default
Meat consumption (kg/yr)	63	RESRAD default
Soil ingestion (g/yr)	36.5	RESRAD default
Drinking water intake (L/yr)	510	RESRAD default
Contaminated fraction		
Drinking water	1	Assumed groundwater was the only water source
Livestock water	1	
Irrigation water	1	
Plant food	0.0125	Calculated with Eq. D5 of RESRAD manual (Yu et al. 2001)
Meat	0.00125	
Milk	0.00125	

TABLE B-2 (Cont.)

Parameter	Value	Comment
Ingestion nondietary		
Livestock fodder intake for meat (kg/d)	68	RESRAD default
Livestock fodder intake for milk (kg/d)	55	RESRAD default
Livestock water intake for meat (L/d)	50	RESRAD default
Livestock water intake for milk (L/d)	160	RESRAD default
Livestock intake of soil (kg/d)	0.5	RESRAD default
Mass loading for foliar deposition (g/m3)	0.0001	RESRAD default
Depth of soil mixing layer (m)	0.15	RESRAD default
Depth of root (m)	0.9	RESRAD default
Groundwater fractional usage		
Drinking water	1	Assumed groundwater was the only water source
Livestock water	1	
Irrigation water	1	
Storage time before use		
Fruit, non-leafy vegetable, and grain (d)	14	RESRAD default
Leafy vegetables (d)	1	RESRAD default
Milk (d)	1	RESRAD default
Meat (d)	20	RESRAD default
Well water (d)	1	RESRAD default
Surface water (d)	1	RESRAD default
Livestock fodder (d)	45	RESRAD default

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