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Standard Guide for Evaluating Disposal Options for Concrete from Nuclear Facility Decommissioning[1]

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INTRODUCTION

Numerous nuclear facilities containing large amounts of concrete are scheduled for decontamination and decommissioning over the next several decades. Much of this concrete is either not contaminated or only lightly contaminated on or near the surface. However, since concrete is slightly porous, it has the potential to be contaminated volumetrically. Volumetric contamination is more difficult to measure than surface contamination, and currently there are no release guidelines for volumetrically contaminated concrete. As a result, large volumes of concrete are often disposed of as radioactive waste at a large cost.

Under certain conditions, the depth or amount of contamination may be limited such that a case can be made for concrete release for other purposes outside of regulatory control. These cases are likely to be ones where the radioactive contamination is shallow and is limited to a depth that can be removed by scabbling (removal of the concrete surface), or where the depth can be estimated based on the history and condition of the concrete. In addition to surface contaminated concrete, some facilities contain activated concrete where the depths of contamination vary. This type of concrete should be handled on a case-by-case basis. Accurate measurements of the radiation source are difficult for activated concrete, because the activated portions of the embedded metal or concrete are partially shielded by the concrete that lies between the source and the measuring device. Care must be taken to measure radiation levels of activated concrete accurately, so actual radiation levels are documented and used when applying release criteria.

This standard guide applies to nonrubbelized concrete that is still in place with a defined geometry and known history where the depth of contamination can be measured or estimated based on its history. It is not practical to measure radiation levels of concrete rubble. The process outlined here starts with characterizing the concrete in place, then evaluating the dose to the public and cost of various disposal options.

1. Scope

1.1 This standard guide defines the process for developing a strategy for dispositioning concrete from nuclear facility decommissioning. It outlines a 10-step method to evaluate disposal options for radioactively contaminated concrete. One of the steps is to complete a detailed analysis of the cost and dose to nonradiation workers (the public); the methodology and supporting data to perform this analysis are detailed in the appendices. The resulting data can be used to balance dose and cost and select the best disposal option. These data, which establish a technical basis to apply to release the concrete, can be used in several ways: (*1*) to show that the release meets existing release criteria, (*2*) to establish a basis to request release of the concrete on a case-by-case basis, (*3*) to develop a basis for establishing release criteria where none exists.

1.2 This standard guide is based on the "Protocol for Development of Authorized Release Limits for Concrete at U.S. Department of Energy Sites," (**1**)[2] from which the analysis methodology and supporting data are taken.

1.3 Guide E1760 provides a general process for release of materials containing residual amounts of radioactivity. In

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[2] The boldface numbers in parentheses refer to a list of references at the end of this standard.

addition, Guide E1278 provides a general process for analyzing radioactive pathways. This standard guide is intended for use in conjunction with Guides E1760 and E1278, and provides a more detailed approach for the release of concrete.

1.4 *This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.*

2. Referenced Documents

2.1 *ASTM Standards:*[3]

E1278 Guide for Radioactive Pathway Methodology for Release of Sites Following Decommissioning (Withdrawn 2005)[4]

E1760 Guide for Unrestricted Disposition of Bulk Materials Containing Residual Amounts of Radioactivity

E1893 Guide for Selection and Use of Portable Radiological Survey Instruments for Performing In Situ Radiological Assessments to Support Unrestricted Release from Further Regulatory Controls

2.2 *ANSI Standards:*[5]

ANSI/HPS N13.12 Surface and Volume Radioactivity Standards for Clearance

ANSI/HPS N13.2 Guide for Administrative Practices in Radiation Monitoring

2.3 *IAEA Standards:*[6]

Safety Series No. 111-P-1.1 Application of Exemption Principles to the Recycle and Reuse of Materials from Nuclear Facilities

IAEA-TECDOC-855 Clearance Levels for Radionuclides in Solid Materials

2.4 *ISO Standards:*[7]

ISO-4037 X and Gamma Reference Radiations for Calibrating Dosimeters and Dose-rate Meters and for Determining their Response as a Function of Photon Energy

ISO-6980-1 Nuclear Energy – Reference beta-particle radiation – Part 1: Methods of production

ISO-6980-2 Nuclear Energy – Reference beta-particle radiation – Part 2: Calibration fundamentals related to basic quantities characterizing the radiation field

ISO-8769 Reference Sources for the Calibration of Surface Contamination Monitors—Beta Emitters (Maximum Beta Energy Greater than 0.15 MeV) and Alpha Emitters

ISO-7503-1 Evaluation of Surface Contamination—Part 1: Beta Emitters (Maximum Beta Energy Greater than 0.15 MeV) and Alpha Emitters

ISO-7503-2 Evaluation of Surface Contamination—Part 2: Tritium Surface Contamination

ISO-7503-3 Evaluation of Surface Contamination—Part 3: Isomeric Transition and Electron Capture Emitters, Low Energy Beta Emitters (E_{Bmax}<0.15 MeV)

2.5 *DOE Standards:*[8]

DOE G 441.1–1B Radiation Protection Programs Guide, Order 5400.5 Radiation Protection of the Public and the Environment, as amended

Order 5400.5 Radiation Protection of the Public and the Environment, as amended

2.6 *U.S. Government Documents:*[9]

NUREG-1640 Radiological Assessments for Clearance of Equipment and Materials From Nuclear Facilities

NUREG/CR-5512 Residual Radioactive Contamination From Decommissioning

10 CFR 20 Standards for Protection Against Radiation

2.7 *NRC Standards:*[10]

Regulatory Guide 1.86 Termination of Operating Licenses for Nuclear Reactors

3. Terminology

3.1 *Definitions of Terms Specific to This Standard:*

3.1.1 *activated concrete*—concrete that has components (such as metal filings or pieces) that have become radioactive through exposure to high radiation fields; the concrete itself is radioactive.

3.1.2 *as low as reasonably achievable (ALARA)*—is a process used for radiation protection to manage and control exposures (both individual and collective to the work force and to the general public) and releases of radioactive material to the environment so that the levels are as low as is reasonable taking into account social, technical, economic, practical, and public policy consideration. **ANSI/HPS N13.12**

3.1.3 *release*—occurs when property is transferred out of regulatory control by sale, lease, gift, or other disposition, provided that the property does not remain under radiological control by a regulatory agency. The release does not apply to real property (such as real estate), radioactive wastes, soils, liquid discharges, or gaseous or radon emissions.

3.1.4 *surface contamination*—radioactive contamination residing on or near the surface of an item. This contamination can be adequately quantified in terms of activity per unit area. **ANSI/HPS N13.12**

3.1.5 *volumetric contamination*—radioactive contamination residing in or throughout the volume of an item. Volumetric contamination can result from neutron activation or from the penetration of radioactive contamination into cracks or interior surfaces within the interior matrix of an item. **ANSI/HPS N13.12**

[3] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

[4] The last approved version of this historical standard is referenced on www.astm.org.

[5] Available from American National Standards Institute (ANSI), 25 W. 43rd St., 4th Floor, New York, NY 10036, http://www.ansi.org.

[6] Available from International Atomic Energy Agency, Wagramerstrasse, PO Box 100 A-1400, Vienna, Austria.

[7] Available from International Organization for Standardization (ISO), 1 rue de Varembé, Case postale 56, CH-1211, Geneva 20, Switzerland.

[8] Available from United States Department of Energy, National Technical Information Service, US Dept. of Commerce, Springfield, VA 22161.

[9] Available from the Superintendent of Documents, US Government Printing Office, Washington, DC 20402.

[10] Available from Nuclear Regulatory Commission, Public Document Room, 1717H St. NW, Washington, DC 20555.

4. Significance and Use

4.1 This standard guide applies to concrete that is still in place with a defined geometry and known, documented history.

4.2 It is not intended for use on concrete that has already been rubbelized where it is difficult to measure the radiation levels and not easy to remove surface contamination to reduce radiation levels after concrete has been rubbelized.

4.3 This standard guide applies to surface or volumetrically contaminated concrete, where the depth of contamination can be measured or estimated based on the history of the concrete.

4.4 This standard guide does not apply to the reinforcement bar (rebar) found in concrete. Although most concrete contains rebar, it is generally removed before the concrete is dispositioned. In addition, rebar may be activated, and is covered under procedures for reuse of scrap metal.

4.5 General unit-dose and unit-cost data to support the calculations is provided in the appendices of this standard guide. However, if site-specific data is available, it should be used instead of the general information provided here.

4.6 This standard guide helps determine estimated doses to the public during disposal of concrete and to future residents of disposal areas. It does not include dose to radiation workers already involved in a radiation control program. It is assumed that the dose to radiation workers is already tracked and kept within acceptable levels through a radiation control program. The cost and dose to radiation workers could be added in to find an overall cost and dose for each option.

5. Elements of the Release Process

5.1 This standard guide describes the steps of an overall release process for radioactively contaminated concrete from decommissioning nuclear facilities. As one of the steps, it provides a method and supporting data to estimate the dose and cost impacts for various disposal options. This data can be used to select the best disposal option, which should be one that meets regulatory guidelines while reducing dose and cost. Release of any surface or volumetrically contaminated material must meet all criteria of the governing regulatory agencies.

5.2 Ref (**2**) described a 10-step release process in the publication, "Authorized Release of DOE's Non-Real Property: Process and Approach." These 10 steps are the basis for the, "Protocol for Development of Authorized Release Limits for Concrete at U.S. Department of Energy Sites" (**1**) and also for this guide.

5.2.1 Characterize property and prepare a description;

5.2.2 Determine whether applicable authorized or supplemental guidelines already exist;

5.2.3 Define authorized or supplemental guidelines needed;

5.2.4 Develop authorized or supplemental guidelines;

5.2.5 Compile and submit application for approval from the regulatory agencies;

5.2.6 Document approved guidelines in the public record;

5.2.7 Implement approved guidelines;

5.2.8 Conduct surveys/measurements;

5.2.9 Verify that applicable authorized or supplemental guidelines have been met; and

5.2.10 Release property.

5.3 *Characterize Property and Prepare a Description:*

5.3.1 Document the concrete's physical and radiological characteristics, including history. The concrete's history and condition can be used to estimate the depth of penetration of radioactive contamination, or this can be measured. Radiological surveys must be done to determine the isotopes and level of radioactive contamination on the surface of the concrete.

5.4 *Determine Whether Authorized Release Guidelines Already Exist:*

5.4.1 If surface or volumetric activity release guidelines exist, and the concrete is below those levels, the concrete can be released through approved regulatory methods. Documents including ANSI/HPS N13.12-1999, U.S. NRC Regulatory Guide 1.86, and others may provide applicable release guidelines. In any case, this standard guide can be used to complete an analysis of the dose and cost for various disposal options and select the best one. All required regulatory approvals must still be obtained before releasing the concrete.

5.4.2 If no existing guidelines apply, this standard guide can be used to estimate the ramifications of each disposal option, select the best disposal option, and then apply for approval to release the material based on these data. Such releases could be done on a case-by-case basis, or to set a new authorized release limit.

5.5 *Define What Authorized or Supplemental Guidelines are Needed:*

5.5.1 If authorized release guidelines do not exist, define what type of guidelines need to be developed:

5.5.1.1 Surface or volumetric contamination;

5.5.1.2 One-time or routine release;

5.5.1.3 Restricted or unrestricted release.

5.6 *Define Authorized or Supplemental Guidelines:*

5.6.1 Estimate the dose and cost for the various disposal options. Each disposal option consists of a set of actions such as decontamination and disposal. The dose and cost of a disposal option depend upon the actions that make up that option. Five actions are defined in the appendices: decontamination, demolition/crushing, packaging/transportation, reuse, and disposal/entombment. The appendices provide the methodology and supporting data to estimate the dose and cost of each action. To evaluate a disposal option, use the applicable sections in the appendices to calculate the dose and cost for each action in the disposal option. Then sum the dose and cost from all of the applicable actions to find the total dose and cost for that disposal option.

5.6.2 The dose estimate is based on the isotopes present, the estimated or measured depth of penetration, and the disposal option. The cost is based on factors associated with the disposal option, such as decontamination, transportation, and disposal. The cost analysis information here does not include cost avoidance through such things as schedule acceleration and reduced surveillance. Formulas and tables of unit-dose and unit-cost data for estimating the dose and cost are in the appendices. However, if site-specific information (such as cost and decontamination factors) is available, it should be used instead of the general information provided here.

5.6.3 After completing a detailed analysis of the estimated dose and cost for each option, compare the results and choose the best option. The best option is likely to be the one that meets regulatory guidelines while reducing dose and cost. The data can be used to support release of the concrete if release guidelines already exist. If release guidelines do not exist, the data can be used to establish a basis to request release of the concrete either on a case-by-case basis or to set new release guidelines.

5.7 *Compile and Submit an Application for Approval to Release Material:*

5.7.1 Present the results of the analysis for the chosen alternative to the governing regulatory agencies to request permission to release the concrete. Document any limitations or restrictions on the use of the concrete (such as decontamination to a certain level), and any comments or recommendations by federal, state, or regulatory agencies in the application. In addition, attach the survey procedures and results to the application.

5.8 *Document the Approved Guidelines in the Public Record:*

5.8.1 Document the planned release of concrete in the public record to provide the public with information about radiation levels and expected dose.

5.9 *Implement the Approved Guidelines:*

5.9.1 Once the governing regulatory agencies approve the release, the approved guidelines can be implemented. This should be done in compliance with all required regulations and site specific procedures and requirements.

5.10 *Conduct Surveys/Measurements:*

5.10.1 Conduct radiological surveys to show that the concrete meets applicable release guidelines. Previously conducted surveys can be used if the documentation is sufficient to meet regulatory requirements. Documentation should show that surveys were done according to site-specific procedures and should include survey results. Guidelines such as Guide E1893 may provide useful information about conducting surveys.

5.11 *Verify that Applicable Authorized or Supplemental Guidelines Have Been Met:*

5.11.1 Compare the survey results with the release guidelines to verify that the release guidelines have been met and document the results.

5.12 *Release Material:*

5.12.1 Before releasing the concrete, verify that all of the applicable regulations and procedures have been met. When compliance with all requirements has been verified and documented, the concrete may be released under direction of the governing regulatory agencies.

6. Quality Assurance

6.1 This standard guide addresses release of concrete that was previously radioactively contaminated, so quality assurance principles and methods should be applied both in the initial surveys and data collection, and in estimating the dose and cost of disposal options. Care should be taken to ensure that all work is done according to appropriate quality assurance methods and procedures. These quality assurance procedures should be established before initiating the calculations contained in the appendices. Quality assurance procedures are especially important when using site-specific data for the calculations in Appendix X1.

7. Use of the Appendices

7.1 Appendix X1 through Appendix X5 provide details about how to complete step 5.6 to estimate the dose and cost for various disposal options. The methodology and formulas are presented in Appendix X1, while Appendix X2 through Appendix X5 provide unit-dose factors, unit-cost factors, and other data that can be used in the formulas. After using the methodology and data in the appendices to complete step 5.6, the resulting estimates of dose and cost can be used to select the best disposal option and proceed through the remaining steps of the process.

APPENDIXES

(Nonmandatory Information)

X1. METHODOLOGY TO ESTIMATE DOSE AND COST FOR DISPOSAL OPTIONS FOR CONCRETE FROM D&D OF NUCLEAR FACILITIES

INTRODUCTION

Adapted from the Argonne report, "Protocol for Development of Authorized Release Limits for Concrete of U.S. Department of Energy Sites," (**1**).

X1.1 These sections describe the methodology used to estimate the costs and nonradiation worker doses for the disposal options. Seven general options are described here. Other options may be feasible, and can usually be analyzed as subsets of these general options. The options may include:

X1.1.1 Decontaminate, dispose of all low-level radioactive waste (LLW), crush and reuse as roadbed material.

X1.1.2 Crush without decontamination and reuse as road-bed material.

X1.1.3 Decontaminate, dispose of all LLW, demolish, and dispose of the decontaminated material as construction debris, or reuse as backfill.

X1.1.4 Demolish, without decontamination and either dispose as construction debris, or reuse it as backfill.

X1.1.5 Demolish without decontamination and dispose of all materials as LLW.

X1.1.6 Decontaminate the structure and reuse.

X1.1.7 Demolish with or without decontamination and entomb the demolished material.

X1.2 For each of the options, one or more of the following individual actions may apply:

X1.2.1 Decontamination;

X1.2.2 Demolition/crushing;

X1.2.3 Packaging/transportation;

X1.2.4 Reuse; and

X1.2.5 Disposal/entombment.

X1.2.6 The dose and cost calculation methods for each action are discussed in the individual sections of this appendix. To find the total nonradiation worker dose for each disposal option, the dose and cost for all applicable actions need to be summed. Table X1.1 provides a list of the options and the applicable sections of this appendix for estimating the costs and associated radiological doses.

X1.2.7 The costs or radiological doses (when applicable) can be estimated by using unit-cost or unit-dose factors. The unit-cost factors were obtained from such sources as Refs (**2, 3**) and (**4**) and others. The unit-cost factors for the applicable sections are provided in the individual sections and in Appendix X2 through Appendix X5. Unit-dose factors are used to estimate the radiological doses to members of the public from the reuse or disposal of concrete materials. These factors were generated with a suite of computer codes such as RESRAD (**5**), RESRAD-BUILD (**6**), RESRAD-RECYCLE (**7**), TSD-DOSE (**8**) and RISKIND (**9**). The unit-dose factors are presented in Appendix X2 through Appendix X5 and discussed in the specific sections below. These calculations assume that source distribution throughout the mass is uniform, and that no hot spots exist. If significant variations of source throughout the mass or in the surface distribution exist, these should be taken into account with more detailed analysis and calculations. Radiological doses are estimated only for nonradiation workers (that is, workers not already part of a radiation protection program). Although doses for radiation workers are not included here, they should be added when comparing the comprehensive cost and dose for each option. For the cost components, if site-specific or process-specific costs are available, then those values should be used instead of the unit-cost factors presented in this document.

X1.3 *Decontamination*—For contaminated concrete materials, decontamination can remove the amount of contamination on the material. In general, contaminants are less likely to migrate into the concrete when the surface is painted or coated. In dry areas, contaminant migration into unpainted concrete will probably be limited to the top ¼ in. If the concrete has been exposed to contaminated liquids for long periods, or is cracked, the contaminants may migrate farther into the concrete matrix. The process rates and costs for decontamination can vary greatly because of the large number of factors that affect technology efficiency and effectiveness. A common technique for removing fixed contamination from concrete walls and floors is the use of hand-held or automated scabbling units. These units mechanically remove a thin layer (⅛ to ¼ in.) from the surface of the concrete. Another commonly used technique for removing loose contamination is spraying the surface with a nontoxic cleaner and wiping, although strippable coatings have also been used with success. The use of water and abrasive blasting is limited because of problems with handling the waste that is generated. For each decontamination method considered, the decontamination efficiency, volume of waste generated, and cost need to be calculated. The decontamination efficiency will be used to estimate the dose from reuse or disposal. The volume of waste generated will be used to estimate the transportation and disposal costs. It is assumed that the decontamination worker is already part of an ALARA program, so this dose is not included here. To support completion of the formulas in the decontamination module, Appendix X2 has unit operational cost, production rates, and waste generation information for some decontamination methods. The waste from decontamination activities will be disposed of in a LLW radioactive disposal site.

TABLE X1.1 Concrete Disposal Options and the Corresponding Cost and Dose Assessment Sections

Options	Appendix Sections
Decontaminate the concrete material, dispose of all LLW, and crush and reuse the decontaminated material	Decontamination, Demolition/Crushing, Packaging/Transportation, Reuse, and Disposal
Crush and reuse the concrete without decontamination	Demolition/Crushing, Packaging/Transportation, and Reuse
Decontaminate the concrete, dispose of all LLW, demolish the structure, and dispose of the decontaminated material as construction debris (nonradiological landfill) or reuse as backfill	Decontamination, Demolition/Crushing, Packaging/Transportation, Reuse, and Disposal
Demolish the structure and dispose of the concrete material as construction debris or reuse as backfill (nonradiological landfill—no decontamination)	Demolition/Crushing, Packaging/Transportation, Reuse, and Disposal
Demolish the structure and dispose of all materials as LLW	Demolition/Crushing, Packaging/Transportation, and Disposal
Decontaminate the building and reuse as office space	Decontamination, Packaging/Transportation, Reuse, and Disposal
Demolish the building and entomb on-site	Demolition/Crushing, and Disposal/Entombment

X1.3.1 *Decontamination Efficiency*—Decontamination efficiency (D_{EF}), a measure of the amount of contamination left after decontamination, must be estimated so that the dose from either reuse or disposal after decontamination can be estimated. The decontamination efficiency is defined here to be the inverse of the decontamination factor (*DF*) (that is, $D_{EF} = 1/DF$). The D_{EF} value of 0 is interpreted as meaning all radioactive material has been removed from the surface of the concrete material; the D_{EF} value of 1 means no decontamination was performed. Generally, decontamination is limited to surface-contaminated concrete materials; hence, for most activated volumetrically contaminated concrete, the decontamination efficiency should be set equal to 1.

X1.3.1.1 If field measurements are available, the decontamination efficiency is derived in the following manner:

$$D_{EF} = \frac{A_{Final}}{A_{Initial}} \tag{X1.1}$$

where:

A_{Final} = total activity, dpm/100 cm^2, after decontamination, and
$A_{Initial}$ = total activity, dpm/100 cm^2, prior to decontamination.

X1.3.1.2 If no field measurements are available, the decontamination efficiency can be estimated for contamination distributed uniformly throughout a given thickness of the concrete material as:

$$D_{EF} = \left[1 - \left(\frac{RR}{T_C}\right) \times P\right] \tag{X1.2}$$

where:

D_{EF} = decontamination efficiency applied to all isotopes,
RR = removal rate, thickness/pass,
P = number of passes or treatments, and
T_C = thickness of the contamination.

X1.3.1.3 Appendix X2 lists some decontamination technologies for both loose and fixed contamination and provides estimated parameter values for the removal rate.

X1.3.2 *Waste Generation*—The total amount of waste generated during decontamination is used as input when estimating the cost associated with the transportation of the decontamination wastes to a LLW disposal facility. For decontamination technologies that provide a waste generation rate in units of cubic feet of waste generated per square foot of material treated (ft^3/ft^2), the total amount of waste generated is estimated as:

$$WasteGen = Area \times WGR + Other \tag{X1.3}$$

where:

$WasteGen$ = total amount of waste generated, ft^3,
$Area$ = area of the concrete material being decontaminated, ft^2,
WGR = waste generation rate, ft^3/ft^2, and
$Other$ = other wastes generated during the decontamination process (personal protective equipment [PPE], chemicals, etc.).

X1.3.2.1 For fixed contamination, decontamination is performed by physically removing layers of concrete. Hence the total amount of waste generated is estimated as:

$$WasteGen = Area \times RR \times P + Other \tag{X1.4}$$

where:

RR = removal rate (thickness/pass), and
P = number of passes or treatments.

X1.3.2.2 If a concrete structure is decontaminated with abrasive blasting, the total amount of waste generated is a combination of both factors and is therefore estimated as:

$$WasteGen = Area \times \left[\left(RR \times P\right) + WGR\right] + Other \tag{X1.5}$$

Appendix X2 provides the waste generation rates for some decontamination technologies.

X1.3.3 *Decontamination Costs*—Three components must be considered in estimating the cost for the decontamination technologies: (*1*) amortization cost for the equipment, (*2*) process costs, and (*3*) labor costs. The amortization cost for the equipment takes into account the cost of purchasing the decontamination equipment, the equipment life, and the interest rate. The process cost is the cost of operating the equipment, which may include supplies required to run the equipment or may include costs for routine maintenance. The labor costs are the costs associated with workers using the decontamination equipment. Although other costs may also be associated with decontamination, only these costs are considered here because they would contribute the most to the total cost associated with decontamination activities. The hourly amortization cost (EC), over the life of the equipment is given as:

$$EC = \left[\frac{PI\left(1+I\right)^N}{\left\{\left(1+I\right)^N - 1\right\}}\right] \times \frac{1}{8760} \tag{X1.6}$$

where:

P = purchase cost of the equipment,
I = interest rate,
N = equipment life, yr, and
1/8760 = conversion from per year to per h.

X1.3.3.1 The total cost for decontamination operations is estimated as:

$$Decon\$ = EC \times UT \times A \times P \times \left(PC + \frac{1}{PR} \times HC\right) \tag{X1.7}$$

where:

$Decon\$$ = total cost for decontamination, \$,
EC = amortization cost for the decontamination equipment, \$/h,
UT = equipment use time for decontamination operations, h,
A = area, ft^2,
P = number of passes or treatments,
PC = process cost, \$/ft^2/pass or treatment,
PR = production rate, ft^2/h/pass or treatment, and
HC = hourly cost for a decontamination worker, \$/h.

The values for the capital cost, production rates, and hourly costs for some decontamination technologies are provided in Appendix X2.

X1.4 *Demolition/Crushing*—For all options except building reuse, the concrete material would undergo some demolition and possibly further processing, including crushing. The methods used to demolish concrete structures include controlled blasting and use of wrecking balls, backhoe-mounted rams, rock splitters, paving breakers, and others. The size and type of concrete material to be demolished would determine the actual method selected. As they are for decontamination, the demolition workers are assumed to be part of a radiation protection program; hence, the radiological doses associated with demolition are already kept ALARA and are not included here. The unit-cost factor for demolition has been estimated at $1/ft^2$ ($10.76/m^2$) of building area (**3**). The cost for demolition is estimated as:

$$Demol\$ = A \times DemolCF \quad (X1.8)$$

where:

$Demol\$$ = cost for demolition, $,
A = building area, ft^2, and
$DemolCF$ = demolition unit cost factor, $/ft^2$.

X1.4.1 For the options that involve further processing of the concrete material by crushing, the cost for crushing is estimated as:

$$Crush\$ = M \times CF \quad (X1.9)$$

where:

$Crush\$$ = cost for crushing the concrete material, $,
M = mass of the material, metric ton (MT), and
CF = unit cost factor for crushing the material.

Ref (**3**) provides a lognormal distribution for the cost associated with concrete crushing. On the basis of the parameters of the lognormal distribution, the 50th percentile value for the unit-cost factor for crushing and screening the concrete material was estimated at $23/MT.

X1.4.2 The process of crushing concrete into aggregate for reuse generates unusable fines that must be sent to a disposal facility. The mass of fines generated has been estimated to be approximately 30 % of the mass of the pre-crushed concrete (**3**). Hence, the amount of fines (M_{Fines}) is estimated as:

$$M_{Fines} = F \times M \quad (X1.10)$$

where:

F = fraction of mass converted to fines, and
M = mass of the pre-crushed concrete.

X1.5 *Packaging/Transportation*—This section provides the means for estimating the costs and risks associated with packaging and transporting the concrete materials and any waste generated from decontamination, demolition, and crushing activities. To complete this section, the distance, number of shipments, and associated costs should be documented. Unit-cost data for packaging, transport, and disposal is in the appendix. The methodology for estimating the dose to a truck driver transporting these materials is applied to the options involving transport of the concrete material to a nonradiological landfill. This dose is proportional to the number of shipments, amount and type of isotopes, and distance. For such options, the assumption is made that the truck driver is not a radiation worker and, hence, is not part of a radiation protection program, so the dose is included here. However, a truck driver transporting LLW to a radioactive disposal site is not included, as it is assumed that this person is already part of an ALARA program. In all cases, dose to people living along the transportation corridor should be included.

X1.5.1 *Packaging/Transportation Costs*—Two components are involved in estimating the costs of transportation activities: packaging costs and the costs associated with transportation. The packaging costs are estimated by evaluating the expenses associated with packaging the concrete into 55-gal drums, B25-type containers, or soft-sided containers.

X1.5.1.1 For 55-gal drums, the number of containers can be estimated on the basis of the mass of the material by using the equation below:

$$Containers = \frac{M}{\rho} \times \frac{1}{Vol_{container}} \quad (X1.11)$$

where:

M = mass of the material,
ρ = bulk density, and
$Vol_{container}$ = volume of the shipping container.

X1.5.1.2 If the volume of the material (rather than the mass of the material) is provided, then the number of containers required can be estimated by using this equation:

$$Containers = \frac{V}{Vol_{container}} \quad (X1.12)$$

where:

V = volume of the material, and
$Vol_{container}$ = volume of the cargo container (provided in Appendix X3).

X1.5.1.3 The B25 and soft-sided containers have weight restrictions that must be met. These restrictions are approximately 8000 lb per container for B25 containers and 24 000 lb for soft-sided containers. Therefore, if the amount of material placed into the cargo container is limited by weight, the number of containers can be estimated from:

$$Containers = \frac{M}{K} \quad (X1.13)$$

where:

M = mass, lb, and
K = weight restriction, lb.

X1.5.1.4 If the volume of the material is known, then the number of containers can be estimated as:

$$Containers = \frac{V \times \rho}{K} \quad (X1.14)$$

where:

V = volume, ft^3, and
ρ = bulk density, lb/ft^3.