INNOVATIVE TECHNOLOGY
Summary Report

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RESRAD-Build

A Model to Estimate Dose From
Contaminated Structures

Deactivation and Decommissioning
Focus Area

Prepared for
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INNOVATIVE TECHNOLOGY

Summary Report

RESRAD-Build

A Model to Estimate Dose From Contaminated Structures

OST Reference #2103

Deactivation and Decommissioning Focus Area

Demonstrated at
Hanford Site
Richland, Washington

INNOVATIVE TECHNOLOGY
Summary Report

Purpose of this document

Innovative Technology Summary Reports are designed to provide potential users with the information they need to quickly determine if a technology would apply to a particular environmental management problem. They are also designed for readers who may recommend that a technology be considered by prospective users.

Each report describes a technology, system, or process that has been developed and tested with funding from DOE's Office of Science and Technology (OST). A report presents the full range of problems that a technology, system, or process will address and its advantages to the DOE cleanup in terms of system performance, cost, and cleanup effectiveness. Most reports include comparisons to baseline technologies as well as other competing technologies. Information about commercial availability and technology readiness for implementation is also included. Innovative Technology Summary Reports are intended to provide summary information. References for more detailed information are provided in an appendix.

Efforts have been made to provide key data describing the performance, cost, and regulatory acceptance of the technology. If this information was not available at the time of publication, the omission is noted.

All published Innovative Technology Summary Reports are available on the OST Web site at http://ost.em.doe.gov under "Publications."

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SECTION 1

SUMMARY

The RESRAD-BUILD model was developed by Argonne National Laboratory (ANL) to estimate dose to a hypothetical receptor from a radiologically contaminated building or structure. The RESRAD-BUILD technology can calculate dose for a variety of hypothetical scenarios, decay-time intervals, and radionuclides that are selected by the user for site-specific conditions. Using RESRAD-BUILD to calculate dose, only the building material that may pose a risk must be demolished and disposed. Use of the model resulted in agreement with the U.S. Environmental Protection Agency (EPA) that the deepest portions of below grade slightly contaminated concrete tunnels could be abandoned in place as part of the Hanford Site C Reactor decommissioning plans. The traditional (baseline) technology is to demolish and dispose of all structural material (including below grade reactor pipe tunnel concrete structures) even if this material is only slightly contaminated. Agreement with the regulators to avoid complete removal is needed. The RESRAD-BUILD improved technology allowed maintenance of the project schedule (which otherwise would have been delayed by 6 weeks) and reduced costs by 50%, a saving of $147,000 for 298 m^3 (364 yd^3) of concrete that did not have to be removed.

■ Technology Summary

This section summarizes the demonstration of an improved characterization technology, RESRAD-BUILD, developed by Argonne National Laboratory (ANL). The RESRAD-BUILD model is an exposure pathway and analysis code used to determine whether radiologically contaminated buildings and structures can be free released for a specific land use (e.g., residential or industrial). The model provides estimates of dose to a hypothetical receptor from the structure. The RESRAD-BUILD technology can calculate dose from variety of site-specific hypothetical scenarios, decay-time intervals, and radionuclides. The RESRAD-BUILD model was demonstrated for the U. S. Department of Energy's (DOE) C Reactor Interim Safe Storage (ISS), Large-Scale Demonstration and Deployment Project (LSDDP) at the Hanford Site in Richland, Washington.

When using the RESRAD-BUILD code, specific project assumptions must be developed with the appropriate regulatory agencies, especially the cleanup criteria and the exposure scenario to be used. The C Reactor demonstration of RESRAD-BUILD modeled hypothetical future use of below grade portions of the reactor building complex. A residential exposure scenario with a cleanup criteria of 15 mrem/yr above background (Environmental Protection Agency [EPA] draft guidance) was used to coordinate decommissioning with adjacent ongoing remedial actions conducted in accordance with an existing *Comprehensive Environmental Response, Compensation, and Liability Act of 1980* (CERCLA) Record of Decision.

Problem Addressed

DOE's nuclear facilities require characterization and documentation of the results as part of planning and decision making for decontamination and decommissioning (D&D) projects and to release areas that have been cleaned up. Evaluation of buildings and structures that are only slightly contaminated to allow unrestricted release is an important component of the D&D program. Currently, buildings and structures that have slight radioactive contamination are demolished and the debris is considered to be solid low-level radioactive waste (SLLRW) and is disposed of in a SLLRW burial facility. This method is costly, labor intensive, adds long periods of time to the project schedule, and may not be the best approach.

Features and Configuration

- Can be installed on most personal computers
- Applicable to a variety of hypothetical scenarios and final land-use alternatives
- Capable of providing well-documented estimates of annual exposure
- Has flexible report generation capabilities that are easily integrated with existing software.
- Includes default parameter-value file and dose conversion-factors files
- Uses customized user-friendly input windows or instructions for input information
- Uses graphic information to show the position of the sources and receptors.

Potential Markets and Applicability

The technology is suitable for DOE nuclear facility D&D sites or similar sites that must evaluate slightly contaminated buildings and structures to facilitate property transfer or release. By using RESRAD-BUILD with various hypothetical scenarios, hypothetical human receptors, radionuclides, decay times, and input parameters, the user can obtain clear, concise, and comprehensive annual exposure estimates for building and structure characterization in support of D&D activities.

Advantages of the Improved Technology

Category	Comments
Cost	Implementing the RESRAD-BUILD technology for below grade reactor pipe tunnel concrete structures resulted in a savings of 50% of the baseline estimated costs and improved the D&D project schedule at C Reactor.
Performance	The RESRAD-BUILD model produced well-documented conservative calculations of annual exposure to a hypothetical receptor, indicated that slightly contaminated below grade structures can remain in place, and won regulatory approval.
Implementation	No special site services were required to implement the RESRAD-BUILD technology. Agreement with the regulators to avoid complete removal is needed.
Secondary Waste Generation	RESRAD-BUILD does not generate secondary waste.
ALARA and Safety	Use of the RESRAD-BUILD enhances as low as reasonably achievable (ALARA) practice and safety for the D&D crews compared to the baseline because by using RESRAD-BUILD, some or all of the demolition and disposal activities may not be required. However, ALARA is not enhanced for the hypothetical dose recipient.

Operator Concerns

- The regulatory approval process and agreement on the scenarios and input parameters may be time-consuming and costly. As with any radiological pathway analysis and calculations, care must be taken in selecting the hypothetical scenarios, hypothetical receptor activities, input parameters, and the radionuclides of potential concern and their activities.
- The code is limited to four different geometries (i.e., point, line, disk, and cylinder). There are also limitations in source size selection due to the geometries, especially for disk and cylindrical sources.
- RESRAD (soils) must be used in conjunction with RESRAD-BUILD to model fate and transport of radionuclides through the soil column to groundwater.

Skills/Training

The training required to run the code properly is less than one day in length, provided that the trainees are proficient in standard computer software operation. A person trained in a radiological discipline and who has the knowledge of the site setting, site historical operation, site contamination, and radiological modeling is required to help select proper input parameters.

■ Demonstration Summary

This report covers the period August and September 1997, when the RESRAD-BUILD code was assessed.

Demonstration Site Description

At its former weapons production sites, DOE is conducting an evaluation of improved technologies that might prove valuable for facility D&D. DOE's Office of Science & Technology/Deactivation and Decommissioning Focus Area, in collaboration with the Environmental Restoration Program, is undertaking a major effort of demonstrating improved technologies at its sites nationwide, and if successfully demonstrated at the Hanford Site, these improved technologies could be implemented at other DOE sites and similar government or commercial facilities. As part of placing C Reactor into ISS, contaminated structures outside of the safe storage enclosure (SSE) must undergo D&D unless the contamination levels are shown to be acceptable when considering possible uses for the land. The below grade pipe tunnels outside of the ISS have slightly contaminated concrete ceilings, walls and floors, and steel pipe and gratings.

Regulator Issues

- The RESRAD-BUILD model is an exposure pathway analysis code that can be used for characterizing and releasing slightly contaminated structures and buildings; therefore, there are no special regulatory permits required for use of the model. However, approval of regulatory agencies (e.g., EPA for a CERCLA site) for the use and application of the code must be obtained when it is used to free release buildings and structures.

- The RESRAD-BUILD model can yield well qualified estimates and establish whether the potential future total dose to a human is less than the 15 mrem/year (draft EPA guidance limit).

Technology Availability

This technology is available through ANL. DOE contractors can obtain the code free of cost, and the private sector can obtain the code for a nominal cost -- a few hundred dollars.

Technology Limitations/Needs for Future Development

- Disk and cylindrical source size selections are limited.

- As with all mathematical models, the code should be continually evaluated and improved for pathway models, exposure dose calculations, format variety, and user interface.

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Others
All published Improved Technology Summary Reports are available on the Internet at http://em-50.em.doe.gov. The Technology Management System, also available through the EM50 web site, provides information about Office of Science and Technology (OST) programs, technologies, and problems. The OST reference # for RESRAD-BUILD, a Model to Estimate Dose from Contaminated Structures, is No. 2103.

TECHNOLOGY DESCRIPTION

■ Overall Technology/Process Definition

DOE's nuclear facilities require characterization and documentation of the results as part of planning and decision-making for D&D projects and to release areas that have been cleaned up. Many of the structures are slightly contaminated with radionuclides fixed within the structural material. Evaluating these structures for unrestricted release is an important component of the D&D program. Structures that have only slight radioactive contamination have been demolished, and the debris is considered to be SLLRW and has been disposed of in a SLLRW burial facility. This method is very costly, labor intensive, adds long periods of time to the project schedule, and may not always be necessary.

The RESRAD-BUILD computer code can calculate the dose to a hypothetical receptor from residual radioactivity in the structural material to determine if it actually is SLLRW. Thus, RESRAD-BUILD provides an attractive alternative to traditional methods of D&D for slightly contaminated buildings and structures. The RESRAD-BUILD model is based on the most current scientific information, pathway analysis methods, and electronic data generation and storage methods. The system consists of these distinct components:

Components

- Main executable file
- Default parameter-value file
- Dose conversion-factors file
- Template input file
- Customized user-friendly input
- Graphic information to show the position of the sources and receptors.

Overview

The RESRAD-BUILD model was developed by ANL. It provides estimates of dose to a hypothetical receptor from a radiologically contaminated building or structure. The RESRAD-BUILD technology can calculate dose from a variety of hypothetical scenarios, decay-time intervals, and radionuclides. The model allows many of the input parameters to be selected by user.

RESRAD-BUILD is characterized by the following features, capabilities, and configuration:

- Can be installed on most personal computers (PCs)
- Capable of providing well-documented estimates of annual exposure to a hypothetical human receptor from variety of pathways and radionuclides
- Adaptable to a variety of building and structure configurations
- Allows electronic storage of calculated annual exposure results by pathways, radionuclides, and totals for a variety of decay-time intervals
- Has flexible report generation capabilities that are easily integrated with other software.

Essentially, the RESRAD-BUILD computer code is a pathway analysis model designed to evaluate the potential radiological dose incurred by a hypothetical human receptor who works or lives in a radiologically contaminated building. The radioactive material in the building can be released into the indoor air by several mechanisms such as the following:

  - Diffusion (occurs when contaminants come off the contaminated structure for any reason and spread freely into the surrounding air)
  - Mechanical removal (occurs when there is a building renovation or physical work)

- Erosion (occurs when the contaminated structure loses some of its material to the environment due to natural aging effects.

The transport of radioactive material inside the contaminated building from one room to another is calculated with an indoor air quality model. The air quality model considers the transport of the radioactive dust particulate and radon progeny due to air exchange, deposition and resuspension, and accounts for radionuclides decay and ingrowth.

A single run of the RESRAD-BUILD code can model a building or structure with up to the following:

- Three rooms or compartments
- Ten distinct source locations
- Ten receptor locations.

Six exposure pathways are considered in the RESRAD-BUILD code:

- Direct external exposure to source radionuclides
- Direct external exposure to redeposited radioactive material
- Direct external exposure to resuspended radioactive material in air (air submersion)
- Inhalation of airborne radioactive particulates
- Inhalation of aerosol indoor radon progeny
- Inadvertent ingestion of radioactive material, directly from the source material or resuspended/redeposited radioactive materials.

A shielding material can be specified between each source-receptor pair for direct external pathway dose estimation. The code also allows the user to construct multiple hypothetical exposure scenarios by adjusting the model input parameters. Figure 1 lists default parameters used by the RESRAD-BUILD model.

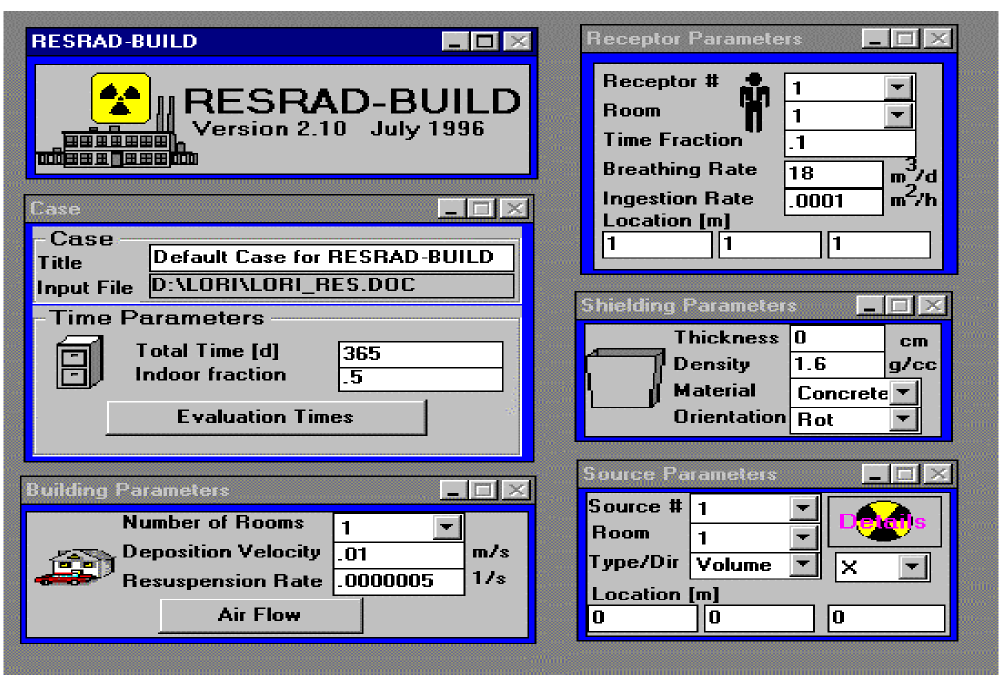

Figure 1. RESRAD-BUILD start window showing parameters.

System Operation

Preparation

Approximately two weeks are required to determine applicability of RESRAD-BUILD to a specific situation and to develop appropriate data. Additional tasks involve interfacing with regulators and performing radiological characterization surveys.

Setup and Operation

A half day is required to set up and test the software initially and to run a site-specific scenario. The following steps are performed to run a scenario:

- Install the software on the PC
- Run the sample cases provided with the software package
- Check the results of the sample runs to ensure that the software is properly installed
- Check the input parameters windows (if operating the code in the Microsoft Windows™ environment) or menus (if operating the code in the DOS environment)
- Select and input the parameters for the site-specific hypothetical scenarios
- Save the input file for each case
- Run the case
- Save the results into an output file.

Under ideal conditions (if the input parameters and the geometries are predetermined), preparing the input file and running a case could take less than one hour.

™Microsoft Windows is a registered trademark of Microsoft Corporation, Redmond, Washington.

■ Demonstration Plan/Overview

Site Description

The demonstration was conducted at the C Reactor building at DOE's Hanford Site. One purpose of the LSDDP is to demonstrate and document performance data and costs for improved technologies that will result in more cost effective D&D and will aid in placing the C Reactor into an ISS mode for up to 75 years, or until the final disposal of the reactor's core is completed. The ISS objectives include placing the reactor in a condition that will 1) not increase future decommissioning costs, 2) minimize the potential for releases to the environment, and 3) reduce the frequency of inspections, thereby reducing potential risk to workers.

Model results were applied to below grade pipe tunnels at the C Reactor building. Instead of demolishing and removing these concrete structures that lie outside of SSE as originally planned, surfaces were surveyed and sampled, and the floors and most of the walls were left as is. The tunnel ceilings and the upper one meter of the tunnel walls were demolished, and approximately half of the concrete debris was removed and half was allowed to fall to the floor of the tunnels. The remaining tunnel walls and floors remained intact. Also, steel piping and grating were surveyed and remained. This demonstration was the first use of RESRAD-BUILD to limit large-scale demolition/removal of a contaminated structure at a DOE site.

Demonstration Objectives

The objectives of the demonstration included the following tasks:

- Compare the RESRAD-BUILD model against other models to determine if the results produced are consistent.
- Establish an average and a range for parameters to be used by the RESRAD-BUILD model at C Reactor.
- Establish four hypothetical scenarios to be used by RESRAD-BUILD at C Reactor:

  1) Residential
  2) Recreational
  3) Excavation worker
  4) Industrial worker.

- Evaluate the cost of using RESRAD-BUILD for a specific structure or building against the estimated cost of the baseline (dismantling and removing the entire tunnel structures).
- Evaluate the effectiveness of RESRAD-BUILD as a tool for evaluating residual radioactive contamination in facilities and as a basis for releasing those facilities.
- Support the C Reactor ISS Project needs, including providing information for regulatory negotiations and release of structures.

The concept was reviewed with the EPA representative. A draft "Guidance for Radiological Release of DOE Real Property Under ERC Management" was developed in October 1997 and was approved by EPA. Proposed exposure scenarios and sampling/analysis requirements were reviewed with the EPA representative and agreed upon, and input parameter values were selected and submitted to the EPA. Model runs were performed during July, August, and September 1997 and were reviewed with the EPA representative. The timeframe for other activities was as follows:

- Sampling/analysis requirements were incorporated into the C Reactor D&D Project Sampling and Analysis Plan (SAP), which was reviewed and approved by EPA in April 1998.
- Radiological characterization surveys of the pipe tunnels were performed in May 1998.

- The pipe tunnel ceilings and top one meter of walls were caved in, and sample analyses results and RESRAD-BUILD final results were obtained from April through June 1998.

- A verification report summarizing survey results, sample analyses results, and RESRAD-BUILD final results is being issued to EPA at the end of the C Reactor D&D Project (September 1998).

■ Technology Performance/Results

RESRAD-BUILD

Four hypothetical exposures scenarios were modeled. A brief description of each scenario used is described below:

- **Residential hypothetical scenario** consisted of a three-room, two-story house. The individual hypothetical receptor was assumed to live in the house 350 days/year and to spend 12 hours/day inside the house. The living room was assumed to the largest room (4 m by 6 m) and the other two rooms (a bedroom and an office) were assumed to be the same size (3 m by 4 m). It was assumed that the hypothetical receptor spends 8 hours/day sleeping in the bedroom, 3 hours/day in the living room, and 1 hour/day at home-related office work.

- **Recreational hypothetical scenario** consisted of one large room (10 m by 10 m), and it was assumed that the hypothetical receptor would go to this area twice a season, spend the weekend there, and use the site as a rest area. It was assumed that the receptor would spend 16 days/year in this area, and 10 hours/day would be indoors.

- **Excavation worker hypothetical scenario** consisted of one large room (20 m by 20 m), and it was assumed that the hypothetical receptor would go to this area, excavate the structure, discover the room, and spend two weeks (10 days, 8 hours/day) in the excavated area before the worker notices that the structure is unusual and leaves the area.

- **Industrial worker hypothetical scenario** consisted of a one large room (20 m by 20 m), and it was assumed that the hypothetical receptor would go to this area for surveillance and maintenance once every two weeks (25 days/year) and would spend 2 hours each time indoors to perform the required tasks.

Nine evaluation times (the times that exposure to the hypothetical receptor were calculated for) were selected:

- Present time (t = 0 y)

- 10 years from present (t = 10 y), arbitrary time frame suggested by EPA

- 35 years from present (t = 35 y), from Record of Decision specifications

- 75 years from present (t = 75 y), from Record of Decision specifications

- 100 years from present (t = 100 y), arbitrary time frame suggested by EPA

- 250 years from present (t = 250 y), arbitrary time frame suggested by EPA

- 500 years from present (t = 500 y), arbitrary time frame suggested by EPA
- 1,000 years from present (t = 1,000 y), EPA required for the Environmental Impact Statement (EIS) and waste storage

- 10,000 years from present (t = 10,000 y), EPA required for the EIS and waste storage.

Three different hypothetical receptor locations were assumed. The coordinates of each receptor location from a corner of each room were given in {X,Y,Z} format and are as follows:

- 1 m from the first wall, 1 m from the second wall, and 1 m from the floor
- 1.5 m from the first wall, 1.5 m from the second wall, and 1 m from the floor
- 2 m from the first wall, 2 m from the second wall, and 1 m from the floor.

Assumptions regarding the source geometry locations were the following:

- All walls and floors were contaminated.

- The depth of contamination in the structural material ranged from 0.5 cm to 5 cm.

- All sources were volumetric.

- Unit concentrations (1 pCi/g) of C Reactor radionuclides of potential concern were used to allow for easy normalization to all sample results.

- The source material was concrete.

The following model parameters were varied to observe their sensitivity in the model:

- Deposition velocity
- Resuspension rate
- Air exchange rate
- Breathing rate
- Direct ingestion rate
- Incidental ingestion rate
- Source thickness
- Source density
- Erosion rate.

Other Models

RESRAD-BUILD results were compared to another software program developed by Grove Engineering, Rockford, Illinois, entitled Microshield™ 4.0 (MS4). Both Microshield™ 4.0 (MS4) and the RESRAD-BUILD 2.1 were run for the same geometries, shield materials, receptor locations, and radionuclides to evaluate the variation in their predictions of exposure. MS4 is a point-kernel model that calculates the exposure rate more accurately than the deterministic method used by RESRAD-BUILD. The limits set by 10 CFR 835 for release of surfaces were matched to a volumetric source to estimate the equivalent radionuclide activity in the volume source.

The RESRAD-BUILD model was found to be more conservative in dose estimation (external exposure pathway) than the MS4 code. For example, in order to reach the 15 mrem/yr allowable limit, the MS4 shielding code estimated a concentration of 271 pCi/g of Cs-137/Ba-137m. For this same limit, the RESRAD-BUILD model predicted a concentration of only 112 pCi/g of Cs-137/Ba-137m. The MS4 shielding code allows for a better definition of source geometry than RESRAD-BUILD, which offers only four geometries. It should be noted that the
comparison of RESRAD-BUILD and Microshield™ was intended only as a rough arithmetic check on dose rates and curie levels. Only order-of-magnitude differences between results obtained using each code would be considered for further examination. For this demonstration, the results obtained using each code were consistent; therefore, RESRAD-BUILD was not examined further in this regard.

Baseline

™Microshield 4.0 is a registered trademark of Grove Engineering, Rockford, Illinois.

The estimated cost required to demolish, remove, and dispose of the entire below grade structure is included for comparison with the improved method. (See Section 5 and Appendix C.) The tunnels are mainly 2.1 to 4.9 m (7 to 16 ft) wide and 3.7 m (12 ft) high with 0.3-m (1-ft.)-thick walls and 20-cm (8-in.)-thick ceilings. The 9 tunnels are of various lengths, and the total volume of concrete involved is 542 m^3 (709 yd^3) The tunnel ceilings are at grade. The time required to demolish and remove 542 m^3 (709 yd^3) of concrete would be approximately 6 weeks. The tunnels contain 24 m^2 (259 ft^2) of steel grating and 1,526 m (5,005 linear ft) of steel piping, of which 198 m (651 linear ft) is 40.6 to 61 cm (16 to 24 in.) in diameter. If this large-bore portion of the piping were removed, it would have to be split longitudinally for surveying for proper disposal as low-level waste. The remaining piping, which is relatively small-bore, could be removed and sized with a heavy-duty shear with the concrete debris.

Meeting Performance Objectives

The objectives listed in the demonstration overview section were met. The main purpose of this demonstration was to evaluate the RESRAD-BUILD code as a pathway analysis code to estimate the annual exposure from contaminated buildings and structures. The RESRAD-BUILD code produced conservative results.

Comparison of Improved Technology to Baseline

Table 1 summarizes the performance and operation of the improved technology compared to the baseline technology.

Table 1. Summary of performance and operation - baseline versus improved technology demonstration

Activity or Feature	Baseline Technology	Improved Technology
Field time	It would take 6 weeks to remove the concrete.	Much less than baseline technology.(1)
Setup (2)	Could vary from days to weeks for each D&D activity.	Two weeks to develop data and ½ day to setup the program.
Flexibility	Depends on the tools and equipment used to perform the D&D. But predicted D&D activities would be much less flexible than the improved technology.	More flexible than baseline depends on scenario and input parameter selection.
Safety	Due to nature of operations there would more chance to have an accident.	Safer than baseline technology (no demolition activities).
Waste generation	Much more than the improved technology, including 542 m^3 (709 yd^3) of concrete, 1,526 m (5,005 linear ft) of steel pipe and 24 m^2 (259 ft^2) of steel grating.	None.
Utility requirements (3)	Depends on the tools and equipment used to perform the D&D. Diesel fuel and plant electric, air, and water and utility resource requirements could be intensive.	Minimal to none (110 VAC electric outlet).

Table 1. Summary of performance and operation - baseline versus improved technology demonstration

Activity or Feature	Baseline Technology	Improved Technology
Ease of Use/Training (3, 4)	Depends on the tools and equipment used to perform demolition activities. Extensive training is often required.	Easy to use the model (program) and train personnel to run the model.(5)

Table 1 Notes:

1. The improved system can be operated with one person for setup and running the code; therefore, improved labor efficiency.
2. Setup, as used to describe baseline, includes time to mobilize D&D equipment and tools, dress-up time, and preparation checks performed on D&D equipment and tools used for baseline technology. The RESRAD-BUILD setup requires time to load the computer code and run example cases to make sure the software operates properly.
3. The costs and effort to maintain baseline equipment would be much higher than for the RESRAD-BUILD software.
4. Training and ease of use are not applicable if RESRAD-BUILD is deployed by a subcontractor service.
5. In addition, a person trained in a radiological discipline and who has the knowledge of the site setting, site historical operation, site contamination, and radiological modeling is required to help select proper input parameters.

DOE facilities present a wide range of D&D working conditions. The working conditions for an individual job directly affect the manner in which D&D work is performed. Evaluations of the improved and baseline technologies presented in this report are based upon a specific set of conditions or work practices found at the Hanford Site and are presented in Table 2. This table is intended to help the technology user identify work item differences between the baseline and improved technologies.

Table 2. Summary of variable conditions

Variable	Baseline Technology	The RESRAD-BUILD Technology
Scope of Work		
Quantity and type of material	All the gas and water pipe tunnels, steel items, and concrete walls, floors and ceilings would be removed. Includes 198 m (651 LF) of large-bore pipe that must be split prior to disposal, 24 m^2 (259 ft^2) of grouting, and 541.7 m^2 (708.5 yd^3) of concrete.	All the gas and water pipe tunnels steel items and concrete floors and walls and caved-in ceiling would be left in place based on model runs.
Location of test area	The Hanford Site C Reactor water and gas pipe tunnels.	The Hanford Site C Reactor water and gas pipe tunnels.
Nature of work	Complete demolition and removal of concrete tunnel structures.	Exposure dose estimates surveys, sampling, and analyses, and release of the structures and areas (no decontamination or complete demolition).
Work Environment		
Level of contamination in the test areas	The demonstration area is not a radiation area. Any contamination that might be present is fixed.	The demonstration area is not a radiation area. Any contamination that might be present is fixed.
Condition of floor in test areas	Unobstructed.	Unobstructed.
Work Performance		
Compliance requirements	Must meet Appendix D, 10 CFR 835 (see Attachment 1 to Procedure 2.3.3 in BHI-SH-02, Vol. 2, *Safety and Health Procedures*, “Unconditional Surface Contamination Release.”)	Must meet DOE exposure limit of 15 mrem/year to a hypothetical receptor.
Work Process Steps		
Samples/surface surveys	D&D activities may require more surface surveys than baseline.	More core samples than baseline may be required for the RESRAD-BUILD model.

Table 2. Summary of variable conditions

Variable	Baseline Technology	The RESRAD-BUILD Technology
Demolition	All contaminated materials must be packaged and removed.	Only selected areas that exceed the compliance requirements would be removed.

Table 3 summarizes parameter values used for modeling at C Reactor (assumed values) and also lists the model default values that would be used in the absence of a defined input value. The model is most sensitive to values used for erosion rate and air exchange rate.

Table 3. Input parameters used for the RESRAD-BUILD demonstration

Input Parameter	Value Suggested	Model Default	Remarks
Deposition velocity (m/s)	0.001	0.01	Hanford specific parameter (maximum value). This parameter affects the inhalation and incidental ingestion exposure/dose.
Resuspension rate (per second)	5.0E-07	5.0E-07	This would affect the exposure/dose for incidental ingestion and inhalation pathways.
Building air exchange rate (per hour)	0.8	0.8	Based on the design of the buildings in Richland, Washington area (keeping doors and windows closed most of the time) the default value is a good representation of the air exchange rate.
Room air exchange rate (per hour)	3.0	1	Engineering computations indicate a range of 0.3 to 25 per hour depends on outdoor and indoor temperature difference. The time-weighted annual average is approximately 3. This directly affects the exposure dose via inhalation pathway.
Inhalation rate (m^3/d)	15 residential and recreational 30 industrial	18	EPA OSWER Directive 9200.4.18 recommendation for indoor/outdoor, residential/industrial activities. The inhalation pathway dose would be directly proportional to this value and the exposure dose will change accordingly.
Incidental ingestion rate (cm^2/h)	0.0001	0.0001	This parameter is directly related to the incidental exposure/dose rate but does not significantly affect the total exposure and dose for all pathways.
Source density (g/cm^3)	2.43	2.65	Affects the external exposure pathway exposure/dose. As density increases the exposure/dose contribution decreases.
Source thickness (cm)	0.5	15	Engineering sampling results indicated that the contamination did not penetrate the concrete walls beyond ~0.5 cm.
Source erosion rate (cm/d)	2.4E-08	2.4E-08	A very important parameter that affects most pathways contribution. As a function of time, inhalation and incidental pathways exposure/dose increases, but external exposure decreases.

Input Parameter	Value Suggested	Model Default	Remarks
Fraction of source released to air	0.01	0.1	Since the walls would be painted for both residential and industrial usage, the contaminated medium would not readily form an aerosol. The exposure pathways for inhalation and incidental ingestion would be directly affected by this parameter.

The model is also sensitive to the radioisotopes that are of concern. Long-term exposures computed by the model are most affected if transuranic isotopes are involved, while short-term exposures are most affected if fission fragments (e.g., strontium-90 and cesium-137) are involved.

Skills/Training

The training required to run the code properly is less than one day in length, provided that the trainees are proficient in standard computer software operation. A person trained in a radiological discipline and who has knowledge of the site setting, site historical operations, site contamination, and radiological modeling is required to help select proper input parameters.

Operational Concerns

- The regulatory approval process and agreement on the scenarios and input parameters may be time consuming and costly. Thus, as with any radiological pathway analysis and calculation, care should be taken in selecting the hypothetical scenarios, hypothetical receptor activities, input parameters, and the radionuclides of potential concern and their activities.

- The code is limited to four different geometries (i.e., point, line, disk, and cylinder). There are also limitations in source size selection due to the geometries, especially for disk and cylindrical sources.

SECTION 4

TECHNOLOGY APPLICABILITY AND ALTERNATIVE TECHNOLOGIES

■ Technology Applicability

- RESRAD-BUILD is applicable to free-releasing structures and buildings with slight or suspect volumetric radionuclide contamination that are slated for remediation or D&D activities and release.
- This technology can be used to calculate thorough, well-documented, annual exposures to a hypothetical human receptor from various exposure pathways and radionuclides.
- This technology allows the user to devise hypothetical scenarios applicable to the final land-use requirements.
- The system may be used for both interior and exterior surfaces of buildings and structures.
- The RESRAD-BUILD model is user-friendly and flexible. It is compatible with most PC and operating software, and runs in both DOS and Windows environments.

■ Competing Technologies

Alternative methods to the RESRAD-BUILD technology are the other pathway analysis codes such as GENII (Pacific Northwest National Laboratory), Comply (EPA and U.S. Nuclear Regulatory Commission [NRC]), and Cap88-PC (EPA and NRC). However, most of these codes are not as comprehensive as RESRAD-BUILD in terms of the pathways that are associated with radiologically contaminated buildings and structures. Therefore, several codes must be combined to obtain the same final results as RESRAD-BUILD (e.g., use of a shielding code such as Microshield™ [Grove Engineering]) for the external exposure pathway along with hand calculations or another code such as GENII for other pathways).

Another alternative would be to decontaminate (to free-release levels) and re-survey contaminated structures, and not remove the structures. This alternative is more costly than using either the improved technology to avoid removal or the baseline technology for complete removal.

■ Patents/Commercialization/Sponsor

This technology is available through ANL. DOE contractors can obtain the code free of charge, and the private sector can obtain it for a few hundred dollars.

The demonstration at C Reactor was sponsored by DOE's Office of Science & Technology/Deactivation and Decommissioning Focus Area, in collaboration with the Environmental Restoration Program.

COST

Introduction/Methodology

This cost analysis compares the improved RESRAD-BUILD radiological-dose modeling technology to a baseline consisting of conventional demolition. The remediation work that is estimated in this analysis consists of final closure of nine pipe tunnels underneath the C Reactor floor. Remediation costs for only the portion of each tunnel that extends beyond the walls for the ISS enclosure (the structure that will remain in place after interim decommissioning of C Reactor is complete) are considered. The estimate for the improved technology is based on using RESRAD-BUILD and leaving the structural material (i.e., concrete, and some steel piping and grating) at the site. The estimate for the baseline is based on removing and disposing the tunnel structures and their piping. For this demonstration, RESRAD-BUILD saved approximately 50% compared to the baseline. Details of the cost comparison are in Appendix C of this report and summarized in Figure 2.

Cost Analysis

The RESRAD-BUILD software is available at no charge for government users. The cost for tunnel remediation for the improved technology includes obtaining data for setting up the RESRAD-BUILD model, running the model, collecting samples and performing laboratory analyses to confirm that any contamination that will remain in place
is below the threshold limits established by the model output, and placing the structure into its final configuration for the long term. The baseline consists of completely removing the tunnel structures and disposing of the demolition debris as low-level radioactive waste.

Both the RESRAD-BUILD technology and the baseline costs are based on the experience of the test engineer. The crews and production rates used for demolition costs are based on observations of previous demolition work at C Reactor. The demolition quantities (e.g., the amount of concrete to be demolished) are based on quantity take-offs from the “as-built” construction drawings. Tables with detailed costs for both the RESRAD-BUILD and the baseline technologies are in Appendix C.

The most significant conditions and assumptions affecting costs for this demonstration are as follows:

- Amount of confirmatory sampling required.
- Only piping that is known to be contaminated (e.g., the gas pipes and drains) are internally sampled or surveyed.
- 75% of the tunnel surface is surveyed.
- 10 core-drill samples are collected from the tunnel surfaces for laboratory analysis.
- Long-term configuration for leaving contamination in place assumes that the tunnel ceiling and upper 1 m (3 ft) of the walls are demolished and the tunnel is backfilled with gravel and ceiling/walls debris.
- Baseline consists of disposal rather than decontamination.
- Cost of baseline waste disposal as low-level radioactive waste disposed at the Hanford Site Environmental Restoration Disposal Facility (ERDF) is $60/ton. (Costs using the baseline technology at other sites would likely be higher, because disposal costs are generally higher at other sites than at the Hanford Site).
- No decontamination is required to comply with threshold contamination levels determined by RESRAD-BUILD model runs.

For additional discussion of cost variable conditions that may occur when using the improved technology and the potential effect these conditions may have on unit costs and production rates, refer to Section 3 of this report.

■ Cost Conclusions

The costs for the improved and baseline technologies are summarized in Figure 2. These costs do not include overhead or general and administrative (G&A) markup costs and do not include management, health and safety oversight, or quality assurance costs. Sampling and analysis costs for the baseline technology are assumed to be zero, since the ERDF does not require detailed analysis of waste for disposal. Disposal costs for the improved technology are also assumed to be zero since any concrete debris removed from the walls or ceiling of the
tunnels will remain within the tunnels.

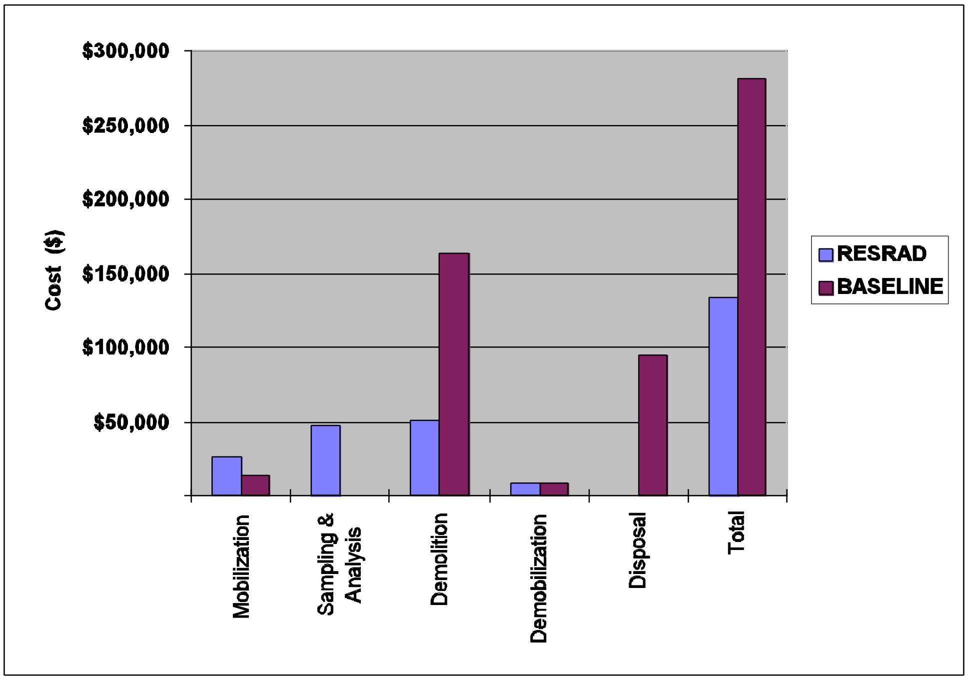

Figure 2. Estimated costs for improved and baseline technologies.

The primary difference between the improved and baseline technologies' costs is the baseline's inclusion of structural demolition, debris preparation, and disposal. Preparing the concrete for disposal includes shearing the debris so no dimension exceeds 0.6 m (2 ft) and shearing any rebar that projects beyond the concrete. Preparation for pipe disposal includes splitting pipes that are 41 cm (16 in.) in diameter or larger to meet the waste acceptance criteria for low-level radioactive waste burial. Preparation adds approximately $75,000 to the baseline costs; preparation and disposal are 60% of the baseline's cost.

The mobilization costs for the RESRAD-BUILD and the baseline technologies are similar, with the exception that RESRAD-BUILD includes costs for setting up and running the RESRAD-BUILD model. The RESRAD-BUILD alternative requires radiological surveys and laboratory sample analyses that are not included in the baseline costs. These additional costs for RESRAD-BUILD are required to ensure that the contamination left in place is below the threshold levels established by the RESRAD-BUILD model.

The cost savings for RESRAD-BUILD, as compared with the demolition baseline, will vary from one situation to the next. Particularly, the confirmatory sampling, long-term configuration, preparation for disposal, and disposal costs will be specific to each site. Additionally, the effort required for the RESRAD-BUILD model will depend upon the complexity of the exposure pathways and the nature of regulatory and public involvement in the decision-making process. Despite the potential variation, it is anticipated that a remediation strategy that uses RESRAD-BUILD will provide substantial savings if the model results indicate that leaving slightly contaminated structures in-place pose essentially no risk to humans or the environment.

REGULATORY/POLICY ISSUES

Regulatory Considerations

- The RESRAD-BUILD model is an exposure pathway analysis code that can be used for characterizing and releasing slightly contaminated structures and buildings, therefore, there are no special regulatory permits required for its operation and use. However, regulatory approval needs to be obtained for the application of this code when it is used to free-release buildings and structures.

- The C Reactor demonstration of RESRAD-BUILD modeled future use of below grade portions of the reactor building complex to a residential exposure scenario with a cleanup criteria of 15 mrem/yr above background (proposed EPA cleanup criteria [OSWER 9200.4.18]). The residential exposure scenario and 15 mrem/yr cleanup criteria were used to coordinate decommissioning with adjacent ongoing remedial actions conducted in accordance with an existing CERCLA Record of Decision.

Safety, Risk, Benefits, and Community Reaction

Worker Safety

- No specific worker safety issues are identified in order to apply the improved technology.

Community Safety

- The RESRAD-BUILD improved technology presents no adverse impacts to community safety.

Environmental Impacts

- Implementation of the RESRAD-BUILD technology would result in leaving a structure in place that has a very low level of radioactive contamination. The modeling shows the impacts of various land-use scenarios in terms of potential dosages to receptors.

Socioeconomic Impacts, and Community Perception

- No socioeconomic impacts are expected with the use of this technology.

- This technology should be perceived by the public as acceptable since it reduces demolition costs and overall radiation exposure.

LESSONS LEARNED

Implementation Considerations

- The code is very sensitive to some of the input parameters. The RESRAD-BUILD model can determine dose from a variety of pathways and radionuclides. The doses to a human receptor are calculated and reported by radionuclide and by pathway. In addition, the exposure from all radionuclides and over all pathways is calculated and reported. Therefore, when available, site-specific parameters should be used.

- The RESRAD-BUILD model is well suited for release of the structures and buildings that are slightly contaminated with radionuclides. The exposure to a human receptor from the radioactive contamination can be calculated to show whether it is below the 15 mrem/year EPA draft guidance limit (OSWER 9200.4.18)

- The hypothetical exposure scenarios for hypothetical receptors should be as close as possible to the reality of land use. In addition, regulatory agencies (e.g., EPA) should be involved in developing the hypothetical exposure scenarios to be used for building or structure free release since their acceptance of the code's application is essential.

- It is necessary to know the radionuclides of potential concern and their activities within the building material matrix.

Technology Limitations/Needs for Future Development

- The code would be more useful if it were expanded beyond the current four geometries and source size selections, especially for disk and cylindrical sources.

- The RESRAD-BUILD code is continually being improved to make it more precise, upgrade the pathway models and exposure dose calculations, and improve the user interface.

Technology Selection Considerations

- The technology is suitable for DOE nuclear facility D&D sites or similar sites that must evaluate slightly contaminated buildings and structures to facilitate property transfer or release.

- This technology can be useful for building and structure characterization in support of D&D activities.

- By using various pathways and radionuclides, the RESRAD-BUILD model can provide information regarding dominant pathway(s), pathway(s) of potential concern, and radionuclide(s) of potential concern.

APPENDIX A

REFERENCES

10 CFR 835, "Standards for Protection Against Radiation," *Code of Federal Regulations*, as amended.

Argonne National Laboratory (ANL), 1994, *RESRAD-BUILD: A Computer Model for Analyzing the radiological Doses Resulting from the Remediation and Occupancy of Buildings Contaminated with Radioactive Material*, ANL/EAD/LD-3, Argonne National Laboratory, Argonne, Illinois.

BHI-SH-02, Vol. 2, *Safety and Health Procedures*, Procedure 2.3.3, Attachment 1, "Unconditional Surface Contamination Release," Bechtel Hanford, Inc., Richland, Washington.

Comprehensive Environmental Response, Compensation, and Liability Act of 1980 (CERCLA), 42 U.S.C. 9601, et seq.

EPA, Draft, OSWER 9200.4.18, U.S. Environmental Protection Agency, Washington, D.C.

OMB, *Cost Effective Analysis*, OMB Circular No. A-94, Office of Management and Budget, Washington D.C.

USACE, 1996, *Hazardous, Toxic, Radioactive Waste Remedial Action Work Breakdown Structure and Data Dictionary*, Headquarters, U.S. Army Corps of Engineers, Washington, D.C.

APPENDIX B

TECHNOLOGY COST ANALYSIS

Introduction

The RESRAD-BUILD software is available to government users at no charge. The cost for tunnel remediation using the improved technology includes obtaining data for setting up and running the RESRAD-BUILD model; collecting samples and performing laboratory analyses to confirm that any contamination that will remain in place is below the threshold limits established by the model output; and placing the structure into its final configuration for the long term. The baseline costs consist of completely removing the tunnel structures and disposal of the demolition debris as low-level radioactive waste. Both the RESRAD-BUILD and the baseline costs are based on the experience of the test engineer. The crews and production rates used for demolition costs are based on observations of previous demolition work at C Reactor. The demolition quantities (e.g., the amount of concrete to be demolished) are based on quantities from the "as-built" construction drawings.

The selected basic activities being analyzed come from the *Hazardous, Toxic, Radioactive Waste Remedial Action Work Breakdown Structure and Data Dictionary* (HTRW RA WBS) (USACE 1996). The HTRW RA WBS, developed by an interagency group, was used in this analysis to provide consistency with the established national standards.

Some costs are omitted from this analysis so that it is easier to understand and to facilitate comparison with costs for other DOE sites. The overhead and G&A mark-up costs for the site contractor managing the demonstration are omitted from this analysis. Overhead and G&A rates for each DOE site vary in magnitude and in the way they are applied. Decision makers seeking site-specific costs can apply their site's rates to this analysis without having to first back-out the rates used at the Hanford Site. Engineering, quality assurance, administrative costs, and taxes on services and materials are also omitted from this analysis for the same reasons. Work days are computed as eight hours. The hourly rates for site labor and for government-owned equipment are based on standard rates for the site (1997 rates were used to maintain consistency with earlier demonstrations performed at C Reactor).

The following assumptions were used as the basis of the cost analysis:

- Only the gas pipes and floor drain pipes are assumed to be cut open and surveyed for contamination, and all pipe exterior surfaces are surveyed.
- Ten core samples are taken from the tunnel's surfaces and the laboratory analyses are for isotopic plutonium and uranium and include gross alpha and beta, gamma energy, total strontium, and americium (analysis cost per sample of $2,350).
- 75% of the tunnel surfaces (i.e., walls, floors, and ceiling) are surveyed to determine contamination levels.
- The long-term configuration of the tunnels requires demolishing the ceiling and walls to 1 m (3 ft) below grade and backfill with gravel material (concrete from ceiling and upper walls is also used as fill).
- No decontamination is required to comply with threshold contamination levels determined by RESRAD-BUILD model runs.

Tables B-1 and B-2 provide unit durations for work activities and labor and equipment unit costs in a format that will accommodate insertion of site-specific quantities (in the total quantity column). This will allow a site-specific cost to be developed by the potential technology user.

Table B-1. RESRAD-BUILD - cost summary

Work Breakdown Structure (WBS)	Unit Cost (UC)						Total Qty (TQ)	Unit of Measure	Total Cost (TC)	Crew	Comments
	Labor		Equipment		Other	Total UC					
	HRS	Rate	HRS	Rate							
MOBILIZATION (WBS 331.01)								**Subtotal**	**$26,099**		
RESRAD-BUILD Model											
Develop Data	80	$65				$5,214	1	Lump Sum (LS)	$5,214	SC	
Run Model	1	$65				$65	1	LS	$65	SC	
Document Results	40	$65				$2,607	1	LS	$2,607	SC	
Sample Work Package					$4,663	$4,663	1	LS	$4,663		Includes preparation and review.
Demolition Package					$4,663	$4,663	1	LS	$4,663		Includes preparation and review.
Load Equipment	8	$194	8	$300		$3,949	1	LS	$3,949	2TM, 2OP, 1RG, 4 TT, 4LB, 2SH, 1RH, 1BT, 1WT	Load equipment from equipment pool.
Transport	2	$194	2	$300		$987	1	LS	$987	same crew	
Unload Equipment	8	$194	8	$300		$3,949	1	LS	$3,949	same crew	
SAMPLING AND ANALYSIS (WBS 331.02.08)								**Subtotal**	**$47,684**		
Pipe Sampling/Survey											
Survey Pipe Exterior	0.014	$50	0.014	$1.38		$.71	5005	LF	$3,562	1RCT, 1RS	Includes all pipe sizes.
Survey Suspect Pipe	0.6	$113	0.6	$0.50		$71	15	Each	$1,064	1RCT, 2DD, 1CT	Cut access port and swipe at 20-ft intervals also bends and fitting. 15 minutes each x 2.5 for productivity loss.
Count for Swipes	0.033	$50	0.033	$1.38		$1.70	15	Each	$25	1RCT, 1RS	
Tunnel Sample/Survey											
Survey Walls/Floors	0.014	$50	0.014	$1.38		$.73	10550	Square Feet (SF)	$7,739	1RCT, 1RS	Survey 75% of surface for walls and floors at rate of 3 sf/min x 2.67 (productivity loss).
Survey Grating	0.014	$50	0.014	$1.38		$.73	194	SF	$142	1RCT, 1RS	Survey 75% of surface of grating.
Core Sample	1.2	$223			$2,437	$2,704	13	Each	$35,152	2SM, 2DD, 1RCT	Drill to collect 1 kg of sample. Sample analysis $2,350 each plus $87 each for transport. 10 sample locations plus 3 QA.
DEMOLITION (WBS 331.17.04)								**Subtotal**	**$50,919**		
Collapse Tunnel Ceiling	0.13	$375	0.13	$215		$78	244	Cubic Yards (CY)	$19,178	3OP, 2DD, 2RCT, 1SU, 1TM, 1RH, 2SH, 1WT	Production rate of 7.5 cy/hr (in-place yards).
Remove Walls to 3 ft Below Grade and flush debris into tunnel	0.13	$336	0.13	$149		$64	101	CY	$6,516	2OP, 2DD, 2RCT, 1SU, 1TM, 2SH, 1WT	Remove top of concrete walls to 3 ft below grade. Production rate of 7.5 cy/hr (in-place yards).
Backfill Trenches	0.038	$385	0.038	$173		$21	1190	CY	$25,225	3DT, 2DZ, 1LD, 1WT, 4TM, 3OP, 2DD, 1SU	Production rate of 26.5 cy/hr (in-place yards). Assumes that the concrete debris provides some of the backfill.

Table B-1. RESRAD-BUILD - cost summary (cont.)

Work Breakdown Structure (WBS)	Unit Cost (UC) Labor HRS	Labor Rate	Equipment HRS	Equipment Rate	Other	Total UC	Total Qnty (TQ)	Unit of Measure	Total Cost (TC)	Crew	Comments
DEMOBILIZATION (WBS 331.21)								**Subtotal**	**$8,886**		
Load Equipment	8	194	8	300		$3,949	1	LS	$3,949		Same as mobilization.
Transport	2	194	2	300		$987	1	LS	$987		Same as mobilization.
Unload Equipment	8	194	8	300		$3,949	1	LS	$3,949		Same as mobilization.
DISPOSAL (WBS 332.18)								**Subtotal**	**$0**		
Disposal of Concrete					$60	$60	0	Tons	$0		Disposal as low level radioactive waste.
								TOTAL:	$133,588		

Notes:

1 TC = UC X TQ

2 Individual crew members and equipment are shown for each activity element using abbreviation for each. The abbreviation, crew item, and the hourly rate for each item are shown in the following table:

Abbre-viation	Crew Item	Hourly Rate ($)	Abbre-viation	Crew Item	Hourly Rate ($)	Abbre-viation	Crew Item	Hourly Rate	Abbre-viation	Crew Item	Hourly Rate
SU	Field Supervisor	59.60	RG	Rigger	43.57	TT	Truck/Tractor	11.71	DT	Dump Truck	11.51
DD	D&D Worker	31.97	SC	Scientist	65.18	LB	Low Boy Trailer	0.48	DZ	Dozer	49.47
TM	Teamster	36.35	SM	Sample Collector	54.52	SH	Shear/Excavator	66.50	LD	Loader	23.97
OP	Heavy Equipment Operator	38.68	RCT	Radiological Control Technician	49.50	RH	Ram Hoe	66.50	RS	Radiological Survey Equip.	1.38
						BT	Bucket Thumb	36.25	CT	Cutting Torch	0.50

Table B-2. Baseline - cost summary

Work Breakdown Structure (WBS)	Unit Cost (UC) Labor HRS	Labor Rate	Equipment HRS	Equipment Rate	Other	Total UC	Total Qty (TQ)	Unit of Measure	Total Cost (TC)	Crew	Comments
MOBILIZATION (WBS 331.01)								**Subtotal**	**$13,549**		
Sample Work Package					$4,663	$4,663	0				Not required.
Demolition Package					$4,663	$4,663	1	Lump Sum (LS)	$4,663		Includes preparation and review.
Load Equipment	8	194	8	300		$3,949	1	Each	$3,949	2TM, 2OP, 1RG, 4TT, 4LB, 2SH, 1RH, 1BT, 1WT	Load equipment from equipment pool.
Transport	2	194	2	300		$987	1	Each	$987	Same crew	
Unload Equipment	8	194	8	300		$3,949	1	Each	$3,949	Same crew	
DEMOLITION (WBS 331.17.04)								**Subtotal**	**$163,656**		
Collapse Tunnel Ceiling	0.13	$375	0.13	$215		$78	244	Cubic Yards (CY)	$19,178	3OP, 2DD, 2RCT, 1SU, 1TM, 1RH, 2SH, 1WT	Production rate of 7.5 cy/hr (in-place yards).
Remove Walls/Floors	0.13	$336	0.13	$149		$64	464	CY	$29,921	2OP, 2DD, 2RCT, 1SU, 1TM, 2SH, 1WT	Remove top of concrete walls to 3 ft below grade. Production rate of 7.5 cy/hr (in-place yards).
Size and Load Concrete	0.13	$396	0.13	$209		$81	709	CY	$57,121	4OP, 3DD, 1RCT, 1SU, 1TM, 2SH, 1BT, 1LD, 1WT	Reduce size and cut projecting rebar to meet waste acceptance criteria for disposal. Production rate 7.5 cy/hr (in-place yards).
Remove Pipes/Grating	0.01	$336	0.01	$149		$7	651	LF	$4,576	2OP, 2DD, 2RCT, 1SU, 1TM, 2SH, 1WT	Cut pipe and supports as needed for removal. Production rate 34 ft/hr for each shear. Large-bore pipe only -- must be removed and split.
Split Large Pipe	0.05	$336	0.05	$149		$22	651	LF	$14,201	Same crew	Production rate 11 ft/hr for each shear.
Load Pipe & Grating	0.06	$120	0.06	$36		$9	651	LF	$6,109	1OP, 1BT, 1DD, 1RCT	
Backfill Tunnel	0.04	$385	0.04	$173		$21	1535	CY	$32,550	3DT, 2DZ, 1LD, 1WT, 4TM, 3OP, 2DD, 1SU	Production rate of 26.5 cy/hr (in-place yards).
DEMOBILIZATION (WBS 331.21)								**Subtotal**	**$8,886**		
Load Equipment	8	194	8	300		$3,949	1	LS	$3,949		Same as mobilization.
Transport	2	194	2	300		$987	1	LS	$987		Same as mobilization.
Unload Equipment	8	194	8	300		$3,949	1	LS	$3,949		Same as mobilization.
DISPOSAL (WBS 331.18)								**Subtotal**	**$94,636**		
Disposal of Concrete					$60	$60	1481	Tons	$88,846		Disposal of low level radioactive waste.
Disposal of Pipe					$60	$60	97	Tons	$5,790		Disposal of low level radioactive waste.
								TOTAL:	$280,726		

APPENDIX C

ACRONYMS AND ABBREVIATIONS

Acronym/ Abbreviation	Description
ALARA	as low as reasonably achievable
ANL	Argonne National Laboratory
CERCLA	*Comprehensive Environmental Response, Compensation, and Liability Act of 1980*
D&D	decontamination and decommissioning
DOE	U.S. Department of Energy
EIS	environmental impact statement
EPA	U.S. Environmental Protection Agency
ERDF	Envirommental Restoration and Disposal Facility
G&A	general and administrative (costs)
HTRW	Hazardous, Toxic, Radioactive Waste
ISS	interim safe storage
LF	linear ft
LSDDP	Large-Scale Demonstration and Deployment Project
NRC	U.S. Nuclear Regulatory Commission
OST	Office of Science and Technology
PC	personal computer
RA	remedial action
SAP	sampling and analysis plan
SLLRW	solid low-level radioactive waste
SSE	safe storage enclosure
WBS	work breakdown structure

Note: Additiional definitions are included in and below Table B-1 in Appendix B.