FINAL

DERIVATION OF SITE-SPECIFIC DCGLs FOR NORTH COUNTY STRUCTURES

ST. LOUIS, MISSOURI

October 18, 2004

U.S. Army Corps of Engineers
St. Louis District Office
Formerly Utilized Sites Remedial Action Program

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prepared by
U.S. Army Corps of Engineers, St. Louis District Office, Formerly Utilized Sites Remedial Action Program

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Contributed to the preparation of this document and should not be considered an eligible contractor for its review.

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ACRONYMS

Ac-227	actinium - 227
AEC	Atomic Energy Commission
ANL	Argonne National Laboratory
ARAR	Applicable Relevant and Appropriate Requirements
CERCLA	Comprehensive Environmental Restoration Cleanup Liability Act
CFR	Code of Federal Regulations
cm^3	cubic centimeters
COC	contaminant(s) of concern
CSM	conceptual site model
DCF	dose conversion factor
DCGL	derived concentration guideline levels
DOE	U.S. Department of Energy
dpm	disintegrations per minute
DSR	dose to source ratio
EPA	Environmental Protection Agency
FUSRAP	Formerly Utilized Sites Remedial Action Program
g	gram
m	meter
m^2	square meters
m^3	cubic meters
MED	Manhattan Engineering District
mrem/year	millirem per year
NRC	Nuclear Regulatory Commission
Pa-231	Protactinium - 231
pCi	picocurie
pCi/g	picocuries per gram
PNL	Pacific Northwest Laboratory
Ra-226	radium - 226
Ra-228	radium - 228
SAIC	Science Applications International Corporation
SNM	special nuclear material
TEDE	total effective dose equivalent
Th-228	thorium - 228
Th-230	thorium - 230
Th-232	thorium - 232
U-234	uranium - 234
U-235	uranium - 235
U-238	uranium - 238
USACE	U.S. Army Corps of Engineers

1.0 INTRODUCTION

1.1 PURPOSE

The purpose of this report is to present derived concentration guideline levels (DCGLs) for North County Structures at the St. Louis Formerly Utilized Sites Remedial Action Program (FUSRAP) sites. The RESRAD-BUILD[1] computer code (Version 3.1) was used to determine dose to source ratios (DSR) for individual radionuclides. The DSR was used to calculate individual radionuclide DCGLs that were equivalent to 15 millirem per year (mrem/year). The use of the DCGLs specified herein for structures is protective under the Comprehensive Environmental Restoration Cleanup Liability Act (CERCLA) for all scenarios to include residential. Pending revision of RESRAD-BUILD to calculate risks associated with structures, protectiveness will be documented by comparison with ARARs and using EPA guidance that 15 mrem per year equates to 3 X 10^{-4} risk. Institutional controls are not required for any structure or area that is suitable for unrestricted use and unlimited exposure. This report also describes how compliance may be demonstrated with dose-based limits using applicable isotopic DCGLs to calculate site-specific gross Alpha or gross Beta DCGLs.

1.2 SCOPE

The scope of this document is limited to North County structures that have been impacted by transport of soil containing radionuclides from Manhattan Engineering District/Atomic Energy Commission (MED/AEC) operations and are currently part of the FUSRAP managed by the U.S. Army Corps of Engineers (USACE). This document addresses MED/AEC-related surficial contamination on structures within St Louis North County sites. To the extent possible, DCGLs are derived in this report using applicable information from prior FUSRAP documents to ensure consistency between dose models. For the purposes of this document, structures include (but are not limited to):

- Buildings and portions of buildings, including roof areas and foundations
- Footings, retaining walls, and stop logs
- Piping and ducting
- Utility poles
- Bridges and supporting structures
- Pavement
- Consolidated material to be left in place
- Other similar items where surficial contamination is of concern

[1]Under the sponsorship of the U.S. Department of Energy, the Environmental Assessment Division of Argonne National Laboratory developed the RESRAD family of computer codes to assess human health and environmental risk at sites contaminated with radioactive materials. Additional information on the RESRAD family of codes including RESRAD-BUILD is found on the Internet site http://web.ead.anl.gov/resrad/home2/.

2.0 SITE HISTORY AND DESCRIPTION

From 1942 to 1957, under contracts with the MED and the AEC, the St. Louis Downtown Site (SLDS) was used to produce uranium compounds by processing various forms of uranium-bearing feed materials. In 1946, the MED acquired the 21.7-acre tract of land now known as the St. Louis Airport Site (SLAPS) to store residues and scrap from uranium processing at the Mallinckrodt Plant. In 1966 and 1967, most of the stored residues were sold and removed from the SLAPS. On-site structures at the SLAPS were razed and buried on the property. Buried deposits of uranium-238 (U-238), radium-226 (Ra-226), and thorium-230 (Th-230) remain on the SLAPS property. The company that purchased the vast majority of the material stored at the SLAPS moved the materials to the Hazelwood Interim Storage Site (HISS) on Latty Avenue. Most of this material was later shipped to Colorado. Over time, residues migrated from the sites (via runoff onto adjacent properties and into Coldwater Creek (CWC) or windblown) or were released or otherwise deposited when material was hauled along road and rail transportation routes, contaminating the soil and sediment at the SLAPS and Latty Avenue VPs.

2.1 NORTH COUNTY VPS

The North County VPs consist of three main groups of properties:

1. Those that are contiguous to SLAPS or HISS and were potentially impacted by contamination transport mechanisms,

2. Those properties potentially impacted by movement of contaminated residuals from SLAPS to the HISS on possible haul routes, and

3. Properties potentially impacted by CWC and the associated deposition of sediment. In some cases, soil contamination may have subsequently been spread to structures.

Depending on the history of the structure's use, its location, its date of construction, and the history of the surrounding soils, the potential for surficial contamination may exist on the exterior only, the interior only, on or under the foundation only, or in any combination of these locations.

The potential radiological contaminants at the North County VPs are members of the naturally occurring uranium, thorium, and actinium decay series. The predominant contaminant is Th-230, a member of the uranium decay series.

3.0 DEVELOPMENT OF DERIVED CONCENTRATION GUIDELINE LEVELS

This section describes the method for deriving DCGLs for North County Structures. The method is broken into five components, each of which is described in the sections that follow:

- Selecting a dose limit,
- Developing the conceptual site model (CSM),
- Identifying potential exposure scenarios,
- Identifying the most limiting scenario, and
- Calculating radionuclide-specific DCGLs from RESRAD-BUILD output.

3.1 SELECTION OF ANNUAL PUBLIC DOSE LIMIT

Several factors were taken into consideration for the selection of the annual public dose limit.

- 10 CFR Part 20, Subpart E, *Radiological Criteria for License Termination*, requires cleanup to 25 mrem/year.

- *Feasibility Study for the St. Louis North County Site* (USACE, 2003) indicates a limiting dose of 19 mrem/year (Table D-11) based upon the benchmark dose approach. A benchmark dose is the dose that is found to be equivalent to 40 CFR 192 cleanup standards for Ra-226 of 5 picocuries per gram (pCi/g) surface and 15 pCi/g subsurface, using modeling.

- EPA OSWER 9200.4-18, *Establishment of Cleanup Levels for CERCLA Sites with Radioactive Contamination*, recommends that cleanup attain a dose of 15 mrem/year. This level equates to approximately 3 X 10^{-4} increased lifetime risk and is consistent with levels generally considered protective.

The Nuclear Regulatory Commission (NRC) requires cleanup to 25 mrem/year. The North County Feasibility Study establishes 19 mrem/year as a benchmark dose in accordance with relevant and appropriate guidance for cleanup of radionuclides in soil. The ARAR of 5 pCi/g of Ra-226 was used to set the benchmark dose. The EPA guidance recommends 15 mrem/year as clean up criteria. Since the EPA has a lower limit of 15 mrem/year, the 10 CFR 20 limit and benchmark dose will automatically be satisfied if DCGLs equivalent to the EPA limit are met. The impact to the cost of the overall project due to DCGLs based on 15 mrem/year verses 19 mrem/year is not anticipated to be significant due to the number of buildings likely to be impacted. Therefore, DCGLs in this report were developed based on the 15 mrem/year limit.

3.2 CONCEPTUAL SITE MODEL (CSM)

In order for an exposure to occur, there must be a contaminated medium (source term), a receptor, and a complete pathway for the contaminant to reach the receptor. The relationship between these three factors is described in the CSM. The CSM for North County structures is illustrated in Figure 3-1. Figure 3-1

identifies the contaminated medium considered in this report, potential receptors, and the exposure pathways that could lead to a radiological dose (in mrem/year) to potential receptors.

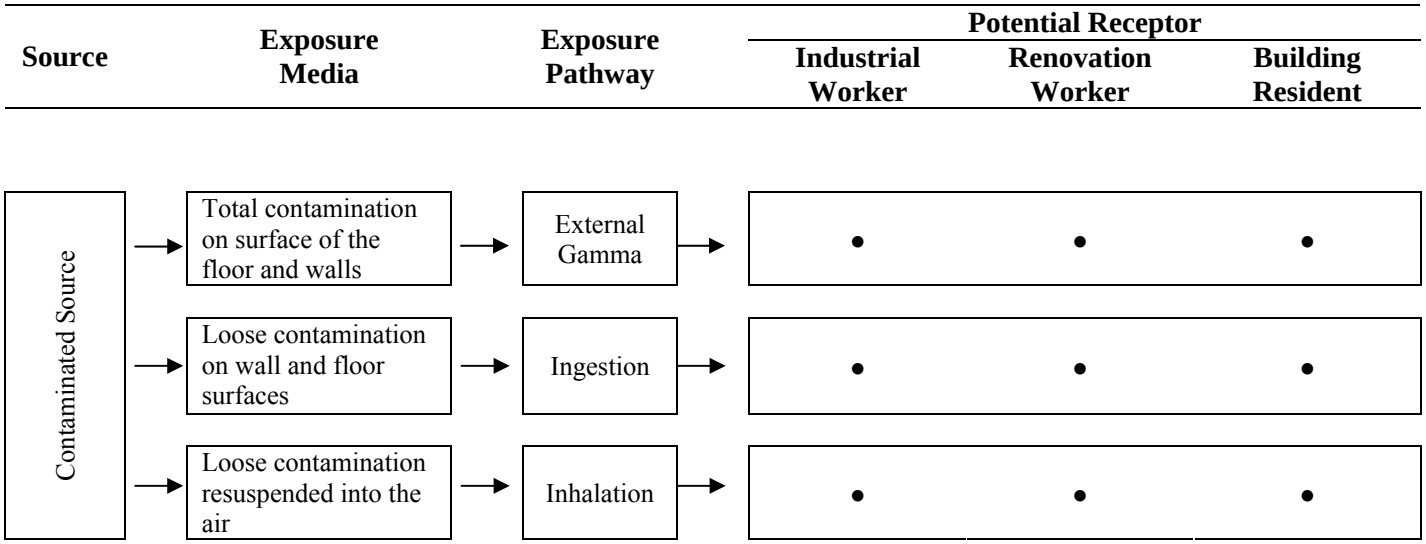

Figure 3-1. Conceptual Site Model for North County Structures

The CSM assumes that a potentially impacted building was intact and occupied. Three receptors[2] were selected for comparison: (1) an industrial worker, (2) a renovation worker, and (3) a building resident. Considering the potential buildings that may be impacted in North County, the industrial worker is considered the most likely long-term receptor for future use. The renovation worker is considered a conservative short-term receptor, assuming some remodeling is required to make the building suitable for future use. The building resident is not a likely receptor; however, to determine the most limiting scenario, a dose assessment for the building resident scenario was performed. Additional receptors associated with the renovation scenario (i.e., those listed in NUREG-1640, handling, transportation, disposal, etc.) were also considered. The DSR for North County's predominant contaminant of concern, Th-230, for the additional receptor scenarios (NUREG-1640) when compared to the DSR of the most limiting scenario identified in this report were found to be less limiting as shown in Table 3-6. Determination of the most limiting scenario is presented in section 3.4.

Although not shown in Figure 3-1, the CSM assumes that receptors are exposed in a single room with a contaminated source. It is also assumed that the ingestion pathway is completed through the re-deposition of suspended dust particles followed by inadvertent hand-to-mouth transfer. This approach represents the RESRAD-BUILD default pathway for ingestion. The direct ingestion pathway (without considering re-deposition) is assumed to be negligible for all scenarios.

The complete exposure pathways for all three scenarios are:

- External gamma exposure,
- Indirect ingestion of re-deposited non-fixed contamination, and
- Inhalation of re-suspended non-fixed contamination.

[2] Receptor scenarios are based primarily upon NRC guidance found in NUREG/CR-5512.

The external gamma pathway is independent of the contaminant nature (loose or fixed). However, the ingestion and inhalation pathways are subject only to the quantity of loose contamination that may be inadvertently transferred to the mouth or re-suspended into the air. Section 3.3 provides additional details regarding the potential exposure scenarios and presents the exposure parameters used in dose modeling.

Although the CSM (consisting of three scenarios) assumed an intact and occupied building, an additional conceptual model was considered. The scenario for this model was the "onsite resident – post demolition". This model assumed that the contaminated structure was demolished, buried onsite, and a residence established over the rubble. Due to the type and location of buildings that may potentially be impacted, this was not a likely model. However, a dose assessment using RESRAD Version 6.21 was performed to use in determining the most limiting scenario. Determination of the most limiting scenario is presented in section 3.4.

3.3 POTENTIAL EXPOSURE SCENARIOS

As shown in the CSM, three potential building occupancy (assuming the building was left intact and was occupied) exposure scenarios were considered: 1) industrial worker, 2) renovation worker, and 3) building resident. A fourth scenario, the onsite resident – post demolition, was also considered.

The CSM assumed a simple, one-room configuration that is easy to conceptualize and can represent rooms in any North County building. Contamination was assumed to be distributed uniformly over the entire floor and all four walls from the floor up to 2 meters. The CSM also assumed an area source. Tables 3-1 through 3-3 present the RESRAD-BUILD input parameter values used in the derivation of building DCGLs for the industrial worker, renovation worker, and building resident, respectively. The parameters were determined by using applicable guidance in the following priority:

1. Risk Assessment Guidance for Superfund
2. NRC guidance (NUREGs, etc.)
3. ANSI guidance
4. RESRAD-BUILD default values

Table 3-4 presents the RESRAD non-default parameter values used in the derivation of building DCGLs for the onsite resident – post demolition. The onsite resident scenario was based upon the same assumptions that were used in the risk assessments performed in the *Feasibility Study for the North County Site* (USACE, 2003).

3.3.1 DEFINING THE SOURCE TERM

As stated in Section 2.1, depending on the history of the structure's use, its location, its date of construction, and the history of the surrounding soils, the potential for surficial contamination may exist on the exterior only, the interior only, on or under the foundation only, or in any combination of these locations. Also, prior data indicates that contamination in potentially affected structures in North County is usually spotty and tightly adherent to the structure surface. To determine an appropriate source term to be used in dose assessments, the following was considered:

- Contamination of structure material not in direct contact with contaminated soil most likely occurred due to transport of contaminants through the air (e.g., dust)

- Contamination of structure material by air transport would most likely result in higher levels of contamination on horizontal areas (floors, top of equipment, structural I-beams, etc.) than on vertical areas

- Potential volumetric contamination of material (e.g., roofing material, insulation)

- Most affected North County structures are large industrial buildings (e.g., manufacturing facilities, warehouses) however some of these structures have smaller office areas as well

- Historical data that gives insight to the physical characteristics of the contamination (e.g., location, removal fraction)

- Characteristics of the contaminants of concern (e.g., activity fractions, ingrowth of daughters, etc.)

Empirical historical data indicates that contamination found on North County Structures is spotty and tightly adherent (i.e., average removal fraction less than 5%). Additionally, office and warehouse areas have varying sizes, shapes, and features (e.g., drop ceilings, light fixtures, pipes, conduit, structural framework, window ledges, etc.). In order to develop generic parameters for a source term that fit each case, a single 100 m^2 room with 2.5 m walls was selected. This size room was slightly larger than an office, yet smaller than a warehouse/manufacturing room. This size room was appropriate since the primary dose pathway was due to inhalation and dose from inhalation is inversely proportional to the room volume for the same source term. The room size was also consistent with room sizes selected for dose assessments at other FUSRAP sites (e.g., Windsor, CT).

The area that may be potentially contaminated in a warehouse/manufacturing room is considerably more than that of an office. However, as stated earlier, contamination found on North County Structures is likely to be spotty. Additionally, office areas are likely to be cleaner than warehouse rooms. Therefore, the contaminated portion of the selected room was set at uniform contamination of the entire floor and the lower 2 m of all four walls. This source area accounts for smaller offices that may have contamination in them and warehouse/manufacturing rooms that have more potentially contaminated surface areas. Since the contamination in the larger rooms is likely to be spotty and farther away from the receptor (e.g., horizontal structural roof supports, etc.), the source term was effectively safe-sided by placing all of the source term in close proximity to the receptor so that exposures are fully protective regardless of room size.

With regard to volumetric contamination, FUSRAP contaminants generally do not have the ability to penetrate surfaces such that they are volumetrically contaminated. Contamination found in roof components (e.g., VP-2L) was removable surface contamination that was subsequently encased by application of additional roofing over a roof surface that exhibited concentrations of radionuclides that exceeded background. Contamination of insulation, if present, should be present on the outer surface of the material and would represent the worst case with respect to potential for inhalation or ingestion of the associated contamination. Therefore the source term was based upon surficial contamination.

Given that contaminants other than Th-230 that may exist on structures within the North St. Louis County Sites are likely to be a small fraction of the Th-230 activity, Th-230 was used for determining the limiting scenario.

An assessment (for years 0, 1, 5, 10, 15, 20, 25, 30, and 1000) using all radionuclide contaminants of concern was performed to determine when the maximum dose would occur during the 1000 year period. The maximum exposure from the sum of all radionuclides occurred at year zero (0). Although certain radionuclides (i.e., Th-232, Th-228 and Pa-231) had maximum doses at times other than year 0, the prescribed DCGLs in this report are those from the year of maximum total dose (year 0). Given that the surface contamination is removed in the first 10,000 days, the remaining pathway after 27 years is limited to external radiation. Since the primary dose pathway is inhalation, doses after 10,000 days are not as significant as those in earlier years even when considering daughter ingrowth.

It is notable that Th-232 is not a significant contaminant within the North St. Louis County sites, thus the dose associated with Th-232 and its daughter Th-228 is not a significant contributor to total dose. Also, Pa-231 is initially present in waste at 4.5% of the activity concentration of Th-230, thus it has limited dose implications as well.

3.3.2 BUILDING OCCUPANCY – INDUSTRIAL WORKER

The industrial worker scenario assumes that the critical receptor is a typical industrial worker who works 8 hours per day for 250 days a year. The individual works in the building structure that is contaminated with surficial radioactive material. The radioactive material can be released into the indoor air by mechanisms such as mechanical removal (decontamination activities) or erosion (removal of surface contamination). The applicable pathways for the industrial worker include:

- External exposure to penetrating radiation from surface sources,
- Inhalation of airborne radioactive particulates, and
- Secondary ingestion of surface contamination.

Table 3-1 Parameters for RESRAD-BUILD Building Occupancy Scenario (Industrial Worker)

Parameter	Description	Value	Justification
Time Parameter			
Exposure Duration	Amount of time that exposure occurs	365 days	NUREG/CR-5512, Volume 1, Section 3.2.1
Indoor Fraction	Fraction of the exposure duration that is spent inside the building	0.23	8 hours/day; 250 days/year
Evaluation Time	Times at which doses are calculated	0 year	RESRAD-BUILD Default
Building Parameters			
Number of Rooms	Number of compartments in the building	1	RESRAD-BUILD Default
Deposition Velocity	Velocity at which airborne particles are deposited onto the floor surfaces	0.01 m/sec	RESRAD-BUILD Default (A sensitivity test resulted in no significant difference between the default value and the min. and max values listed in NUREG/CR-6697)
Resuspension Rate	Rate at which deposited material is resuspended into the air	5.0 E-07 sec^{-1}	RESRAD-BUILD Default (Approximate midpoint between NUREG/CR-6697 min. and max values)
Building Exchange Rate	Total volume of air going out of the building per unit time divided by the total volume of the building	0.8 hr^{-1}	RESRAD-BUILD Default Consistent with value of 0.75 hr^{-1} for conditioned spaces (cited by American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Inc.)
Room Area	Floor Area of the room	100 m^2	NUREG/CR-5512, Volume 1, Section 6.2.1
Room Height	Height of the room	2.5 m	RESRAD-BUILD Default Consistent with NUREG/CR-6697 most likely value of 2.4 m
Room Exchange Rate	Total volume of air going out of the room per unit time divided by the total vol. of the room	0.8 hr^{-1}	RESRAD-BUILD Default Same as building exchange rate due to single room
In/Out Flow Rate	Flow rates of air into and out of the room	200 m^3/hr	Room volume (250 m^3) * Room exchange rate (0.8 hr^{-1})
Receptor Parameters			
Number of Receptors		1	RESRAD-BUILD Default
Room # Location	Room in which the receptor is located	1	RESRAD-BUILD Default
Time Fraction	Fraction of time within the building that the exposed individual spends at his receptor location	1	RESRAD-BUILD Default
Breathing Rate	Inhalation rate of airborne material at this location	33.6 m^3/day	NUREG/CR-6697 most likely value (Breathing rate = 1.4 m^3/hr)
Ingestion Rate	Ingestion rate of deposited dust for this location	1 E-04 m^2/hr	RESRAD-BUILD Default (Approximate midpoint between NUREG/CR-6697 min. and max values)
Receptor Location	Coordinates of the receptor	5m, 5m, 1m	Located in center of room at height of 1m

Table 3-1 Parameters for RESRAD-BUILD Building Occupancy Scenario (Industrial Worker)

Parameter	Description	Value	Justification
Shielding Parameters			
Thickness	Thickness of the shielding between the contamination source and the receptor location	0	RESRAD-BUILD Default
Density	Density of the shielding material	Not Applicable	
Material	Identification of the shielding material	Not Applicable	
Source Parameters			
Number of Sources		5	Floor and four walls
Room # location	All sources are located in Room # 1	1	
Source Type		Area	Surface contamination only; volume source is not likely due to historical assessment of NC buildings. (No processing of materials or activation of building materials.)
Direction	Axis perpendicular to the exposed area	Floor (z), Ceiling (z), 4 walls (x,y,x,y)	NUREG/CR-5512, Volume 1, Section 6.2.1
Location	Center point of the source in the x, y, z direction	Floor: 5m, 5m, 0m; Walls: 10m, 5m, 1m 5m, 10m, 1m 0m, 5m, 1m; 5m, 0m, 1m	Entire floor and bottom 2 meters of each wall are uniformly contaminated.
Geometry: Area	Area of the exposed surface over which the contamination is evenly distributed	100, 20, 20, 20, 20 m^2	
Air Release Fraction	Fraction of the eroded material that is released into the air	0.07	Most likely value. NUREG/CR-6697
Direct Ingestion	Direct Ingestion rate of the source by any receptor in the room	0 /hr	RESRAD-BUILD Default
Removable Fraction	Fraction of the source that can be linearly removed between t =0 and lifetime	0.2	Most likely value. NUREG/CR-6697
Lifetime	Amount of time in which all of the removable fraction of the source is linearly eroded	10,000 days	Most likely value. NUREG/CR-6697
Radionuclides Concentration	Unit concentration is initially run; results are normalized to 15 mrem/yr to determine each isotopic DCGL	1 pCi/m^2	

3.3.2.1 NON-DEFAULT PARAMETERS

As stated in section 3.3, a hierarchical system was used to derive the RESRAD-BUILD parameters for each applicable scenario. Justification for each non-RESRAD-BUILD default parameter used is given as follows:

- The **Indoor Fraction** was set at 0.23. This equates to an industrial worker working a full work year (eight hours per day, five days per week, and fifty weeks per year) in the contaminated structure as discussed in NUREG/CR-5512 Section 3.2.1.
- The **Room Area** was set at 100 m^2. NUREG/CR-6697 recommends that site-specific values be used if available since the default value is an arbitrary value for a multi-occupant office room. North County structures that are likely to be impacted are primarily commercial manufacturing facilities with room areas much greater than the 36 m^2 default value. Therefore, 100 m^2 was selected as an average value somewhere between office room floor areas and manufacturing floor areas and equivalent to a Class 1 survey unit area.
- The **Breathing Rate** was set at 33.6 m^3/day. This value is more conservative than the default value and is listed in NUREG/CR-6697 as the most likely value for the building occupancy - industrial worker scenario.
- The **Receptor** and **Source Locations** were set to place the receptor 1 meter (m) above the floor in the middle of a 10 m by 10 m room with 2.5 m walls that are contaminated from the floor up to 2 m (~6 feet). The walls and floor are uniformly contaminated.
- The **Air Release Fraction** was set at 0.07. This value is consistent with the default value of 0.1 and is listed in NUREG/CR-6697 as the most likely value.
- The **Removal Fraction** was set at 0.2. This value assumes that 20 % of the contamination is removable at any given time. This value also corresponds to the maximum allowable removable contamination fraction (or percentage) for both the DOE and NRC and is the most likely value as listed in NUREG/CR-6697. This is also a conservative value when compared to the newer NRC guidance most likely value of 0.1 listed in NUREG/CR-6755.
- The **Lifetime** was set at 10,000 days. This value is consistent with the 30-year exposure duration for a resident and the 25-year exposure duration for an industrial worker. This value is also the most likely value as listed in NUREG/CR-6697.

3.3.3 BUILDING OCCUPANCY – RENOVATION WORKER

The renovation worker scenario assumes that the critical receptor is a typical renovation worker who works 8 hours per day for 90 days a year on a building renovation project. The individual works inside the building structure that is contaminated with surficial radioactive material. The radioactive material can be released into the indoor air by mechanisms such as mechanical removal (decontamination activities) or erosion (removal of surface contamination). The applicable pathways for the renovation worker include:

- External exposure to penetrating radiation from surface sources,
- Inhalation of airborne radioactive particulates, and
- Secondary ingestion of surface contamination.

Due to the amount of time the renovation worker spends in the same contaminated building compared to the industrial worker, it is not likely that the renovation worker scenario will be the most limiting.

However, several parameters are more conservative for the renovation worker and therefore the scenarios are compared in Section 3.4.

3.3.3.1 NON-DEFAULT PARAMETERS

As stated in section 3.3, a hierarchical system was used to derive the RESRAD-BUILD parameters for each applicable scenario. Justification for each non-default parameter used is given as follows:

- The **Indoor Fraction** was set at 0.08. This equates to a renovation worker working *less* than a full work year (eight hours per day; ninety days per year) in the contaminated structure as discussed in NUREG/CR-5512 Section 3.1.1. The worker is assumed to be in only one renovation per year.
- The **Room Area** was set at 100 m^2. NUREG/CR-6697 recommends that site-specific values be used if available since the default value is an arbitrary value for a multi-occupant office room. North County structures that are likely to be impacted are primarily commercial manufacturing facilities with room areas much greater than the 36 m^2 default value. Therefore, 100 m^2 was selected as an average value somewhere between office room floor areas and manufacturing floor areas and equivalent to a Class 1 survey unit area.
- The **Resuspension Rate** was set at 1.7 E-6 sec^{-1}. This value is listed in NUREG/CR-6697 Table 7.2-1 for vigorous work including sweeping. The selection of this rate assumes that renovation activities would cause more of the contamination to remain in the room (i.e., fall to the floor, etc.) than the industrial worker activities.
- The **Breathing Rate** was set at 33.6 m^3/day. This value is more conservative than the default value and is set to the same value as an industrial worker since both workers are working indoors.
- The **Ingestion Rate** was set at 2E-4 m^2/hr. Since this rate is expressed as the surface area contacted per unit time and it is likely that renovation workers will have more contact with contaminated surfaces than industrial workers, the default rate was doubled. This value is consistent with the max value of 2.9E-4 m^2/hr listed in NUREG/CR-6697.
- The **Receptor** and **Source Locations** were set to place the receptor 1 meter (m) above the floor in the middle of a 10 m by 10 m room with 2.5 m walls that are contaminated from the floor up to 2 m (~6 feet). The walls and floor are uniformly contaminated.
- The **Air Release Fraction** was set at 0.035. This value accounts for renovation "related activities such as mechanical disturbances that usually generate a relatively small fraction of particulates released to the air verses the amount that tends to fall to the floor and is subsequently removed by housekeeping activities" as stated in NUREG/CR-6697.
- The **Removal Fraction** was set at 0.2. This value assumes that 20 % of the contamination is removable at any given time. This value also corresponds to the maximum allowable removable contamination fraction (or percentage) for both the DOE and NRC and is the most likely value as listed in NUREG/CR-6697. This is also a conservative value when compared to the newer NRC guidance most likely value of 0.1 listed in NUREG/CR-6755.
- The **Lifetime** was set at 1825 days (5 years). This value was set to account for the increased removal rate of the source that would occur during a renovation. This value falls within the range of values listed in NUREG/CR-6697. This value as it relates to air release fraction,

removable fraction, and resuspension rate was calculated at 3280 and was subsequently reduced to 1825 to provide conservatism to account for the air release fraction setpoint.

Table 3-2 Parameters for RESRAD-BUILD Building Occupancy Scenario (Renovation Worker)

Parameter	Description	Value	Justification
Time Parameter			
Exposure Duration	Amount of time that exposure occurs	365 days	NUREG/CR-5512, Volume 1, Section 3.2.1
Indoor Fraction	Fraction of the exposure duration that is spent inside the building	0.08	8 hours/day; 90 days/year
Evaluation Time	Times at which doses are calculated	0 year	RESRAD-BUILD Default
Building Parameters			
Number of Rooms	Number of compartments in the building	1	RESRAD-BUILD Default
Deposition Velocity	Velocity at which airborne particles are deposited onto the floor surfaces	0.01 m/sec	RESRAD-BUILD Default (A sensitivity test resulted in no significant difference between the default value and the min. and max values listed in NUREG/CR-6697)
Resuspension Rate	Rate at which deposited material is resuspended into the air	1.7 E-06 sec^{-1}	NUREG/CR-6697 Table 7.2-1
Building Exchange Rate	Total volume of air going out of the building per unit time divided by the total volume of the building	0.8 hr^{-1}	RESRAD-BUILD Default Consistent with value of 0.75 hr^{-1} for conditioned spaces (cited by American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Inc.)
Room Area	Floor Area of the room	100 m^2	NUREG/CR-5512, Volume 1, Section 6.2.1
Room Height	Height of the room	2.5 m	RESRAD-BUILD Default Consistent with NUREG/CR-6697 most likely value of 2.4 m
Room Exchange Rate	Total volume of air going out of the room per unit time divided by the total volume of the room	0.8 hr^{-1}	RESRAD-BUILD Default Same as building exchange rate due to single room
In/Out Flow Rate	Flow rates of air into and out of the room	200 m^3/hr	Room volume (250 m^3) * Room exchange rate (0.8 hr^{-1})
Receptor Parameters			
Number of Receptors		1	RESRAD-BUILD Default
Room # Location	Room in which the receptor is located	1	RESRAD-BUILD Default
Time Fraction	Fraction of time within the building that the exposed individual spends at his receptor location	1	RESRAD-BUILD Default
Breathing Rate	Inhalation rate of airborne material at this location	33.6 m^3/day	NUREG/CR-6697 most likely value (Breathing rate = 1.4 m^3/hr)
Ingestion Rate	Ingestion rate of deposited dust for this location	2 E-04 m^2/hr	Consistent with NUREG /CR-6697 max value of 2.9E-4
Receptor Location	Coordinates of the receptor	5m, 5m, 1m	Located in center of room at height of 1m

Table 3-2 Parameters for RESRAD-BUILD Building Occupancy Scenario (Renovation Worker)

Parameter	Description	Value	Justification
Shielding Parameters			
Thickness	Thickness of the shielding between the contamination source and the receptor location	0	RESRAD-BUILD Default
Density	Density of the shielding material	Not Applicable	
Material	Identification of the shielding material	Not Applicable	
Source Parameters			
Number of Sources		5	Floor and four walls
Room # location	All sources are located in Room # 1	1	
Source Type		Area	Surface contamination only; volume source is not likely due to historical assessment of NC buildings. (No processing of materials or activation of building materials.)
Direction	Axis perpendicular to the exposed area	Floor (z), Ceiling (z), 4 walls (x,y,x,y)	NUREG/CR-5512, Volume 1, Section 6.2.1
Location	Center point of the source in the x, y, z direction	Floor: 5m, 5m, 0m; Walls: 10m, 5m, 1m 5m, 10m, 1m 0m, 5m, 1m 5m, 0m, 1m	Entire floor and bottom 2 meters of each wall are uniformly contaminated.
Geometry: Area	Area of the exposed surface over which the contamination is evenly distributed	100, 20, 20, 20, 20 m^2	
Air Release Fraction	Fraction of the eroded material that is released into the air	0.035	NUREG/CR-6697. See 3.3.3.1 “Air Release Fraction” bullet.
Direct Ingestion	Direct Ingestion rate of the source by any receptor in the room	0 /hr	RESRAD-BUILD Default
Removable Fraction	Fraction of the source that can be linearly removed between t =0 and lifetime	0.2	Most likely value. NUREG/CR-6697
Lifetime	Amount of time in which all of the removable fraction of the source is linearly eroded	1825 days	See 3.3.3.1 “Lifetime” bullet.
Radionuclides Concentration	Unit concentration is initially run; results are normalized to 15 mrem/yr to determine each isotopic DCGL	1 pCi/m^2	

3.3.4 BUILDING OCCUPANCY – RESIDENT

This scenario assumes that North County structures that may be impacted are used as residences. Since the North County buildings most likely to be impacted are commercial manufacturing facilities that would require extensive renovation to turn them into residential buildings, the residual radioactivity (if any) would likely be reduced during renovation.

For residences along the haul routes, the credibility for the interior rooms to have become contaminated was evaluated. While loose surface contamination might be tracked into a residence via foot traffic, contamination at notable levels is not likely. In addition, residences are generally maintained so that walls are painted, carpet replaced, floors resurfaced, floors cleaned, etc. For comparison purposes, however, 80% of the source term used for the industrial and renovation worker scenarios was used for the building resident scenario.

Additionally, investigations of vicinity properties (containing residences) completed to date have revealed no contamination in excess of remedial goals.

Therefore this is an unlikely scenario due to the nature of buildings likely to be impacted. This scenario assumes the critical receptor is a building resident who lives in the surficially contaminated building 16.4 hours per day for 350 days a year. The radioactive material can be released into the indoor air by mechanisms such as mechanical removal (decontamination activities) or erosion (removal of surface contamination). The applicable pathways for the building resident include:

- External exposure to penetrating radiation from surface sources,
- Inhalation of airborne radioactive particulates, and
- Secondary ingestion of surface contamination.

3.3.4.1 NON-DEFAULT PARAMETERS

As stated in section 3.3, a hierarchical system was used to derive the RESRAD-BUILD parameters for each applicable scenario. Justification for each non-default parameter used is given as follows:

- The **Indoor Fraction** was set at 0.66. This equates to a resident living for a full year (16.4 hours per day, 350 days per year) in the contaminated structure. These values were based upon the onsite resident values for exposure duration that were used in the *Feasibility Study for the St. Louis North County Site* (USACE, 2003).

- The **Room Area** was set at 100 m^2 to be consistent with the other building occupancy scenarios. Since most North County structures that are likely to be impacted are commercial manufacturing facilities, it is likely that most of the contamination in these structures, if any, would be removed during the building renovation required to turn these facilities into residential units. 100 m^2 was selected as an average value somewhere between office room floor areas and manufacturing floor areas and equivalent to a Class 1 survey unit area.

- The **Resuspension Rate** was set at 5 E-9 sec-1. This is the value listed in NUREG/CR-6697 Table 7.2-1 for residents performing normal activities. This value also represents particle sizes of 1 to 5 microns.

- The **Breathing Rate** was set at 13.2 m^3/day. This value is the same as the indoor inhalation rate used for the residential scenario in the North County Feasibility Study (USACE, 2003).

- The **Receptor and Source Locations** were set to place the receptor 1 meter (m) above the floor in the middle of a 10 m by 10 m room with 2.5 m walls that are contaminated from the floor up to 2 m (~6 feet). The walls and floor are uniformly contaminated.

- The **Air Release Fraction** was set at 0.07. This value is consistent with the default value of 0.1 and is listed in NUREG/CR-6697 as the most likely value.

- The **Removal Fraction** was set at 0.1. This value assumes that 10 % of the contamination is removable at any given time. (NUREG-6755) This value also corresponds to the recommended removable contamination fraction (or percentage) for the NRC.

- The **Lifetime** was set at 10,000 days. This value is consistent with the 30-year exposure duration for a resident and the 25-year exposure duration for an industrial worker. This value is also the most likely value as listed in NUREG/CR-6697.

- The **Source Term** was set to 80% of the source term used in the Industrial Worker and Renovation Worker scenarios. In order to compare the scenarios, the reduction in source term is necessary to account for the amount of source removed during renovation. This reduction in source coincides with the assumption that industrial structures would necessarily require renovation prior to use as a residence. The reduction also coincides with the amount of source removed during renovation.

Table 3-3 Parameters for RESRAD-BUILD Building Occupancy Scenario (Resident)

Parameter	Description	Value	Justification
Time Parameter			
Exposure Duration	Amount of time that exposure occurs	365 days	NUREG/CR-5512, Volume 1, Section 3.2.1
Indoor Fraction	Fraction of the exposure duration that is spent inside the building	0.66	16.4 hours/day; 350 days/year (North County FS – Resident)
Evaluation Time	Times at which doses are calculated	0 year; 1 year	RESRAD-BUILD Default
Building Parameters			
Number of Rooms	Number of compartments in the building	1	RESRAD-BUILD Default
Deposition Velocity	Velocity at which airborne particles are deposited onto the floor surfaces	0.01 m/sec	RESRAD-BUILD Default (A sensitivity test resulted in no significant difference between the default value and the min. and max values listed in NUREG/CR-6697)
Resuspension Rate	Rate at which deposited material is resuspended into the air	5.0 E-09 sec^{-1}	NUREG/CR-6697, Table 7.2-1 (1-5 um particle)
Building Exchange Rate	Total volume of air going out of the building per unit time divided by the total volume of the building	0.8 hr^{-1}	RESRAD-BUILD Default Consistent with value of 0.75 hr^{-1} for conditioned spaces (cited by American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Inc.)
Room Area	Floor Area of the room	100 m^2	NUREG/CR-5512, Volume 1, Section 6.2.1
Room Height	Height of the room	2.5 m	RESRAD-BUILD Default Consistent with NUREG/CR-6697 most likely value of 2.4 m
Room Exchange Rate	Total volume of air going out of the room per unit time divided by the total volume of the room	0.8 hr^{-1}	RESRAD-BUILD Default Same as building exchange rate due to single room
In/Out Flow Rate	Flow rates of air into and out of the room	200 m^3/hr	Room volume (250 m^3) * Room exchange rate (0.8 hr^{-1})
Receptor Parameters			
Number of Receptors		1	RESRAD-BUILD Default
Room # Location	Room in which the receptor is located	1	RESRAD-BUILD Default
Time Fraction	Fraction of time within the building that the exposed individual spends at his receptor location	1	RESRAD-BUILD Default
Breathing Rate	Inhalation rate of airborne material at this location	13.2 m^3/day	North County Feasibility Study – Residential scenario
Ingestion Rate	Ingestion rate of deposited dust for this location	1 E-04 m^2/hr	RESRAD-BUILD Default (Approximate midpoint between NUREG/CR-6697 min. and max values)
Receptor Location	Coordinates of the receptor	5m, 5m, 1m	Located in center of room at height of 1m

Table 3-3 Parameters for RESRAD-BUILD Building Occupancy Scenario (Resident)

Parameter	Description	Value	Justification
Shielding Parameters			
Thickness	Thickness of the shielding between the contamination source and the receptor location	0	RESRAD-BUILD Default
Density	Density of the shielding material	Not Applicable	
Material	Identification of the shielding material	Not Applicable	
Source Parameters			
Number of Sources		5	Floor and four walls
Room # location	All sources are located in Room # 1	1	
Source Type		Area	Surface contamination only; volume source is not likely due to historical assessment of NC buildings. (No processing of materials or activation of building materials.)
Direction	Axis perpendicular to the exposed area	Floor (z), Ceiling (z), 4 walls (x,y,x,y)	NUREG/CR-5512, Volume 1, Section 6.2.1
Location	Center point of the source in the x, y, z direction	Floor: 5m, 5m, 0m; Walls: 10m, 5m, 1m 5m, 10m, 1m 0m, 5m, 1m 5m, 0m, 1m	Entire floor and bottom 2 meters of each wall are uniformly contaminated.
Geometry: Area	Area of the exposed surface over which the contamination is evenly distributed	100, 20, 20, 20, 20 m^2	
Air Release Fraction	Fraction of the eroded material that is released into the air	0.07	Most likely value. NUREG/CR-6697
Direct Ingestion	Direct Ingestion rate of the source by any receptor in the room	0 g/hr	RESRAD-BUILD Default
Removable Fraction	Fraction of the source that can be linearly removed between t =0 and lifetime	0.1	Most likely value. NUREG/CR-6755
Lifetime	Amount of time in which all of the removable fraction of the source is linearly eroded	10,000 days	Most likely value. NUREG/CR-6697
Radionuclides Concentration	Unit concentration is initially run; results are normalized to 15 mrem/yr to determine each isotopic DCGL	1 pCi/m^2	

3.3.5 ONSITE RESIDENT – POST DEMOLITION

The onsite resident – post demolition scenario assumes that the building structure (described in the three scenarios above) is demolished, buried on site, and a residence is established on top of the rubble. This scenario assumes that the total activity in the structure (180 picocuries[3]) is distributed uniformly in the soil (3000 m^3). This scenario assumes the same parameters used in the onsite resident scenario in the *Feasibility Study for the St. Louis North County Site* (USACE, 2003).

3.3.5.1 NON-DEFAULT PARAMETERS

RESRAD Version 6.21 was used to evaluate this scenario. The non-default parameters are listed in Table 3-4. Justification for each non-default parameter can be found in the *Feasibility Study for the St. Louis North County Site* (USACE, 2003).

Table 3-4 Non-Default RESRAD Parameter for Onsite Resident

Parameter	Value	Justification
Thickness of contamination zone	0.3 m	North County FS
Inhalation Rate	4836 m^3/yr	North County FS
Mass Loading Factor	0.0001	North County FS
Exposure duration	30 yrs	EPA Risk Assessment Guidance
Fraction of time spend indoors	0.655	Exposure Factor Handbook
Fraction of time spent outdoor	0.0799	Exposure Factor Handbook
Soil ingestion	43.8 kg/yr	Weight Average Soil Ingestion by Adult & Child (Exposure Factor Handbook)

3.4 IDENTIFYING THE MOST LIMITING SCENARIO

As discussed in the Section 3.3, three potential building occupancy and one post-demolition exposure scenarios were considered. The purpose of this section is to document the results of each scenario assuming appropriate source terms and determine which scenario is the most limiting.

The source term used for comparison of the three building occupancy scenarios was 1 pCi/m^2 of Th-230 uniformly distributed on the floor and all four walls from the floor up to 2 m for the Industrial Worker and Renovation Worker scenarios and 0.8 pCi/m^2 of Th-230 for the Building Resident scenario. The source term used for the onsite resident post demolition was calculated by multiplying the uniform activity concentration (1 pCi/m^2) by the total source area (180 m^2) of the building occupancy scenarios and distributing it uniformly in the total volume of soil (3000 m^3). Th-230 was chosen as the source term to compare scenarios because it is the primary contaminant of concern (COC).

$$180\,\mathrm{m}^2 * \frac{1\,\mathrm{pCi}}{\mathrm{m}^2} * \frac{1}{10000\,\mathrm{m}^2 * 0.3\,\mathrm{m}} * \frac{c\mathrm{m}^3}{1.5\,g} * \frac{1\,\mathrm{m}^3}{1E6\,c\mathrm{m}^3} = 4E-8\,\frac{\mathrm{pCi}}{\mathrm{g}}$$

[3] The total activity is calculated by multiplying the uniform activity concentration (1 pCi/m^2) by the total source area (180 m^2: floor 100 m^2 and four 20 m^2 walls).

As discussed in Section 3.2, additional exposure scenarios (i.e., those listed in NUREG-1640 for handling, transportation, disposal, etc.) were considered. Table 3-5 compares the DSR listed in NUREG-1640 to those of the most limiting scenario (industrial worker) and demonstrates that the industrial worker scenario is still the most limiting (highest dose per unit source).

Table 3-5 Comparison of Dose to Source Ratios

	Dose to Source Ratio (mrem/yr / pCi/m^2)									
Scenario	Ac-227	Pa-231	Ra-226	Ra-228	Th-228	Th-230	Th-232	U-234	U-235	U-238
Industrial Worker	**9.2E-04**	**2.4E-04**	**2.3E-05**	**4.3E-05**	**7.5E-05**	**4.8E-05**	**2.5E-04**	**2.0E-05**	**2.0E-05**	**1.8E-05**
Handling[1]	1.7E-05	1.1E-05	1.9E-06	1.0E-06	4.8E-06	3.4E-06	1.5E-05	1.7E-06	1.6E-06	1.5E-06
Transportation[1]	1.7E-07	3.4E-08	2.9E-06	1.4E-06	2.1E-06	3.7E-11	1.0E-08	6.3E-12	1.4E-07	5.6E-09
Disposal[1]	3.4E-06	2.3E-06	4.8E-07	2.8E-07	1.1E-06	6.7E-07	2.9E-06	3.3E-07	3.2E-07	3.0E-07
Road Bed W[1]	1.4E-05	9.3E-06	3.4E-06	1.9E-06	5.2E-06	2.6E-06	1.1E-05	1.3E-06	1.4E-06	1.2E-06
Road Bed N[1]	3.7E-07	3.6E-08	2.1E-06	1.0E-06	1.6E-06	8.5E-10	1.4E-07	7.4E-11	1.3E-07	2.6E-08
LGMASS-N[1]	1.5E-08	1.2E-09	7.4E-08	3.5E-08	4.8E-08	2.4E-11	4.8E-09	1.1E-12	5.2E-09	4.4E-10
Landfill-N[1]	2.6E-06	7.0E-05	1.9E-05	2.3E-09	8.9E-16	7.0E-06	4.4E-05	5.2E-06	4.8E-06	4.1E-06

[1] Scenario from NUREG-1640.

Results of the dose evaluations for the four scenarios listed in section 3.3 are shown in Table 3-6.

Table 3-6 Equivalent Source Term Dose Results (1 pCi/m^2 Th-230)

Scenario	Industrial Worker	Renovation Worker	Building Resident	Onsite Resident
Dose (TEDE[1]) (mrem/yr)	4.8 E-5	4.6 E-5	3.5 E-5	6 E-9

[1] Total effective dose equivalent

As shown in the Table above, the scenarios in order of most limiting to least limiting (due to annual dose) are:

1. Industrial Worker
2. Renovation Worker
3. Building Resident
4. Onsite Resident

The results of the dose assessments for the scenarios show that the most limiting scenario is the Building Occupancy – Industrial Worker. This scenario was selected for determining DCGLs.

3.5 CALCULATING DCGLS FROM RESRAD-BUILD OUTPUT

The industrial worker was the most limiting scenario, as demonstrated in Table 3-6.

To derive the surficial contamination DCGL values that would be equivalent to the benchmark dose limit of 15 mrem/yr, each North County COC plus Pa-231 and Ac-227 were put into the RESRAD-BUILD code with a source term of 1 pCi/m^2 for each radionuclide in order to determine a DSR. The DSR is a derived value, based upon the RESRAD modeling output, that can be used to convert the benchmark dose limit to units of surficial contamination (in pCi/m^2).

Table 3-7 separates each radionuclide COC (plus Ac-227 and Pa-231) and then presents the derived DSR for that radionuclide and its associated progeny due to each source in the building. The DSRs from all sources for each of the radionuclides and progeny are subtotaled. The total DSR for a radionuclide COC is calculated by summing the DSR subtotals.

It is important to note that the DCGLs, when implemented during surveys, are to be compared to residual contamination above background. If background is not taken into consideration, the DCGLs remain fully protective.

Table 3-7 Determination of Total Dose-to-Source Ratio (DSR) from All Sources

RADIONUCLIDE/ PROGENY[1]		SOURCE[2] (based upon 1 pCi/m^2)					DSR SUBTOTAL[3]	TOTAL[4] DSR mrem/yr / pCi/m^2
		1	2	3	4	5		
U-238	U-238	1.0E-05	2.0E-06	2.0E-06	2.0E-06	2.0E-06	1.8E-05	1.8E-05
	U-234	4.6E-11	9.3E-12	9.3E-12	9.3E-12	9.3E-12	8.3E-11	
	Th-230	8.0E-16	1.6E-16	1.6E-16	1.6E-16	1.6E-16	1.4E-15	
	Ra-226	1.2E-19	9.8E-21	9.8E-21	9.8E-21	9.8E-21	1.6E-19	
	Pb-210	4.3E-23	8.4E-24	8.4E-24	8.4E-24	8.4E-24	7.6E-23	
U-235	U-235	1.2E-05	2.1E-06	2.1E-06	2.1E-06	2.1E-06	2.0E-05	2.0E-05
	Pa-231	3.4E-09	6.8E-10	6.8E-10	6.8E-10	6.8E-10	6.1E-09	
	Ac-227	4.2E-10	8.8E-11	8.8E-11	8.8E-11	8.8E-11	7.5E-10	
U-234	U-234	1.1E-05	2.3E-06	2.3E-06	2.3E-06	2.3E-06	2.0E-05	2.0E-05
	Th-230	3.6E-10	7.3E-11	7.3E-11	7.3E-11	7.3E-11	6.5E-10	
	Ra-226	7.7E-14	6.4E-15	6.4E-15	6.4E-15	6.4E-15	1.0E-13	
	Pb-210	2.0E-16	4.0E-17	4.0E-17	4.0E-17	4.0E-17	3.6E-16	
Pa-231	Pa-231	1.1E-04	2.1E-05	2.1E-05	2.1E-05	2.1E-05	1.9E-04	2.4E-04
	Ac-227	2.5E-05	5.0E-06	5.0E-06	5.0E-06	5.0E-06	4.5E-05	
Th-228	Th-228	4.5E-05	7.6E-06	7.6E-06	7.6E-06	7.6E-06	7.5E-05	7.5E-05
Th-232	Th-232	1.4E-04	2.7E-05	2.7E-05	2.7E-05	2.7E-05	2.4E-04	2.5E-04
	Th-228	2.1E-06	3.6E-07	3.6E-07	3.6E-07	3.6E-07	3.5E-06	
	Ra-228	1.4E-06	1.1E-07	1.1E-07	1.1E-07	1.1E-07	1.9E-06	
Th-230	Th-230	2.7E-05	5.4E-06	5.4E-06	5.4E-06	5.4E-06	4.8E-05	4.8E-05
	Ra-226	1.1E-08	9.1E-10	9.1E-10	9.1E-10	9.1E-10	1.5E-08	
	Pb-210	4.2E-11	8.3E-12	8.3E-12	8.3E-12	8.3E-12	7.5E-11	
Ac-227	Ac-227	5.1E-04	1.0E-04	1.0E-04	1.0E-04	1.0E-04	9.2E-04	9.2E-04
Ra-228	Ra-228	7.3E-06	5.3E-07	5.3E-07	5.3E-07	5.3E-07	9.4E-06	4.3E-05
	Th-228	2.0E-05	3.4E-06	3.4E-06	3.4E-06	3.4E-06	3.4E-05	
Ra-226	Ra-226	1.7E-05	1.4E-06	1.4E-06	1.4E-06	1.4E-06	2.3E-05	2.3E-05
	Pb-210	1.2E-07	2.4E-08	2.4E-08	2.4E-08	2.4E-08	2.2E-07	

[1] Each radionuclide was set to 1 pCi/m^2. Doses resulting from the parent and the progeny of each parent are listed.
[2] Source 1 represents the floor; sources 2 – 5 represent each contaminated wall.
[3] Dose subtotal per radionuclide due to sources 1 – 5.
[4] Total DSR from each COC (plus Ac-227 and Pa-231) including dose from progeny due to sources 1 – 5. Total DSR is calculated by summing the dose subtotal values for each radionuclide and its progeny.

Table 3-8 illustrates DSRs adjusted to an equivalent 15 mrem/yr dose for surface concentrations and radionuclide-specific DCGLs.

Table 3-8 Individual Radionuclide DCGLs Equivalent to 15 mrem/yr

Radionuclide	Dose to Source Ratio[1]	Surface Concentration	Surface DCGL[2]
	(mrem/yr) / (pCi/m^2)	(pCi/m^2)	(dpm/100 cm^2)
Ac-227	9.2E-04	1.6E+04	**400**
Pa-231	2.4E-04	6.3E+04	**1,400**
Ra-226	2.3E-05	6.6E+05	**15,000**
Ra-228	4.3E-05	3.5E+05	**7,700**
Th-228	7.5E-05	2.0E+05	**4,400**
Th-230	4.8E-05	3.1E+05	**6,900**
Th-232	2.5E-04	6.1E+04	**1,300**
U-234	2.0E-05	7.7E+05	**17,000**
U-235	2.0E-05	7.4E+05	**16,000**
U-238	1.8E-05	8.4E+05	**19,000**

[1] Results from TOTAL DSR column in Table 3-7.
[2] Results rounded to no more than two significant digits.

4.0 UNCERTAINTY ANALYSIS

DCGL calculations use industry standard modeling tools and representative input parameters that are specifically designed to assess exposure to radionuclides. The approach used assures protectiveness of future receptors likely to be present in the North County structures that may be impacted. The contaminated room modeled in this report contains no windows or doors and contains no furniture. The receptor is assumed to spend 100% of on-site occupancy at the center of the contaminated room.

RESRAD-BUILD considers two pathways to generate the airborne concentration caused by the contaminated area sources. The primary source of airborne contamination is direct removal from the surface source, described by a removable fraction, time of source removal (lifetime), and air fraction. For this analysis, a removable fraction of 0.2 was set for both the walls and floor of the room. This means that the floor and four walls will erode at the same rate, which is conservative. It is likely that the floor will have more physical contact than the walls. The time to source removal is 10,000 days, defined as the most likely value by NUREG/CR 6697. Based on the removable fraction of 0.2, and lifetime of 10,000 days, the resuspension rate of the contaminants from the contaminated surface is equal to 2.3 E-10. For the industrial worker scenario, the resuspension rate was set at 5 E-07; therefore, this scenario used a more conservative value (on the order of three magnitudes) for the resuspension rate.

Doses calculated using RESRAD-BUILD are heavily dependent on the code's dust resuspension model. Doses specific to the inhalation pathway require that contaminated dust be suspended in the air where the receptor breathes in the material, leading to a radiological dose. Doses specific to the ingestion pathway require that contaminated dust be suspended and then re-deposited on surfaces where the receptor inadvertently ingests the material, leading to a radiological dose. Both the inhalation and the ingestion pathways depend on the model's ability to accurately predict contaminant circulation within the occupied space. RESRAD-BUILD input parameters related to contaminant circulation are sometimes left as defaults, increasing the uncertainty in results. RESRAD default and NRC guidance-based parameter values are used. These values reasonably and conservatively represent current conditions or conditions that would be present in the event of future building occupancy.

The source term used in the building occupancy scenario was set for a uniform contamination of the floor and walls from the floor up to 2 m. It is unlikely that the walls would be as contaminated as the floor due to gravity and geometry. The approach outlined in this report ensures that doses are not underestimated regardless of geometry.

5.0 ALARA ANALYSIS

ALARA is an integral component of the benchmark dose and compliance with ARARs requires documentation that doses are ALARA. Therefore, an ALARA analysis conducted in support of the DCGL development has been incorporated as Appendix B to this report. This analysis documents that it is not appropriate to further lower DCGLs pursuant to ALARA. Documentation of ALARA is also an integral component of residual site dose and risk assessments and will be incorporated into post remedial action reports for portions of the site that are remediated and into final status survey reports for areas not requiring remediation.

6.0 SUMMARY

6.1 SUMMARY OF DCGL DETERMINATION

A conceptual site model was established to determine the applicable pathways for two likely (industrial worker and renovation worker) and two unlikely (building occupancy - resident and onsite resident – post demolition) scenarios. The radionuclide-specific DCGL values calculated in this report for the most limiting scenario considered a potential dose limit (15 mrem/yr) that is protective of human health and the environment. The receptor was selected as a member of the respective critical group representing long-term or full-time employees (industrial worker). RESRAD-BUILD Version 3.1 was used to calculate DCGL concentrations using parameter values primarily from EPA and NRC guidance. Results presented in Table 6-1 are based upon 15 mrem/yr and a 20% removable contamination.

Table 6-1 DCGL Results

Analyte	**Surface DCGL** (dpm/100 cm^2)
Ac-227	400
Pa-231	1,400
Ra-226	15,000
Ra-228	7,700
Th-228	4,400
Th-230	6,900
Th-232	1,300
U-234	17,000
U-235	16,000
U-238	19,000

Table 6-1 results may be used to calculate gross Alpha or gross Beta DCGLs based upon known site-specific information. Using site-specific activity fractions, the gross Alpha or Beta DCGL can be calculated by the following equation:

$$\text{Gross Alpha or Beta DCGL} = \frac{1}{\frac{ActivityFraction_1}{DCGL_1} + \frac{ActivityFraction_2}{DCGL_2} + \frac{ActivityFraction_3}{DCGL_3} + etc...}$$

7.0 REFERENCES

ANL 2000. *Development of Probabilistic RESRAD 6.0 and RESRAD-BUILD 3.0 Computer Codes*, ANL/EAD/TM-98, NUREG/CR-6697, prepared for the U.S. Nuclear Regulatory Commission, November.

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APPENDIX A

RESRAD-BUILD OUTPUT

APPENDIX A – RESRAD-BUILD OUTPUT

Appendix A presents the RESRAD-BUILD Version 3.1 output for the industrial worker scenario. Each radionuclide COC plus Ac-227 and Pa-231 were used in the source term. Dose resulting from each individual radionuclide for each source is presented in Table 3-7.

```
** RESRAD-BUILD Program Output, Version 3.1 05/27/03 14:52  Page:   1 **
Title : NC Building Occupancy-All Radionulcides
Input File : C:\Winbld\NCBDOccupancyAllRad.bld
```

RESRAD-BUILD Table of Contents

```
** RESRAD-BUILD Program Output, Version 3.1 05/27/03 14:52  Page:   2 **
Title : NC Building Occupancy-All Radionulcides
Input File : C:\Winbld\NCBDOccupancyAllRad.bld
```

RESRAD-BUILD Input Parameters

Number of Sources : 5
Number of Receptors: 1
Total Time : 3.650000E+02 days
Fraction Inside : 2.300000E-01

Receptor Information

Receptor	Room	x [m]	y [m]	z [m]	FracTime	Inhalation [m3/day]	Ingestion(Dust) [m2/hr]
1	1	5.000	5.000	1.000	1.000	3.36E+01	1.00E-04

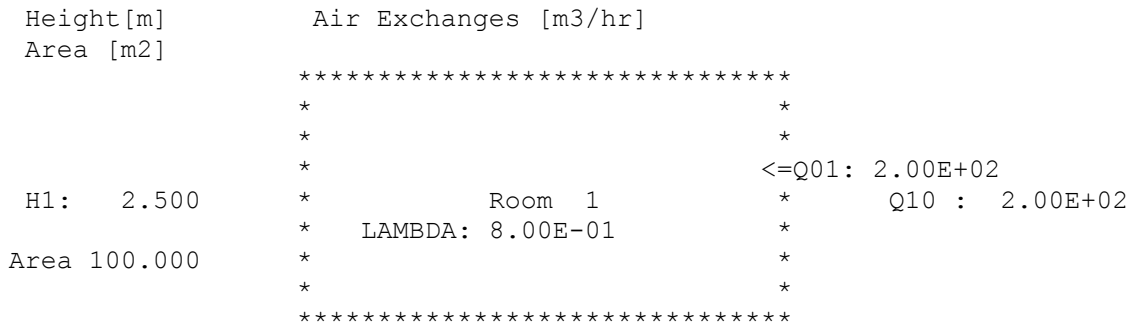
Receptor-Source Shielding Relationship

Receptor	Source	Density [g/cm3]	Thickness [cm]	Material
1	1	2.40E+00	0.00E+00	Concrete
1	2	2.40E+00	0.00E+00	Concrete
1	3	2.40E+00	0.00E+00	Concrete
1	4	2.40E+00	0.00E+00	Concrete
1	5	2.40E+00	0.00E+00	Concrete

```
** RESRAD-BUILD Program Output, Version 3.1 05/27/03 14:52  Page:   3 **
Title : NC Building Occupancy-All Radionulcides
Input File : C:\Winbld\NCBDOccupancyAllRad.bld
```

Building Information

Building Air Exchange Rate: 8.00E-01 1/hr



Deposition velocity: 1.00E-02 [m/s] Resuspension Rate: 5.00E-07 [1/s]

```
** RESRAD-BUILD Program Output, Version 3.1 05/27/03 14:52  Page:   4 **
Title : NC Building Occupancy-All Radionulcides
Input File : C:\Winbld\NCBDOccupancyAllRad.bld


              ========  Source Information  ========


 Source:  1
         Location::  Room :  1  x:   5.00 y:   5.00  z:   0.00[m]
         Geometry::  Type: Area        Area:1.00E+02 [m2]  Direction: z
         Pathway ::
              Direct Ingestion Rate:    0.000E+00 [1/hr]
              Fraction released to air: 7.000E-02
              Removable fraction:       2.000E-01
              Time to Remove:           1.000E+04 [day]

              Radon Release Fraction:   1.000E-01


   Contamination::
    Nuclide Concentration      Dose Conversion Factors
    _______ _____________  ____________________________________

                           Ingestion   Inhalation  Submersion
                [pCi/m2]   [mrem/pCi]  [mrem/pCi]  [mrem/yr/
                                                   (pCi/m3)]
     U-238     1.000E+00   2.690E-04   1.180E-01   1.600E-04
     U-235     1.000E+00   2.670E-04   1.230E-01   9.030E-04
     U-234     1.000E+00   2.830E-04   1.320E-01   8.930E-07
     PA-231    1.000E+00   1.060E-02   1.280E+00   2.010E-04
     TH-232    1.000E+00   2.730E-03   1.640E+00   1.020E-06
     TH-230    1.000E+00   5.480E-04   3.260E-01   2.040E-06
     TH-228    0.000E+00   8.080E-04   3.450E-01   9.410E-03
     AC-227    1.000E+00   1.480E-02   6.720E+00   2.160E-03
     RA-228    1.000E+00   1.440E-03   5.080E-03   5.590E-03
     RA-226    1.000E+00   1.330E-03   8.600E-03   1.040E-02
     PB-210    0.000E+00   7.270E-03   2.320E-02   1.050E-05
```

```
** RESRAD-BUILD Program Output, Version 3.1 05/27/03 14:52  Page:   5 **
Title : NC Building Occupancy-All Radionulcides
Input File : C:\Winbld\NCBDOccupancyAllRad.bld


 Source:  2
        Location::  Room :  1  x:   5.00 y:  10.00  z:   1.00[m]
        Geometry::  Type: Area        Area:2.00E+01 [m2]  Direction: y
        Pathway ::
             Direct Ingestion Rate:    0.000E+00 [1/hr]
             Fraction released to air: 7.000E-02
             Removable fraction:       2.000E-01
             Time to Remove:           1.000E+04 [day]

             Radon Release Fraction:   1.000E-01
```

Contamination::

Nuclide	Concentration	Dose Conversion Factors		
	[pCi/m2]	Ingestion [mrem/pCi]	Inhalation [mrem/pCi]	Submersion [mrem/yr/ (pCi/m3)]
U-238	1.000E+00	2.690E-04	1.180E-01	1.600E-04
U-235	1.000E+00	2.670E-04	1.230E-01	9.030E-04
U-234	1.000E+00	2.830E-04	1.320E-01	8.930E-07
PA-231	1.000E+00	1.060E-02	1.280E+00	2.010E-04
TH-232	1.000E+00	2.730E-03	1.640E+00	1.020E-06
TH-230	1.000E+00	5.480E-04	3.260E-01	2.040E-06
TH-228	0.000E+00	8.080E-04	3.450E-01	9.410E-03
AC-227	1.000E+00	1.480E-02	6.720E+00	2.160E-03
RA-228	1.000E+00	1.440E-03	5.080E-03	5.590E-03
RA-226	1.000E+00	1.330E-03	8.600E-03	1.040E-02
PB-210	0.000E+00	7.270E-03	2.320E-02	1.050E-05

```
** RESRAD-BUILD Program Output, Version 3.1 05/27/03 14:52  Page:   6 **
Title : NC Building Occupancy-All Radionulcides
Input File : C:\Winbld\NCBDOccupancyAllRad.bld


 Source:  3
        Location::  Room :  1  x:  10.00 y:   5.00  z:   1.00[m]
        Geometry::  Type: Area        Area:2.00E+01 [m2]  Direction: x
        Pathway ::
             Direct Ingestion Rate:    0.000E+00 [1/hr]
             Fraction released to air: 7.000E-02
             Removable fraction:       2.000E-01
             Time to Remove:           1.000E+04 [day]

             Radon Release Fraction:   1.000E-01
```

Contamination::

Nuclide	Concentration	Dose Conversion Factors		
	[pCi/m2]	Ingestion [mrem/pCi]	Inhalation [mrem/pCi]	Submersion [mrem/yr/ (pCi/m3)]
U-238	1.000E+00	2.690E-04	1.180E-01	1.600E-04
U-235	1.000E+00	2.670E-04	1.230E-01	9.030E-04
U-234	1.000E+00	2.830E-04	1.320E-01	8.930E-07
PA-231	1.000E+00	1.060E-02	1.280E+00	2.010E-04
TH-232	1.000E+00	2.730E-03	1.640E+00	1.020E-06
TH-230	1.000E+00	5.480E-04	3.260E-01	2.040E-06
TH-228	0.000E+00	8.080E-04	3.450E-01	9.410E-03
AC-227	1.000E+00	1.480E-02	6.720E+00	2.160E-03
RA-228	1.000E+00	1.440E-03	5.080E-03	5.590E-03
RA-226	1.000E+00	1.330E-03	8.600E-03	1.040E-02
PB-210	0.000E+00	7.270E-03	2.320E-02	1.050E-05

```
** RESRAD-BUILD Program Output, Version 3.1 05/27/03 14:52  Page:   7 **
Title : NC Building Occupancy-All Radionulcides
Input File : C:\Winbld\NCBDOccupancyAllRad.bld


 Source:  4
        Location::  Room :  1  x:   0.00 y:   5.00  z:   1.00[m]
        Geometry::  Type: Area        Area:2.00E+01 [m2]  Direction: x
        Pathway ::
             Direct Ingestion Rate:    0.000E+00 [1/hr]
             Fraction released to air: 7.000E-02
             Removable fraction:       2.000E-01
             Time to Remove:           1.000E+04 [day]

             Radon Release Fraction:   1.000E-01
```

Contamination::

Nuclide	Concentration	Dose Conversion Factors		
	[pCi/m2]	Ingestion [mrem/pCi]	Inhalation [mrem/pCi]	Submersion [mrem/yr/ (pCi/m3)]
U-238	1.000E+00	2.690E-04	1.180E-01	1.600E-04
U-235	1.000E+00	2.670E-04	1.230E-01	9.030E-04
U-234	1.000E+00	2.830E-04	1.320E-01	8.930E-07
PA-231	1.000E+00	1.060E-02	1.280E+00	2.010E-04
TH-232	1.000E+00	2.730E-03	1.640E+00	1.020E-06
TH-230	1.000E+00	5.480E-04	3.260E-01	2.040E-06
TH-228	0.000E+00	8.080E-04	3.450E-01	9.410E-03
AC-227	1.000E+00	1.480E-02	6.720E+00	2.160E-03
RA-228	1.000E+00	1.440E-03	5.080E-03	5.590E-03
RA-226	1.000E+00	1.330E-03	8.600E-03	1.040E-02
PB-210	0.000E+00	7.270E-03	2.320E-02	1.050E-05

```
** RESRAD-BUILD Program Output, Version 3.1 05/27/03 14:52  Page:   8 **
Title : NC Building Occupancy-All Radionulcides
Input File : C:\Winbld\NCBDOccupancyAllRad.bld


 Source:  5
        Location::  Room :  1  x:   5.00 y:   0.00  z:   1.00[m]
        Geometry::  Type: Area        Area:2.00E+01 [m2]  Direction: y
        Pathway ::
             Direct Ingestion Rate:    0.000E+00 [1/hr]
             Fraction released to air: 7.000E-02
             Removable fraction:       2.000E-01
             Time to Remove:           1.000E+04 [day]

             Radon Release Fraction:   1.000E-01
```

Contamination::

Nuclide	Concentration	Dose Conversion Factors		
	[pCi/m2]	Ingestion [mrem/pCi]	Inhalation [mrem/pCi]	Submersion [mrem/yr/ (pCi/m3)]
U-238	1.000E+00	2.690E-04	1.180E-01	1.600E-04
U-235	1.000E+00	2.670E-04	1.230E-01	9.030E-04
U-234	1.000E+00	2.830E-04	1.320E-01	8.930E-07
PA-231	1.000E+00	1.060E-02	1.280E+00	2.010E-04
TH-232	1.000E+00	2.730E-03	1.640E+00	1.020E-06
TH-230	1.000E+00	5.480E-04	3.260E-01	2.040E-06
TH-228	0.000E+00	8.080E-04	3.450E-01	9.410E-03
AC-227	1.000E+00	1.480E-02	6.720E+00	2.160E-03
RA-228	1.000E+00	1.440E-03	5.080E-03	5.590E-03
RA-226	1.000E+00	1.330E-03	8.600E-03	1.040E-02
PB-210	0.000E+00	7.270E-03	2.320E-02	1.050E-05

```
** RESRAD-BUILD Program Output, Version 3.1 05/27/03 14:52  Page:   9 **
Title : NC Building Occupancy-All Radionulcides
Input File : C:\Winbld\NCBDOccupancyAllRad.bld
Evaluation Time:    0.000000     years

              ================================================
              ================================================
              ===       Assessment for Time:  1              ===
              ===             Time =0.00E+00 yr              ===
              ================================================
              ================================================

              ========  Source Information  ========


 Source:  1
         Location::  Room :  1  x:   5.00 y:   5.00  z:   0.00 [m]
         Geometry::  Type: Area        Area:1.00E+02 [m2]  Direction: z
         Pathway ::
              Direct Ingestion Rate:    0.000E+00 [1/hr]
              Fraction released to air: 7.000E-02
              Removable fraction:       2.000E-01
              Time to Remove:           1.000E+04 [day]



         Contamination::     Nuclide    Concentration
                                          [pCi/m2]
                              U-238       1.000E+00
                              U-235       1.000E+00
                              U-234       1.000E+00
                              PA-231      1.000E+00
                              TH-232      1.000E+00
                              TH-230      1.000E+00
                              TH-228      0.000E+00
                              AC-227      1.000E+00
                              RA-228      1.000E+00
                              RA-226      1.000E+00
                              PB-210      0.000E+00
```

```
** RESRAD-BUILD Program Output, Version 3.1 05/27/03 14:52  Page:  10 **
Title : NC Building Occupancy-All Radionulcides
Input File : C:\Winbld\NCBDOccupancyAllRad.bld
Evaluation Time:    0.000000     years


 Source:  2
        Location::  Room :  1  x:   5.00 y:  10.00  z:   1.00 [m]
        Geometry::  Type: Area        Area:2.00E+01 [m2]  Direction: y
        Pathway ::
             Direct Ingestion Rate:    0.000E+00 [1/hr]
             Fraction released to air: 7.000E-02
             Removable fraction:       2.000E-01
             Time to Remove:           1.000E+04 [day]



        Contamination::     Nuclide    Concentration
                                         [pCi/m2]
                             U-238       1.000E+00
                             U-235       1.000E+00
                             U-234       1.000E+00
                             PA-231      1.000E+00
                             TH-232      1.000E+00
                             TH-230      1.000E+00
                             TH-228      0.000E+00
                             AC-227      1.000E+00
                             RA-228      1.000E+00
                             RA-226      1.000E+00
                             PB-210      0.000E+00
```

```
** RESRAD-BUILD Program Output, Version 3.1 05/27/03 14:52  Page:  11 **
Title : NC Building Occupancy-All Radionulcides
Input File : C:\Winbld\NCBDOccupancyAllRad.bld
Evaluation Time:    0.000000     years


 Source:  3
        Location::  Room :  1  x:  10.00 y:   5.00  z:   1.00 [m]
        Geometry::  Type: Area        Area:2.00E+01 [m2]  Direction: x
        Pathway ::
             Direct Ingestion Rate:    0.000E+00 [1/hr]
             Fraction released to air: 7.000E-02
             Removable fraction:       2.000E-01
             Time to Remove:           1.000E+04 [day]



        Contamination::     Nuclide    Concentration
                                         [pCi/m2]
                             U-238       1.000E+00
                             U-235       1.000E+00
                             U-234       1.000E+00
                             PA-231      1.000E+00
                             TH-232      1.000E+00
                             TH-230      1.000E+00
                             TH-228      0.000E+00
                             AC-227      1.000E+00
                             RA-228      1.000E+00
                             RA-226      1.000E+00
                             PB-210      0.000E+00
```

```
** RESRAD-BUILD Program Output, Version 3.1 05/27/03 14:52  Page:  12 **
Title : NC Building Occupancy-All Radionulcides
Input File : C:\Winbld\NCBDOccupancyAllRad.bld
Evaluation Time:    0.000000     years


 Source:  4
        Location::  Room :  1  x:   0.00 y:   5.00  z:   1.00 [m]
        Geometry::  Type: Area        Area:2.00E+01 [m2]  Direction: x
        Pathway ::
             Direct Ingestion Rate:    0.000E+00 [1/hr]
             Fraction released to air: 7.000E-02
             Removable fraction:       2.000E-01
             Time to Remove:           1.000E+04 [day]



        Contamination::     Nuclide    Concentration
                                         [pCi/m2]
                             U-238       1.000E+00
                             U-235       1.000E+00
                             U-234       1.000E+00
                             PA-231      1.000E+00
                             TH-232      1.000E+00
                             TH-230      1.000E+00
                             TH-228      0.000E+00
                             AC-227      1.000E+00
                             RA-228      1.000E+00
                             RA-226      1.000E+00
                             PB-210      0.000E+00
```

```
** RESRAD-BUILD Program Output, Version 3.1 05/27/03 14:52  Page:  13 **
Title : NC Building Occupancy-All Radionulcides
Input File : C:\Winbld\NCBDOccupancyAllRad.bld
Evaluation Time:    0.000000     years


 Source:  5
        Location::  Room :  1  x:   5.00 y:   0.00  z:   1.00 [m]
        Geometry::  Type: Area        Area:2.00E+01 [m2]  Direction: y
        Pathway ::
             Direct Ingestion Rate:    0.000E+00 [1/hr]
             Fraction released to air: 7.000E-02
             Removable fraction:       2.000E-01
             Time to Remove:           1.000E+04 [day]



        Contamination::     Nuclide    Concentration
                                         [pCi/m2]
                             U-238       1.000E+00
                             U-235       1.000E+00
                             U-234       1.000E+00
                             PA-231      1.000E+00
                             TH-232      1.000E+00
                             TH-230      1.000E+00
                             TH-228      0.000E+00
                             AC-227      1.000E+00
                             RA-228      1.000E+00
                             RA-226      1.000E+00
                             PB-210      0.000E+00
```

```
** RESRAD-BUILD Program Output, Version 3.1 05/27/03 14:52  Page:  14 **
Title : NC Building Occupancy-All Radionulcides
Input File : C:\Winbld\NCBDOccupancyAllRad.bld
Evaluation Time:    0.000000     years
```

RESRAD-BUILD Dose Tables

Source Contributions to Receptor Doses

[mrem]

	Source 1	Source 2	Source 3	Source 4	Source 5	Total
Receptor 1	8.75E-04	1.71E-04	1.71E-04	1.71E-04	1.71E-04	1.56E-03
Total	8.75E-04	1.71E-04	1.71E-04	1.71E-04	1.71E-04	1.56E-03

```
** RESRAD-BUILD Program Output, Version 3.1 05/27/03 14:52  Page:  15 **
Title : NC Building Occupancy-All Radionulcides
Input File : C:\Winbld\NCBDOccupancyAllRad.bld
Evaluation Time:    0.000000     years
```

Pathway Detail of Doses

[mrem]

Source: 1

Receptor	External	Deposition	Immersion	Inhalation	Radon	Ingestion
1	3.07E-05	1.69E-08	1.33E-10	8.36E-04	4.81E-06	3.73E-06
Total	3.07E-05	1.69E-08	1.33E-10	8.36E-04	4.81E-06	3.73E-06

Source: 2

Receptor	External	Deposition	Immersion	Inhalation	Radon	Ingestion
1	1.99E-06	3.38E-09	2.65E-11	1.67E-04	9.61E-07	7.46E-07
Total	1.99E-06	3.38E-09	2.65E-11	1.67E-04	9.61E-07	7.46E-07

Source: 3

Receptor	External	Deposition	Immersion	Inhalation	Radon	Ingestion
1	1.99E-06	3.38E-09	2.65E-11	1.67E-04	9.61E-07	7.46E-07
Total	1.99E-06	3.38E-09	2.65E-11	1.67E-04	9.61E-07	7.46E-07

Source: 4

Receptor	External	Deposition	Immersion	Inhalation	Radon	Ingestion
1	1.99E-06	3.38E-09	2.65E-11	1.67E-04	9.61E-07	7.46E-07
Total	1.99E-06	3.38E-09	2.65E-11	1.67E-04	9.61E-07	7.46E-07

Source: 5

Receptor	External	Deposition	Immersion	Inhalation	Radon	Ingestion
1	1.99E-06	3.38E-09	2.65E-11	1.67E-04	9.61E-07	7.46E-07
Total	1.99E-06	3.38E-09	2.65E-11	1.67E-04	9.61E-07	7.46E-07

```
** RESRAD-BUILD Program Output, Version 3.1 05/27/03 14:52  Page:  16 **
Title : NC Building Occupancy-All Radionulcides
Input File : C:\Winbld\NCBDOccupancyAllRad.bld
Evaluation Time:    0.000000     years
```

Nuclide Detail of Doses

[mrem]

Source: 1

Nuclide	Receptor 1	Total
U-238		
U-238	1.00E-05	1.00E-05
U-234	1.54E-11	1.54E-11
TH-230	1.14E-16	1.14E-16
RA-226	6.97E-21	6.97E-21
PB-210	0.00E+00	0.00E+00
U-235		
U-235	1.17E-05	1.17E-05
PA-231	1.13E-09	1.13E-09
AC-227	5.98E-11	5.98E-11
U-234		
U-234	1.09E-05	1.09E-05
TH-230	1.21E-10	1.21E-10
RA-226	1.10E-14	1.10E-14
PB-210	1.36E-17	1.36E-17
PA-231		
PA-231	1.07E-04	1.07E-04
AC-227	8.47E-06	8.47E-06
TH-232		
TH-232	1.35E-04	1.35E-04
TH-228	3.44E-07	3.44E-07
RA-228	5.10E-07	5.10E-07
TH-230		
TH-230	2.69E-05	2.69E-05
RA-226	3.67E-09	3.67E-09
PB-210	6.05E-12	6.05E-12
AC-227		
AC-227	5.30E-04	5.30E-04
RA-228		
TH-228	8.25E-06	8.25E-06
RA-228	8.30E-06	8.30E-06
RA-226		
RA-226	1.70E-05	1.70E-05
PB-210	4.18E-08	4.18E-08

```
** RESRAD-BUILD Program Output, Version 3.1 05/27/03 14:52  Page:  17 **
Title : NC Building Occupancy-All Radionulcides
Input File : C:\Winbld\NCBDOccupancyAllRad.bld
Evaluation Time:    0.000000     years


Source:  2

   Nuclide Receptor   Total
               1
 U-238
  U-238    1.97E-06  1.97E-06
  U-234    3.08E-12  3.08E-12
  TH-230   2.28E-17  2.28E-17
  RA-226   5.81E-22  5.81E-22
  PB-210   0.00E+00  0.00E+00
 U-235
  U-235    2.13E-06  2.13E-06
  PA-231   2.25E-10  2.25E-10
  AC-227   1.19E-11  1.19E-11
 U-234
  U-234    2.18E-06  2.18E-06
  TH-230   2.42E-11  2.42E-11
  RA-226   9.16E-16  9.16E-16
  PB-210   2.68E-18  2.68E-18
 PA-231
  PA-231   2.13E-05  2.13E-05
  AC-227   1.69E-06  1.69E-06
 TH-232
  TH-232   2.70E-05  2.70E-05
  TH-228   5.82E-08  5.82E-08
  RA-228   3.70E-08  3.70E-08
 TH-230
  TH-230   5.38E-06  5.38E-06
  RA-226   3.06E-10  3.06E-10
  PB-210   1.19E-12  1.19E-12
 AC-227
  AC-227   1.06E-04  1.06E-04
 RA-228
  TH-228   1.40E-06  1.40E-06
  RA-228   6.04E-07  6.04E-07
 RA-226
  RA-226   1.41E-06  1.41E-06
  PB-210   8.25E-09  8.25E-09
```

```
** RESRAD-BUILD Program Output, Version 3.1 05/27/03 14:52  Page:  18 **
Title : NC Building Occupancy-All Radionulcides
Input File : C:\Winbld\NCBDOccupancyAllRad.bld
Evaluation Time:    0.000000     years


Source:  3

   Nuclide Receptor   Total
               1
 U-238
  U-238    1.97E-06  1.97E-06
  U-234    3.08E-12  3.08E-12
  TH-230   2.28E-17  2.28E-17
  RA-226   5.81E-22  5.81E-22
  PB-210   0.00E+00  0.00E+00
 U-235
  U-235    2.13E-06  2.13E-06
  PA-231   2.25E-10  2.25E-10
  AC-227   1.19E-11  1.19E-11
 U-234
  U-234    2.18E-06  2.18E-06
  TH-230   2.42E-11  2.42E-11
  RA-226   9.16E-16  9.16E-16
  PB-210   2.68E-18  2.68E-18
 PA-231
  PA-231   2.13E-05  2.13E-05
  AC-227   1.69E-06  1.69E-06
 TH-232
  TH-232   2.70E-05  2.70E-05
  TH-228   5.82E-08  5.82E-08
  RA-228   3.70E-08  3.70E-08
 TH-230
  TH-230   5.38E-06  5.38E-06
  RA-226   3.06E-10  3.06E-10
  PB-210   1.19E-12  1.19E-12
 AC-227
  AC-227   1.06E-04  1.06E-04
 RA-228
  TH-228   1.40E-06  1.40E-06
  RA-228   6.04E-07  6.04E-07
 RA-226
  RA-226   1.41E-06  1.41E-06
  PB-210   8.25E-09  8.25E-09
```

```
** RESRAD-BUILD Program Output, Version 3.1 05/27/03 14:52  Page:  19 **
Title : NC Building Occupancy-All Radionulcides
Input File : C:\Winbld\NCBDOccupancyAllRad.bld
Evaluation Time:    0.000000     years


Source:  4

   Nuclide Receptor   Total
               1
 U-238
  U-238    1.97E-06  1.97E-06
  U-234    3.08E-12  3.08E-12
  TH-230   2.28E-17  2.28E-17
  RA-226   5.81E-22  5.81E-22
  PB-210   0.00E+00  0.00E+00
 U-235
  U-235    2.13E-06  2.13E-06
  PA-231   2.25E-10  2.25E-10
  AC-227   1.19E-11  1.19E-11
 U-234
  U-234    2.18E-06  2.18E-06
  TH-230   2.42E-11  2.42E-11
  RA-226   9.16E-16  9.16E-16
  PB-210   2.68E-18  2.68E-18
 PA-231
  PA-231   2.13E-05  2.13E-05
  AC-227   1.69E-06  1.69E-06
 TH-232
  TH-232   2.70E-05  2.70E-05
  TH-228   5.82E-08  5.82E-08
  RA-228   3.70E-08  3.70E-08
 TH-230
  TH-230   5.38E-06  5.38E-06
  RA-226   3.06E-10  3.06E-10
  PB-210   1.19E-12  1.19E-12
 AC-227
  AC-227   1.06E-04  1.06E-04
 RA-228
  TH-228   1.40E-06  1.40E-06
  RA-228   6.04E-07  6.04E-07
 RA-226
  RA-226   1.41E-06  1.41E-06
  PB-210   8.25E-09  8.25E-09
```

```
** RESRAD-BUILD Program Output, Version 3.1 05/27/03 14:52  Page:  20 **
Title : NC Building Occupancy-All Radionulcides
Input File : C:\Winbld\NCBDOccupancyAllRad.bld
Evaluation Time:    0.000000     years


Source:  5

   Nuclide Receptor   Total
               1
 U-238
  U-238    1.97E-06  1.97E-06
  U-234    3.08E-12  3.08E-12
  TH-230   2.28E-17  2.28E-17
  RA-226   5.81E-22  5.81E-22
  PB-210   0.00E+00  0.00E+00
 U-235
  U-235    2.13E-06  2.13E-06
  PA-231   2.25E-10  2.25E-10
  AC-227   1.19E-11  1.19E-11
 U-234
  U-234    2.18E-06  2.18E-06
  TH-230   2.42E-11  2.42E-11
  RA-226   9.16E-16  9.16E-16
  PB-210   2.68E-18  2.68E-18
 PA-231
  PA-231   2.13E-05  2.13E-05
  AC-227   1.69E-06  1.69E-06
 TH-232
  TH-232   2.70E-05  2.70E-05
  TH-228   5.82E-08  5.82E-08
  RA-228   3.70E-08  3.70E-08
 TH-230
  TH-230   5.38E-06  5.38E-06
  RA-226   3.06E-10  3.06E-10
  PB-210   1.19E-12  1.19E-12
 AC-227
  AC-227   1.06E-04  1.06E-04
 RA-228
  TH-228   1.40E-06  1.40E-06
  RA-228   6.04E-07  6.04E-07
 RA-226
  RA-226   1.41E-06  1.41E-06
  PB-210   8.25E-09  8.25E-09
```

```
** RESRAD-BUILD Program Output, Version 3.1 05/27/03 14:52  Page:  21 **
Title : NC Building Occupancy-All Radionulcides
Input File : C:\Winbld\NCBDOccupancyAllRad.bld
Evaluation Time:     1.00000     years

              ================================================
              ================================================
              ===       Assessment for Time:  2              ===
              ===             Time =1.00E+00 yr              ===
              ================================================
              ================================================

              ========  Source Information  ========


 Source:  1
         Location::  Room :  1  x:   5.00 y:   5.00  z:   0.00 [m]
         Geometry::  Type: Area        Area:1.00E+02 [m2]  Direction: z
         Pathway ::
              Direct Ingestion Rate:    0.000E+00 [1/hr]
              Fraction released to air: 7.000E-02
              Removable fraction:       1.941E-01
              Time to Remove:           1.000E+04 [day]



         Contamination::     Nuclide    Concentration
                                          [pCi/m2]
                              U-238       9.927E-01
                              U-235       9.927E-01
                              U-234       9.927E-01
                              PA-231      9.927E-01
                              TH-232      9.927E-01
                              TH-230      9.927E-01
                              TH-228      3.017E-01
                              AC-227      9.927E-01
                              RA-228      9.927E-01
                              RA-226      9.927E-01
                              PB-210      3.038E-02
```

```
** RESRAD-BUILD Program Output, Version 3.1 05/27/03 14:52  Page:  22 **
Title : NC Building Occupancy-All Radionulcides
Input File : C:\Winbld\NCBDOccupancyAllRad.bld
Evaluation Time:     1.00000     years


 Source:  2
        Location::  Room :  1  x:   5.00 y:  10.00  z:   1.00 [m]
        Geometry::  Type: Area        Area:2.00E+01 [m2]  Direction: y
        Pathway ::
             Direct Ingestion Rate:    0.000E+00 [1/hr]
             Fraction released to air: 7.000E-02
             Removable fraction:       1.941E-01
             Time to Remove:           1.000E+04 [day]



        Contamination::     Nuclide    Concentration
                                         [pCi/m2]
                             U-238       9.927E-01
                             U-235       9.927E-01
                             U-234       9.927E-01
                             PA-231      9.927E-01
                             TH-232      9.927E-01
                             TH-230      9.927E-01
                             TH-228      3.017E-01
                             AC-227      9.927E-01
                             RA-228      9.927E-01
                             RA-226      9.927E-01
                             PB-210      3.038E-02
```

```
** RESRAD-BUILD Program Output, Version 3.1 05/27/03 14:52  Page:  23 **
Title : NC Building Occupancy-All Radionulcides
Input File : C:\Winbld\NCBDOccupancyAllRad.bld
Evaluation Time:     1.00000     years


 Source:  3
        Location::  Room :  1  x:  10.00 y:   5.00  z:   1.00 [m]
        Geometry::  Type: Area        Area:2.00E+01 [m2]  Direction: x
        Pathway ::
             Direct Ingestion Rate:    0.000E+00 [1/hr]
             Fraction released to air: 7.000E-02
             Removable fraction:       1.941E-01
             Time to Remove:           1.000E+04 [day]



        Contamination::     Nuclide    Concentration
                                         [pCi/m2]
                             U-238       9.927E-01
                             U-235       9.927E-01
                             U-234       9.927E-01
                             PA-231      9.927E-01
                             TH-232      9.927E-01
                             TH-230      9.927E-01
                             TH-228      3.017E-01
                             AC-227      9.927E-01
                             RA-228      9.927E-01
                             RA-226      9.927E-01
                             PB-210      3.038E-02
```

```
** RESRAD-BUILD Program Output, Version 3.1 05/27/03 14:52  Page:  24 **
Title : NC Building Occupancy-All Radionulcides
Input File : C:\Winbld\NCBDOccupancyAllRad.bld
Evaluation Time:     1.00000     years


 Source:  4
        Location::  Room :  1  x:   0.00 y:   5.00  z:   1.00 [m]
        Geometry::  Type: Area        Area:2.00E+01 [m2]  Direction: x
        Pathway ::
             Direct Ingestion Rate:    0.000E+00 [1/hr]
             Fraction released to air: 7.000E-02
             Removable fraction:       1.941E-01
             Time to Remove:           1.000E+04 [day]



        Contamination::     Nuclide    Concentration
                                         [pCi/m2]
                             U-238       9.927E-01
                             U-235       9.927E-01
                             U-234       9.927E-01
                             PA-231      9.927E-01
                             TH-232      9.927E-01
                             TH-230      9.927E-01
                             TH-228      3.017E-01
                             AC-227      9.927E-01
                             RA-228      9.927E-01
                             RA-226      9.927E-01
                             PB-210      3.038E-02
```

```
** RESRAD-BUILD Program Output, Version 3.1 05/27/03 14:52  Page:  25 **
Title : NC Building Occupancy-All Radionulcides
Input File : C:\Winbld\NCBDOccupancyAllRad.bld
Evaluation Time:     1.00000     years


 Source:  5
        Location::  Room :  1  x:   5.00 y:   0.00  z:   1.00 [m]
        Geometry::  Type: Area        Area:2.00E+01 [m2]  Direction: y
        Pathway ::
             Direct Ingestion Rate:    0.000E+00 [1/hr]
             Fraction released to air: 7.000E-02
             Removable fraction:       1.941E-01
             Time to Remove:           1.000E+04 [day]



        Contamination::     Nuclide    Concentration
                                         [pCi/m2]
                             U-238       9.927E-01
                             U-235       9.927E-01
                             U-234       9.927E-01
                             PA-231      9.927E-01
                             TH-232      9.927E-01
                             TH-230      9.927E-01
                             TH-228      3.017E-01
                             AC-227      9.927E-01
                             RA-228      9.927E-01
                             RA-226      9.927E-01
                             PB-210      3.038E-02
```

```
** RESRAD-BUILD Program Output, Version 3.1 05/27/03 14:52  Page:  26 **
Title : NC Building Occupancy-All Radionulcides
Input File : C:\Winbld\NCBDOccupancyAllRad.bld
Evaluation Time:     1.00000     years
```

RESRAD-BUILD Dose Tables

Source Contributions to Receptor Doses

[mrem]

	Source 1	Source 2	Source 3	Source 4	Source 5	Total
Receptor 1	8.88E-04	1.73E-04	1.73E-04	1.73E-04	1.73E-04	1.58E-03
Total	8.88E-04	1.73E-04	1.73E-04	1.73E-04	1.73E-04	1.58E-03

```
** RESRAD-BUILD Program Output, Version 3.1 05/27/03 14:52  Page:  27 **
Title : NC Building Occupancy-All Radionulcides
Input File : C:\Winbld\NCBDOccupancyAllRad.bld
Evaluation Time:     1.00000     years
```

Pathway Detail of Doses

[mrem]

Source: 1

Receptor	External	Deposition	Immersion	Inhalation	Radon	Ingestion
1	3.35E-05	1.82E-08	1.44E-10	8.41E-04	1.01E-05	3.77E-06
Total	3.35E-05	1.82E-08	1.44E-10	8.41E-04	1.01E-05	3.77E-06

Source: 2

Receptor	External	Deposition	Immersion	Inhalation	Radon	Ingestion
1	2.17E-06	3.64E-09	2.88E-11	1.68E-04	2.01E-06	7.54E-07
Total	2.17E-06	3.64E-09	2.88E-11	1.68E-04	2.01E-06	7.54E-07

Source: 3

Receptor	External	Deposition	Immersion	Inhalation	Radon	Ingestion
1	2.17E-06	3.64E-09	2.88E-11	1.68E-04	2.01E-06	7.54E-07
Total	2.17E-06	3.64E-09	2.88E-11	1.68E-04	2.01E-06	7.54E-07

Source: 4

Receptor	External	Deposition	Immersion	Inhalation	Radon	Ingestion
1	2.17E-06	3.64E-09	2.88E-11	1.68E-04	2.01E-06	7.54E-07
Total	2.17E-06	3.64E-09	2.88E-11	1.68E-04	2.01E-06	7.54E-07

Source: 5

Receptor	External	Deposition	Immersion	Inhalation	Radon	Ingestion
1	2.17E-06	3.64E-09	2.88E-11	1.68E-04	2.01E-06	7.54E-07
Total	2.17E-06	3.64E-09	2.88E-11	1.68E-04	2.01E-06	7.54E-07

```
** RESRAD-BUILD Program Output, Version 3.1 05/27/03 14:52  Page:  28 **
Title : NC Building Occupancy-All Radionulcides
Input File : C:\Winbld\NCBDOccupancyAllRad.bld
Evaluation Time:     1.00000     years
```

Nuclide Detail of Doses

[mrem]

Source: 1

Nuclide	Receptor 1	Total
U-238		
U-238	1.00E-05	1.00E-05
U-234	4.64E-11	4.64E-11
TH-230	8.00E-16	8.00E-16
RA-226	1.17E-19	1.17E-19
PB-210	4.25E-23	4.25E-23
U-235		
U-235	1.17E-05	1.17E-05
PA-231	3.39E-09	3.39E-09
AC-227	4.16E-10	4.16E-10
U-234		
U-234	1.09E-05	1.09E-05
TH-230	3.63E-10	3.63E-10
RA-226	7.66E-14	7.66E-14
PB-210	2.03E-16	2.03E-16
PA-231		
PA-231	1.07E-04	1.07E-04
AC-227	2.51E-05	2.51E-05
TH-232		
TH-232	1.35E-04	1.35E-04
TH-228	2.11E-06	2.11E-06
RA-228	1.44E-06	1.44E-06
TH-230		
TH-230	2.69E-05	2.69E-05
RA-226	1.09E-08	1.09E-08
PB-210	4.20E-11	4.20E-11
AC-227		
AC-227	5.14E-04	5.14E-04
RA-228		
TH-228	2.00E-05	2.00E-05
RA-228	7.31E-06	7.31E-06
RA-226		
RA-226	1.69E-05	1.69E-05
PB-210	1.24E-07	1.24E-07

```
** RESRAD-BUILD Program Output, Version 3.1 05/27/03 14:52  Page:  29 **
Title : NC Building Occupancy-All Radionulcides
Input File : C:\Winbld\NCBDOccupancyAllRad.bld
Evaluation Time:     1.00000     years


Source:  2

   Nuclide Receptor   Total
               1
 U-238
  U-238    1.97E-06  1.97E-06
  U-234    9.26E-12  9.26E-12
  TH-230   1.60E-16  1.60E-16
  RA-226   9.75E-21  9.75E-21
  PB-210   8.38E-24  8.38E-24
 U-235
  U-235    2.13E-06  2.13E-06
  PA-231   6.77E-10  6.77E-10
  AC-227   8.28E-11  8.28E-11
 U-234
  U-234    2.18E-06  2.18E-06
  TH-230   7.26E-11  7.26E-11
  RA-226   6.38E-15  6.38E-15
  PB-210   4.01E-17  4.01E-17
 PA-231
  PA-231   2.13E-05  2.13E-05
  AC-227   4.99E-06  4.99E-06
 TH-232
  TH-232   2.70E-05  2.70E-05
  TH-228   3.56E-07  3.56E-07
  RA-228   1.05E-07  1.05E-07
 TH-230
  TH-230   5.38E-06  5.38E-06
  RA-226   9.12E-10  9.12E-10
  PB-210   8.28E-12  8.28E-12
 AC-227
  AC-227   1.02E-04  1.02E-04
 RA-228
  TH-228   3.38E-06  3.38E-06
  RA-228   5.32E-07  5.32E-07
 RA-226
  RA-226   1.40E-06  1.40E-06
  PB-210   2.44E-08  2.44E-08
```

```
** RESRAD-BUILD Program Output, Version 3.1 05/27/03 14:52  Page:  30 **
Title : NC Building Occupancy-All Radionulcides
Input File : C:\Winbld\NCBDOccupancyAllRad.bld
Evaluation Time:     1.00000     years


Source:  3

   Nuclide Receptor   Total
               1
 U-238
  U-238    1.97E-06  1.97E-06
  U-234    9.26E-12  9.26E-12
  TH-230   1.60E-16  1.60E-16
  RA-226   9.75E-21  9.75E-21
  PB-210   8.38E-24  8.38E-24
 U-235
  U-235    2.13E-06  2.13E-06
  PA-231   6.77E-10  6.77E-10
  AC-227   8.28E-11  8.28E-11
 U-234
  U-234    2.18E-06  2.18E-06
  TH-230   7.26E-11  7.26E-11
  RA-226   6.38E-15  6.38E-15
  PB-210   4.01E-17  4.01E-17
 PA-231
  PA-231   2.13E-05  2.13E-05
  AC-227   4.99E-06  4.99E-06
 TH-232
  TH-232   2.70E-05  2.70E-05
  TH-228   3.56E-07  3.56E-07
  RA-228   1.05E-07  1.05E-07
 TH-230
  TH-230   5.38E-06  5.38E-06
  RA-226   9.12E-10  9.12E-10
  PB-210   8.28E-12  8.28E-12
 AC-227
  AC-227   1.02E-04  1.02E-04
 RA-228
  TH-228   3.38E-06  3.38E-06
  RA-228   5.32E-07  5.32E-07
 RA-226
  RA-226   1.40E-06  1.40E-06
  PB-210   2.44E-08  2.44E-08
```

```
** RESRAD-BUILD Program Output, Version 3.1 05/27/03 14:52  Page:  31 **
Title : NC Building Occupancy-All Radionulcides
Input File : C:\Winbld\NCBDOccupancyAllRad.bld
Evaluation Time:     1.00000     years


Source:  4

   Nuclide Receptor   Total
               1
 U-238
  U-238    1.97E-06  1.97E-06
  U-234    9.26E-12  9.26E-12
  TH-230   1.60E-16  1.60E-16
  RA-226   9.75E-21  9.75E-21
  PB-210   8.38E-24  8.38E-24
 U-235
  U-235    2.13E-06  2.13E-06
  PA-231   6.77E-10  6.77E-10
  AC-227   8.28E-11  8.28E-11
 U-234
  U-234    2.18E-06  2.18E-06
  TH-230   7.26E-11  7.26E-11
  RA-226   6.38E-15  6.38E-15
  PB-210   4.01E-17  4.01E-17
 PA-231
  PA-231   2.13E-05  2.13E-05
  AC-227   4.99E-06  4.99E-06
 TH-232
  TH-232   2.70E-05  2.70E-05
  TH-228   3.56E-07  3.56E-07
  RA-228   1.05E-07  1.05E-07
 TH-230
  TH-230   5.38E-06  5.38E-06
  RA-226   9.12E-10  9.12E-10
  PB-210   8.28E-12  8.28E-12
 AC-227
  AC-227   1.02E-04  1.02E-04
 RA-228
  TH-228   3.38E-06  3.38E-06
  RA-228   5.32E-07  5.32E-07
 RA-226
  RA-226   1.40E-06  1.40E-06
  PB-210   2.44E-08  2.44E-08
```

```
** RESRAD-BUILD Program Output, Version 3.1 05/27/03 14:52  Page:  32 **
Title : NC Building Occupancy-All Radionulcides
Input File : C:\Winbld\NCBDOccupancyAllRad.bld
Evaluation Time:     1.00000     years


Source:  5

   Nuclide Receptor   Total
               1
 U-238
  U-238    1.97E-06  1.97E-06
  U-234    9.26E-12  9.26E-12
  TH-230   1.60E-16  1.60E-16
  RA-226   9.75E-21  9.75E-21
  PB-210   8.38E-24  8.38E-24
 U-235
  U-235    2.13E-06  2.13E-06
  PA-231   6.77E-10  6.77E-10
  AC-227   8.28E-11  8.28E-11
 U-234
  U-234    2.18E-06  2.18E-06
  TH-230   7.26E-11  7.26E-11
  RA-226   6.38E-15  6.38E-15
  PB-210   4.01E-17  4.01E-17
 PA-231
  PA-231   2.13E-05  2.13E-05
  AC-227   4.99E-06  4.99E-06
 TH-232
  TH-232   2.70E-05  2.70E-05
  TH-228   3.56E-07  3.56E-07
  RA-228   1.05E-07  1.05E-07
 TH-230
  TH-230   5.38E-06  5.38E-06
  RA-226   9.12E-10  9.12E-10
  PB-210   8.28E-12  8.28E-12
 AC-227
  AC-227   1.02E-04  1.02E-04
 RA-228
  TH-228   3.38E-06  3.38E-06
  RA-228   5.32E-07  5.32E-07
 RA-226
  RA-226   1.40E-06  1.40E-06
  PB-210   2.44E-08  2.44E-08
```

** RESRAD-BUILD Program Output, Version 3.1 05/27/03 14:52 Page: 33 **
Title : NC Building Occupancy-All Radionulcides
Input File : C:\Winbld\NCBDOccupancyAllRad.bld
Full Summary

RESRAD-BUILD Dose (Time) Tables

Receptor Doses Received for the Exposure Duration

(mrem)

	Evaluation Time [yr]	
	0.00E+00	1.00E+00
1	1.56E-03	1.58E-03

Receptor Dose/Yr Averaged Over Exposure Duration

(mrem/yr)

	Evaluation Time [yr]	
	0.00E+00	1.00E+00
1	1.56E-03	1.58E-03

APPENDIX B

ALARA ANALYSIS

ALARA ANALYSIS FOR NORTH COUNTY STRUCTURES

1.0 INTRODUCTION

Appendix D of the NMSS Decommissioning Standard Review Plan (NRC, 2000) was used to perform an ALARA analysis for the North County structures. Due to the lack of post-remedial survey data, this simplified ALARA analysis was performed for demonstrating compliance with the ALARA requirements. According to this analysis, if the desired benefits from the remediation are greater than the costs of the actions, the remediation cost being evaluated is cost-effective and should be performed. Conversely, if the benefits are less than the costs, the levels of residual radioactivity are already ALARA without taking remedial action. The analysis was performed based on the most conservative assumption that the industrial receptor will be exposed to the maximum allowable residual radioactive contamination. The assumptions for the industrial receptor are presented in *Derivation of Site-Specific DCGLs for North County Structures* (USACE, 2004).

2.0 DETERMINATION OF $DCGL_W$ FOR RADIONUCLIDE CONTAMINANTS OF CONCERNS (COCS)

The *Derivation of Site-Specific DCGLs for North County Structures* (USACE, 2004) provides the radionuclide-specific DCGLs for the industrial receptor present in structures at the North County Sites. The DCGL for each COC was derived based on the assumption that the average concentration of residual radioactivity would give a dose of 15 mrem per year to the critical receptor. The $DCGL_W$ for each radionuclide COC is presented in the following table.

Table 1: Individual Radionuclide DCGL Equivalent to 15 mrem/yr

Radionuclide	Surface DCGL (dpm/100 cm^2)
Ac-227	400
Pa-231	1,400
Ra-226	15,000
Ra-228	7,700
Th-228	4,400
Th-230	6,900
Th-232	1,300
U-234	17,000
U-235	16,000
U-238	19,000

3.0 DETERMINATION OF CONCENTRATIONS FOR EACH COC

In absence of post-remedial sampling results, average concentrations of radionuclide COCs were calculated based on the sampling results of the structures present at the FUSRAP vicinity property 2L (VP-2L). Those average volumetric concentrations were converted to surface concentrations by assuming a thickness of 0.8 cm and a specific density of 1.5 g/cm^3 for the dust. The results are presented in Table 2.

Table 2. Average Surface Contamination for Each Radionuclide COC

Radionuclides	Concentration	
	Volumetric pCi/g	Surface[1] dpm/100 cm^2
Ac-227	0.21	55.59
Pa-231	0	0
Ra-226	0.42	109.86
Ra-228	0.08	19.85
Th-228	0.29	76.24
Th-230	27.21	7202.9
Th-232	0.22	59.23
U-234	0.32	84.05
U-235	0.15	39.71
U-238	0.32	84.05

1 Surface (dpm/100 cm^2) = Volumetric (pCi/g) x 1.5 g/cm^3 x 0.8 cm x (2.22 dpm/pCi) x 100/100

4.0 RESIDUAL RADIOACTIVITY LEVELS THAT ARE ALARA

The residual radioactivity level that is ALARA is the concentration (Conc) at which the benefit from removal equals to the cost of removal. The ratio of the concentration (Conc) to the $DCGL_W$ can be determined as follows:

$$\frac{Conc}{DCGLw} = \frac{Total\ Cost}{\$2{,}000\ x\ P_D\ x\ A\ x\ 0.015\ x\ F} \quad \frac{r+\lambda}{1-e^{-(r+\lambda)N}}$$

Table 3 defines each of the parameters shown in the above equation, presents the values for each parameter and also provides the justification for the assigned values.

Table 3. Definitions, Assumptions and Justification of Parameters

Symbol	Parameter	Unit	Value	Justification
P_D	Population Density	People /m^2	0.09	NUREG-1496, Volume 2, Appendix B, Table A.1 (NRC, 2000)
A	Area being evaluated	m^2	10,000	Assumed; (no site-specific value)
F	Fraction of residual radioactivity being removed by the remediation action		0.2	20% removable fraction (USACE, 2004)
r	Monetary discount rate	$/yr	$0.07	NUREG/BR-0058
λ	Radiological decay constant	yr^{-1}	~0	Values of λ for most COCs are negligible
N	Number of years over which the collective dose will be calculated	yr	70	NUREG-1496, Volume 2, Appendix B, Table A.1 (NRC, 2000)
	Dose limit for building structures	rem/yr	0.015	USACE, 2004
	Value of a person-rem averted for reductions that would be prohibitively expensive	$	2,000	NUREG/BR-0058

Alternative 5 was selected as the preferred alternative for the North County Feasibility Study (USACE, 2003). Based on the cost estimate for Alternative 5, the total building remediation cost is $16,615,000, and the total remediation Period is 5 years. By using the values from the table above, the ratio of the concentration (Conc) to the $DCGL_W$ can be determined as follows:

$$= \frac{(\$16{,}615{,}000)}{\$2{,}000 * 0.09 \times 10{,}000 \times 0.015 \times 0.2} \quad \frac{0.07}{1 - e^{-(0.07)\,70}}$$

$$= 217$$

The result showed that the concentration needed to be 217 times of the $DCGL_W$ at which the benefit from removal equals the cost of removal. Based on this result, it can be concluded that it will not be necessary to transport additional building materials to an offsite disposal facility to meet the ALARA requirement.

5.0 COST-BENEFIT ANALYSIS

A cost-benefit analysis was conducted to determine the benefits from collective averted dose and to compare the benefit to the daily costs for the remediation action. The following sections summarized the analyses.

5.1 CALCULATION OF BENEFITS FROM COLLECTIVE DOSE AVERTED

Since, the maximum dose for both industrial and remediation worker occurs at year 0, the benefits from collective averted dose, B_{AD} can be calculated using the following equation.

$$B_{AD} = \$2{,}000 * PW\ (AD_{Collective})$$

The present worth of the future collective averted dose, PW ($AD_{Collective}$) can be estimated from the following equation.

$$PW(AD_{Collective}) = P_D \times A \times 0.015 \times F \times \frac{1 - e^{-(r+\lambda)N}}{r+\lambda} \times \Sigma \left(\frac{Conc}{DCGLw}\right)_{COCs\ radionuclides}$$

By using Table 2 surface concentration results and Table 1 surface DCGL results, the sum of ratios for surface concentration to surface DCGL for all radionuclides were determined and the result of the calculation is 1.27. Using that result, and the assigned values presented in Table 3, the present worth of the future collective averted dose was calculated. The result is presented as follows.

$$PW(AD_{Collective}) = 0.09 \times 10000 \times 0.015 \times 0.2 \times \frac{1 - e^{-(0.07)70}}{0.07} \times 1.27$$

$$= 48.5 \text{ person-rem/yr}$$

The benefit from collective averted dose, B_{AD} = \$2,000/ person-rem x 48.5 person-rem/yr
= \$97,048/yr.

5.2 CALCULATION OF REMEDIATION COST PER YEAR

As mentioned earlier, the total remediation cost for Alternative 5 is \$16,615,000. The remediation period for that alternative is 5 years. Hence, the cost per year for the remediation action at North County is estimated at \$(16,615,000/5 years) = \$3,323,000/yr.

The benefit from the averted dose is calculated to be about \$97,048/yr while the cost to perform an additional year of remediation at North County sites would have been approximately \$3,323,000. Since the cost to continue remediation for an additional year exceeds the value of the benefits, additional remedial action would not be required to be ALARA.

6.0 CONCLUSION

The results of the ALARA analysis performed for the North County Structures determined that the remediation cost is very high in comparison to the remediation benefits, thus the sites already meet the ALARA requirements and no additional remedial action would be required.

7.0 REFERENCES

NRC 2000. *NMSS Decommissioning Standard Review Plan*, NUREG–1727, U.S. Nuclear Regulatory Commission, Office of Nuclear Material Safety and Safeguards, Washington, DC, September.

USACE 2003. *Feasibility Study for the St. Louis North County Sites*, St. Louis, November.

USACE 2004. *Derivation of Site-Specific DCGLs for North County Structures*, October.