Comparing Radiation Risk Assessment Models for Radioactively Contaminated Buildings (BPRG/BDCC and RESRAD-BUILD)

By

Nasser Shubayr, PhD
U.S. EPA Research Fellow, ORISE
November 2017

ACKNOWLEDGMENTS

This project was supported in part by an appointment to the Research Participation Program at the Office of Superfund Remediation and Technology Innovation, U.S. Environmental Protection Agency (EPA), administered by the Oak Ridge Institute for Science and Education (ORISE) through an interagency agreement between the U.S. Department of Energy and EPA. This project was under the supervision of Mr. Stuart Walker of the EPA. Special thanks to all of the reviewers, listed below, for their valuable inputs and critiques that improved this paper.

-**Fredrick G. Dolislager,** University of Tennessee/Oak Ridge National Laboratory
-**Karessa L. Manning,** University of Tennessee/Oak Ridge National Laboratory
-**Debra J. Stewart**, University of Tennessee/Oak Ridge National Laboratory

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I. INTRODUCTION

Different agencies have developed models to assess the human health cancer risk from radioactively contaminated buildings that can be used by decision makers. The need for evaluation of indoor building contamination is similar to the need for the evaluation of contaminated soil. The U.S. Environmental Protection Agency (EPA) and the U.S. Department of Energy (DOE) have developed models for both contaminated soil and contaminated buildings. The U.S. EPA has developed the Preliminary Remediation Goals for Radionuclides in Buildings calculator (BPRG) and the Dose Compliance Concentrations for Radionuclides in Buildings calculator (BDCC) . The two calculators were developed for different regulatory requirements. The BPRG calculator is for risk-based regulations while the BDCC calculator is for dose-based regulations. The U.S. DOE developed RESRAD-BUILD. The two agencies' modeling approaches and input parameters are different. This study shows the methodology for the different tools, including exposure scenario and pathways, building descriptions, source descriptions, outputs, and default input parameters.

II. PRELIMINARY REMEDIATION GOALS FOR RADIONUCLIDES IN BUILDINGS (BPRG)

BPRG is an online calculator developed by the U.S. EPA to help assess the need for cleaning up a radioactively contaminated building. The BPRG tool calculates risk-based generic or site-specific concentrations for radionuclides that comply with a risk-based standard of 10^{-4} to 10^{-6}. The BPRG is a deterministic model that generates protective screening values based on the reasonable maximum exposure (RME) exposure parameters. Contaminant activities that are below the BPRGs are removed from further analysis; contaminants that exceed the BPRGs are retained for further risk analysis. RME is derived from standardized equations that combine exposure information and toxicity information in the form of slope factors (SFs). The BPRG calculator may be found at this website: https://epa-bprg.ornl.gov/ . [1]

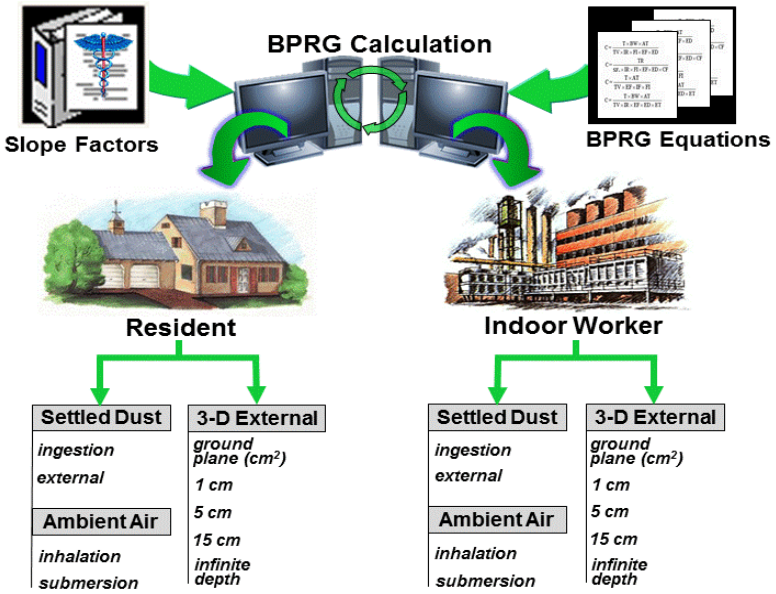

Figure 1: BPRG homepage.

The U.S. EPA also developed the Dose Compliance Concentrations for Radionuclides in Buildings (BDCC) calculator, which is similar to the BPRG calculator for demonstrating compliance with dose-based regulations. BPRG and BDCC calculators are the same, except BPRG calculator uses slope factors (risk coefficients) over a period of exposure (e.g., 26 years for resident at the contaminated site) to provide concentrations for a target risk level; while the BDCC calculator uses dose conversion factors for an annual target dose limit. The BDCC calculator may be found at this website: https://epa-bdcc.ornl.gov/. [2]

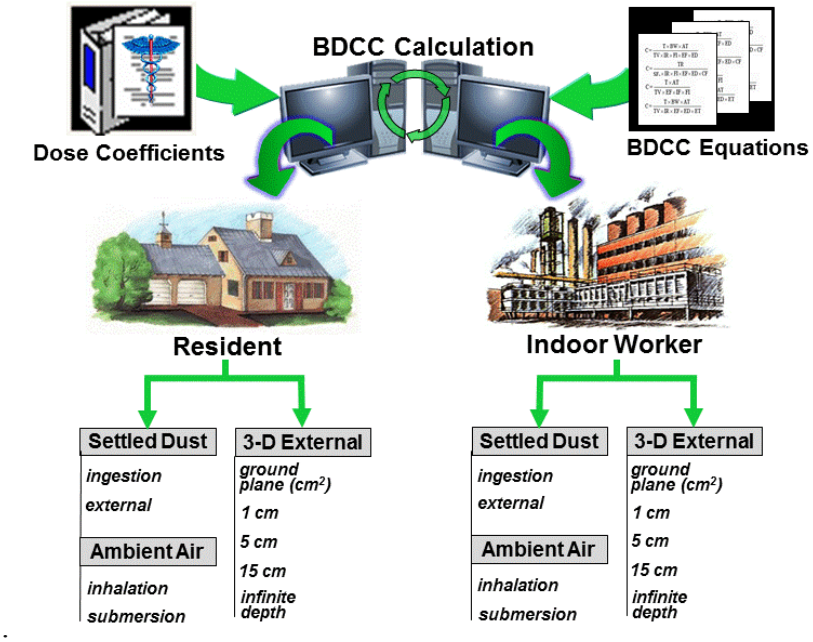

Figure 2: BDCC homepage.

Following the collapse of the World Trade Center (WTC) on September 11, 2001, the outdoor (ambient) environment in the vicinity of the WTC site has been extensively monitored and studied by a multi-agency task force to assess environmental conditions in the area that might pose long-term health risks to local residents. [3] The BPRG/BDCC settled dust and ambient air parameters are based on WTC, except WTC did not include external exposure and

BPRG/BDCC do not include dermal absorption. The ingestion portion of BPRG is slightly updated from WTC, since there have been some changes in the *Exposure Factors Handbook* (a handbook that provides a summary of the available statistical data on various factors used in assessing human exposure). The settled dust parameters are included in Appendix A.

III. RESRAD-BUILD

The RESRAD-BUILD is a computer code developed by Argonne National Laboratory, U.S. DOE, in 1994. It can be used to assess the potential radiological dose for an exposed individual who works or lives in a radioactively contaminated building. The RESRAD-BUILD can perform both deterministic and probabilistic assessments. The result of the assessment performed by RESRAD-BUILD can be viewed in text reports and graphs. RESRAD-BUILD may be downloaded from this website: http://resrad.evs.anl.gov/codes/resrad-build/. [4]

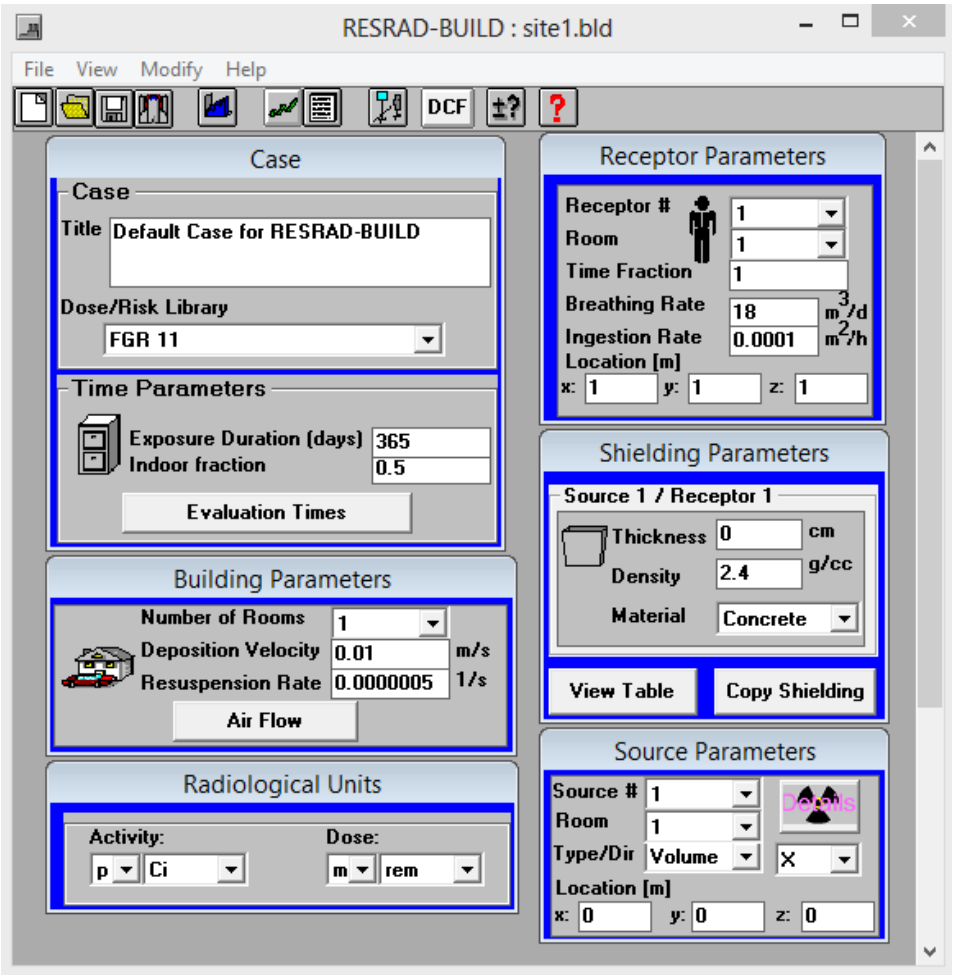

Figure 3: RESRAD-BUILD.

IV. EXPOSURE SCENARIO AND PATHWAYS

The exposure scenarios in BPRG/BDCC calculators are based on the receptors, such as resident and indoor worker, while RESRAD-BUILD is mainly based on potential uses of a building, such as building occupancy and building renovation. The following section highlights the exposure scenario and pathways for BPRG/BDCC calculators and RESRAD-BUILD. Figures in this section have been taken from user's manuals to represent the pathways for each model.

4.1 BPRG/BDCC Exposure Scenarios and pathways

BPRG/BDCC calculators use two scenarios and three exposure pathways for each scenario.

4.1.1 Resident (Adult and Child)

a) Exposure to Settled Dust on Surfaces

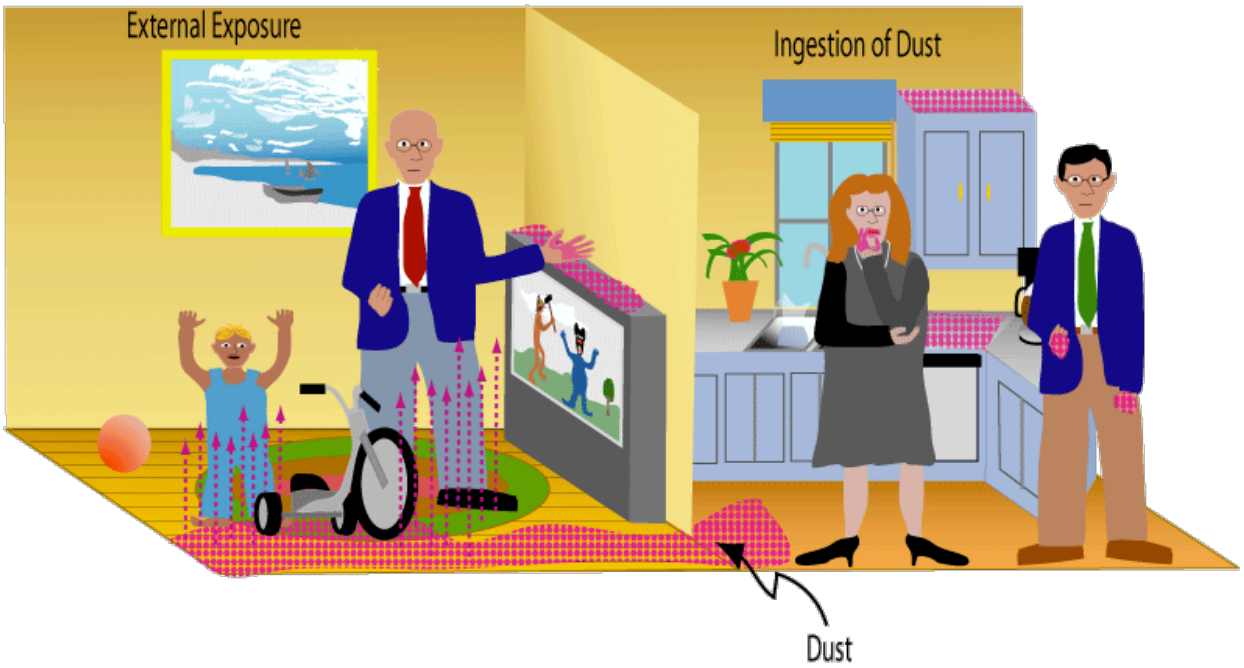

Figure 4: Resident exposure to settled dust on surfaces.

The resident is exposed to the radioactive contaminants in dust that settles in the building via two exposure routes: external exposure and ingestion of dust when hands contact dust-laden surfaces and then contact the mouth. Variation is allowed for contact with hard and soft surfaces, as the transfer to skin varies depending on surface type.

b) Exposure to Ambient Air

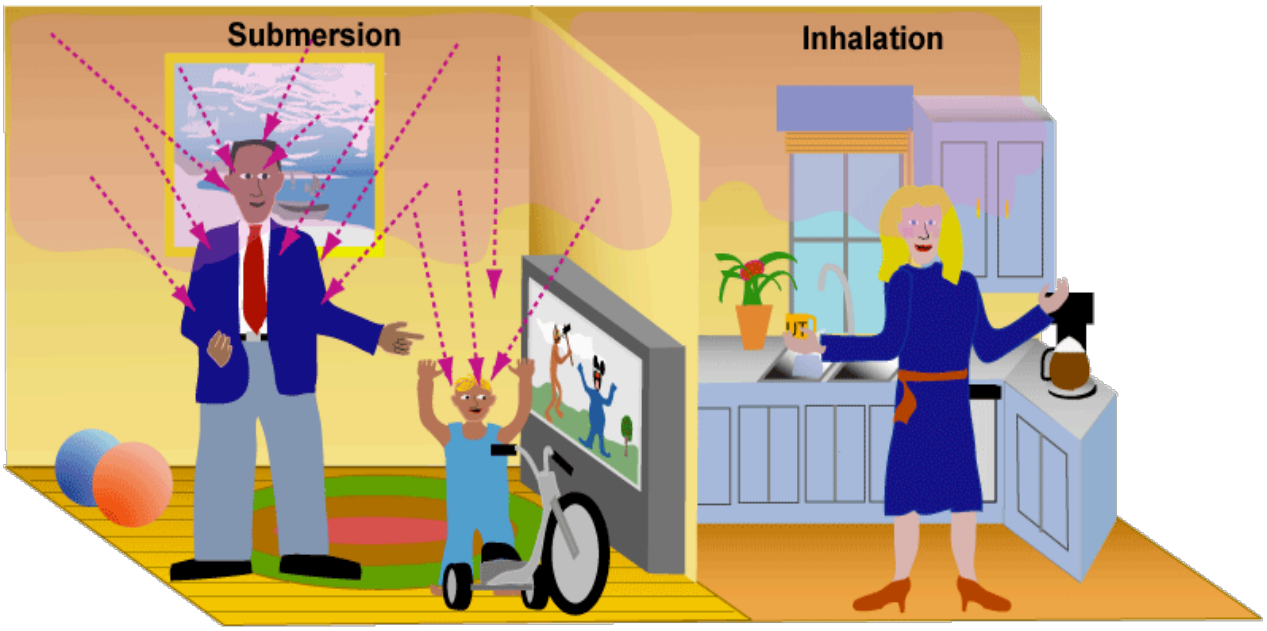

Figure 5: Resident exposure to ambient air.

The resident is exposed to the air in the home via two exposure routes. The first exposure route is inhalation of air. The second exposure route is submersion. Submersion is external exposure from the contaminated air. Inhalation and submersion are assumed to occur for the entire twenty-four-hour day.

Ambient air equations can either: 1) include a half-life decay function, when the contaminant in the air is not being replenished, or 2) not include a half-life decay function, when the contaminant in the air has a continual source.

c) 3-D Direct External Exposure

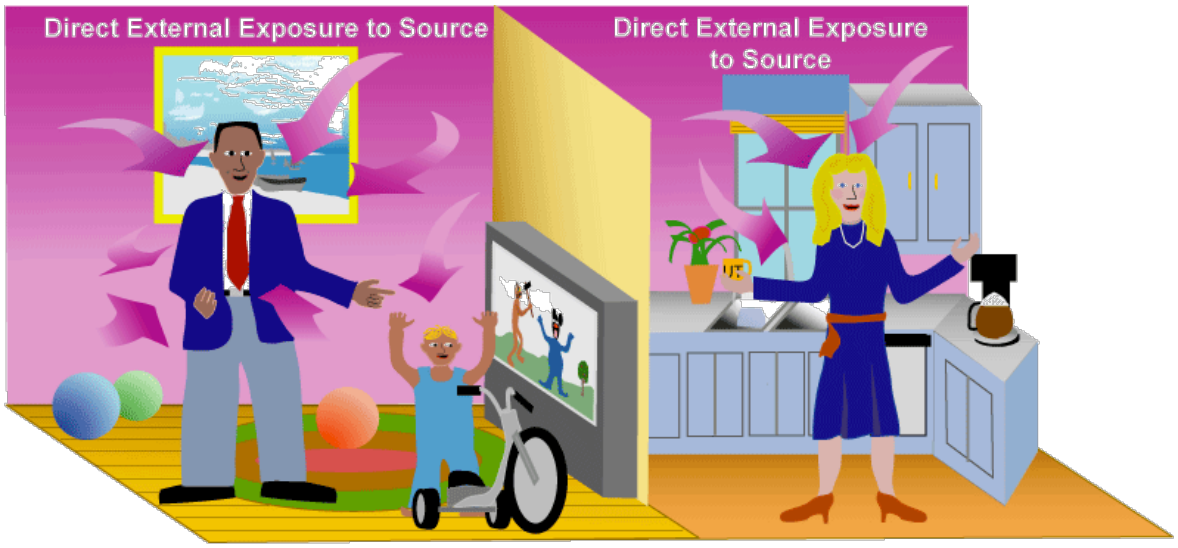

Figure 6: Resident 3-D direct external exposure.

The resident is exposed to radioactive contaminants on or in building materials such as walls, floor, and ceiling. Direct external exposure from these contaminants is the only exposure route in this scenario. This scenario uses various soil volume and ground plane slope factors and surface factors. Surface factors are adjustments to the risk coefficients based on the users position in the room, size of the room, and the construction material.

4.1.2 Indoor Worker

a) Exposure to Dust on Settled Surfaces

The Indoor worker is exposed to the radioactive contaminants in dust that settles in the building. Exposure is via two exposure routes: external exposure and ingestion. Ingestion of dust occurs when hands contact dust-laden surfaces and then contact the mouth. Variation is allowed for contact with hard and soft surfaces, as the transfer to skin varies depending on surface type.

Figure 7: Indoor Worker exposure to dust on settled surfaces.

b) Exposure to Ambient Air

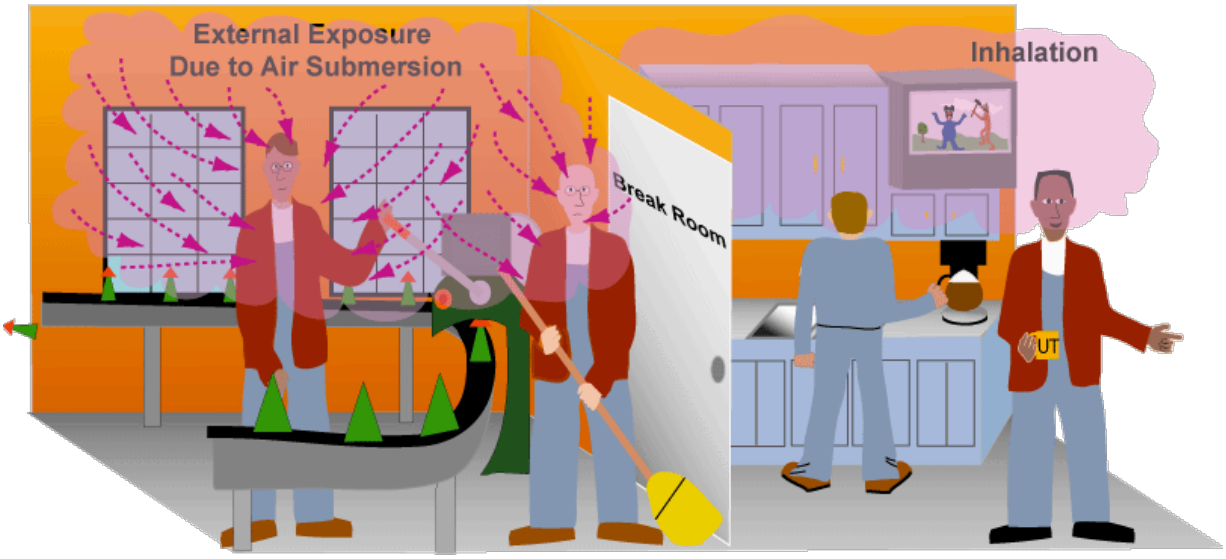

Figure 8: Indoor Worker exposure to ambient air.

This worker is exposed to the air in the building via two exposure routes. The first exposure route is inhalation of air. The second exposure route is submersion. Submersion is

external exposure from the contaminated air. Inhalation and submersion are assumed to occur for the entire eight hour work day.

Ambient air equations can either: 1) include a half-life decay function, when the contaminant in the air is not being replenished, or 2) not include a half-life decay function, when the contaminant in the air has a continual source.

c) 3-D Direct External Exposure

Figure 9: Indoor Worker 3-D direct external exposure.

This worker is exposed to radioactive contaminants on or in building materials such as walls, floor, and ceiling. Direct external exposure from these contaminants is the only exposure route in this scenario. This scenario uses various soil volume and ground plane slope factors and surface factors. Surface factors are adjustments to the risk coefficients based on the users position in the room, size of the room, and the construction material.

4.2 RESRAD-BUILD Exposure scenarios and pathways

RESRAD-BUILD exposure scenarios are based on the potential use of a building. Two building uses are considered in RESRAD-BUILD: building occupancy and building renovation. Each building use considers different receptors.

4.2.1 Building occupancy

The RESRAD-BUILD building occupancy scenario evaluates the release of contaminants into the air due to normal use (residency, workplace) and cleaning of the building (washing the walls or vacuuming the floors). This scenario involves low release over a long period of time (one-year). There are four receptors assumed for this scenario:

a) residents,
b) office workers,
c) industrial workers, and
d) visitors

4.2.2 Building renovation

The RESRAD-BUILD building renovation scenario evaluates the release of contaminants into the air due to building decontamination and renovation activity such as sanding a contaminated floor, chipping concrete, and removing or installing drywall. This scenario involves large release over a short period of time (30-90 days). There are three receptors assumed for this scenario:

a) decontamination workers,
b) building renovation workers, and
c) building demolition workers.

The following exposure pathways are considered in the RESRAD-BUILD:

1. external exposure to penetrating radiation emitted directly from the source,
2. external exposure to penetrating radiation emitted from radioactive particulates deposited on the floors of the compartments,
3. external exposure to penetrating radiation due to submersion in airborne radioactive particulates,
4. inhalation of airborne radioactive particulates,
5. inhalation of aerosol indoor radon decay products and tritiated water vapor,
6. inadvertent ingestion of radioactive material contained in removable material directly from the source, and
7. inadvertent ingestion of airborne radioactive particulates deposited on the surfaces of the building.

V. BUILDING DESCRIPTIONS

Building description includes number of compartments and their positions, building and shielding materials, and dimensions of the compartment.

5.1 BPRG/BDCC BUILDING DESCRIPTION

BPRG/BDCC calculators use one compartment for each calculation. The building gamma-shielding factor is set at one, which indicates that there is no shielding. Three features can define the compartment: room material, room position, and room size. The default (isotope-specific) Room Surfaces Factor is the most protective value given the three features.

a) Room material:	b) Room position:	c) Room size (ft)
1. Adobe 2. Composite 1 room material: drywall room, glass window, wooden doors, drywall walls, concrete floor, drywall ceiling 3. Composite 2 room material: concrete room, wooden doors, concrete floor, drywall ceiling 4. Concrete 5. Drywall 6. Glass 7. Wood 8. Default (isotope-specific)	1. Average 2. Center 3. Center wall 4. Corner 5. Default (isotope-specific)	1. 10x10x10 2. 50x50x50 3. 100x100x10 4. 200x200x20 5. 400x400x40 6. Default (isotope-specific)

5.2 RESRAD-BUILD BUILDING DESCRIPTION

RESRAD-BUILD considers up to three compartments. It can evaluate a wide range of situations, such as a one-room warehouse, a two-room house or apartment, a three-room ranch house, a three-story office building, or a two-story house with a basement. Eight shielding

materials are considered in RESRAD-BUILD: concrete, water, aluminum, iron, copper, tungsten, lead, and uranium. Concrete is set as the default shielding material. The model can display the compartment in 3-Dimensions to illustrate source-receptor locations. RESRAD-BUILD assumes air exchange between connected compartments and the outdoor atmosphere. RESRAD-BUILD uses an indoor air quality model to calculate the contaminant concentration in each compartment.

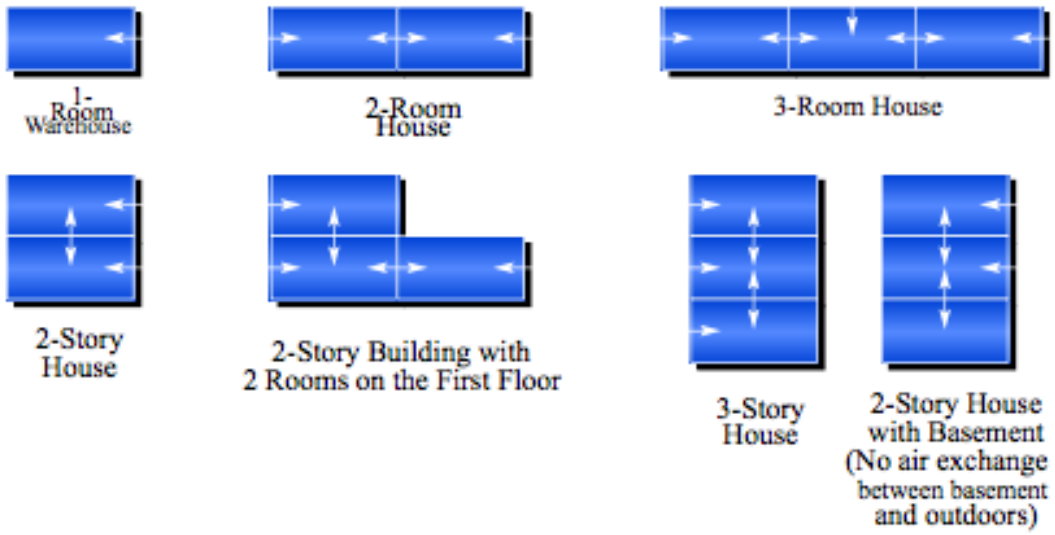

Figure 10: RESRAD-BUILD building geometry.

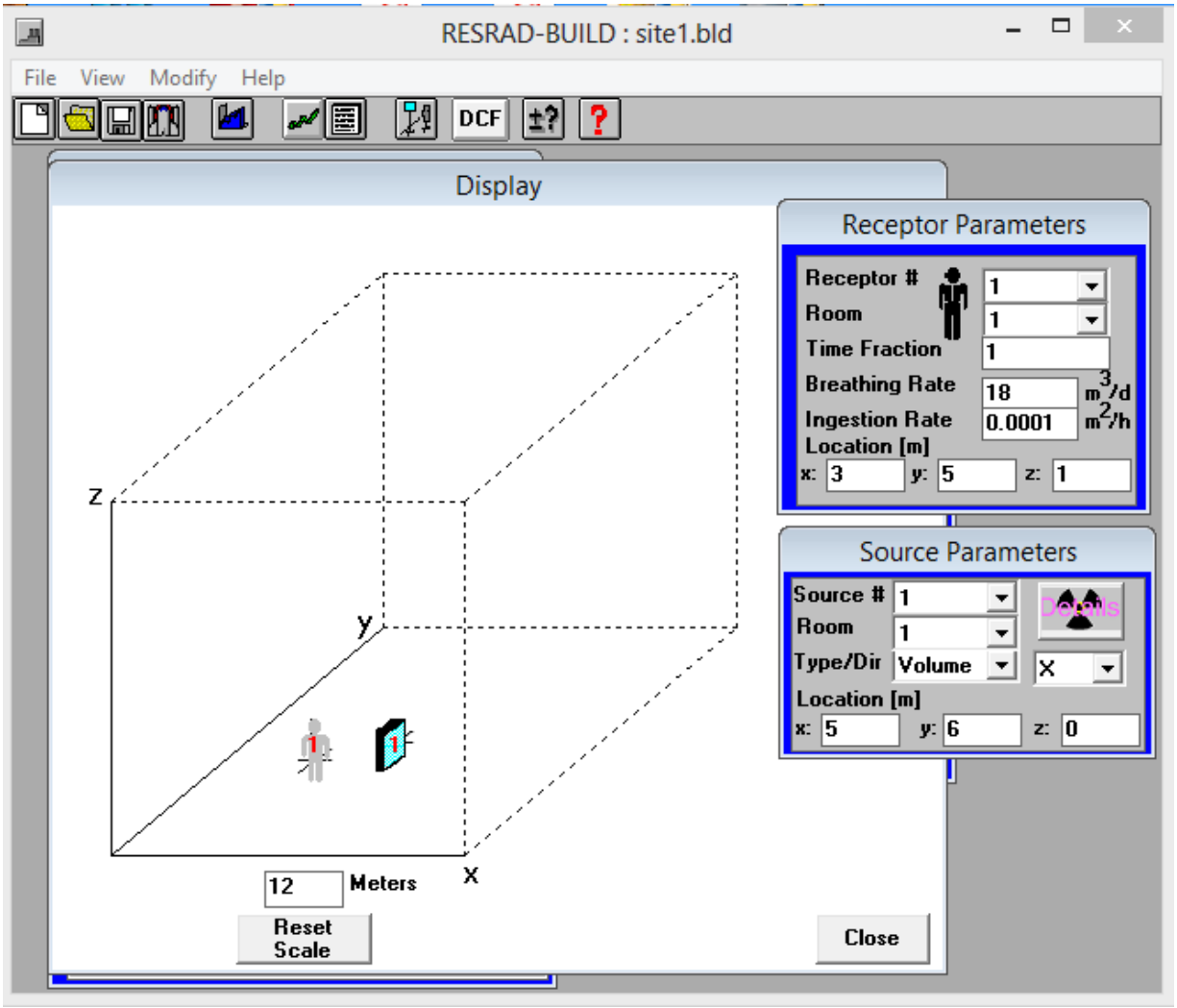

Figure 11: RESRAD-BUILD 3-D demonstration.

VI. SOURCE DESCRIPTIONS

6.1 BPRG/BDCC SOURCE DESCRIPTIONS

BPRG/BDCC calculators contain 1255 radionuclides (including 21 that are commonly found on Superfund sites). The contamination source configurations addressed in the calculations are:

- Area
- Volume

6.2 RESRAD-BUILD SOURCE DESCRIPTIONS

RESRAD-BUILD considers 67 principal radionuclides and 53 progenies (total 120 radionuclides). The contamination sources addressed in the model are:

- Point
- Line
- Area (Circular and Rectangular)
- Volume (Cylindrical and Rectangular prism).

VII. OUTPUTS

7.1 BPRG/BDCC outputs

- Generic tables (include all parameters used in the calculations and the results)
- Site-specific tables (include all parameters used the calculations and the results)

7.2 RESRAD-BUILD outputs

- Summary report provides:
  - ✓ Parameter Used
  - ✓ Source term
  - ✓ Dose
- Detailed Report:
  - ✓ Intermediate calculations involving airflow
  - ✓ Injection rates
  - ✓ External dose parameters
- Graphical Results:
  - ✓ Interactive plotting

VIII. PARAMETERS

The following tables present the occupancy factors, inhalation rates, ingestion rates, and shielding factors for BPRG/BDCC and RESRAD-BUILD:

Occupancy factors	
BPRG/BDCC	
Exposure Duration - indoor worker (yr)	25
Exposure Duration - resident (yr)	26
Exposure Duration - adult resident (yr)	20
Exposure Duration - child resident (yr)	6
Exposure Frequency - indoor worker (days/yr)	250
Exposure Frequency - resident (day/yr)	350
Exposure Frequency - resident adult (day/yr)	350
Exposure Frequency - resident child (day/yr)	350
Air Exposure Time - indoor worker (hr/day)	8
Exposure Time - indoor worker hard surface (hr/day)	4
Exposure Time - indoor worker soft surface (hr/day)	4
Air Exposure Time - resident (hr/day)	24
Air Exposure Time - resident adult (hr/day)	24
Exposure Time - adult resident hard surface (hr/day)	6
Exposure Time - adult resident soft surface (hr/day)	10
Air Exposure Time - resident child (hr/day)	24
Exposure Time - child hard surface (hr/day)	6
Exposure Time - child soft surface (hr/day)	10
RESRAD-BUILD	
Exposure duration days (d)	365
Indoor fraction	0.5

Inhalation Rate	
BPRG/BDCC	
Inhalation Rate – indoor worker (m^3/day; based on a rate of 2.5m^3/hr for 24hr)	60
Inhalation Rate – adult resident (m^3/day; based on IRIS default)	20
Inhalation Rate – child resident (m^3/day; based on IRIS default)	10
RESRAD-BUILD	
Receptor inhalation rate m^3/d	18

Ingestion Rate	
BPRG/BDCC	
Dust Ingestion Factor – indoor worker (cm^2/day)	176.4
RESRAD-BUILD	
Receptor indirect ingestion rate, m^2/h	0.0001

Shielding Factors	
BPRG/BDCC	
Gamma Shielding Factor for air (unitless)	1 (assumes no shielding)
Gamma Shielding Factor for building surfaces (unitless)	1 (assumes no shielding)
RESRAD-BUILD	
In RESRAD-BUILD, shielding is characterized by material type, thickness, and density for eight material types: concrete, water, aluminum, iron, copper, tungsten, lead, and uranium.	

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3. U.S. EPA. (2003). World Trade Center Indoor Environmental Assessment: *Selecting Contaminants of Potential Concern and Setting Health-Based Benchmark*s. Prepared by the Contaminants of Potential Concern (COPC) Committee of the World Trade Center Indoor Air Task Force Working Group. Retrieved from: https://epa-bdcc.ornl.gov/Documents/copc_benchmark.pdf .

4. ANL. (2003). *User's Manual for RESRAD-BUILD Version 3*. Environmental Assessment Division, Argonne National Laboratory, Argonne. Retrieved from: http://resrad.evs.anl.gov/docs/ANL-EAD-03-1.pdf .

APPENDIX A: BPRG/BDCC Parameters

Recommended default input parameters:

Slope Factors	
Definition (units)	**Default**
External Exposure Slope Factor - direct (15 cm soil depth) (risk/yr per pCi/g)	Isotope-specific
External Exposure Slope Factor - direct (1 cm soil depth) (risk/yr per pCi/g)	Isotope-specific
External Exposure Slope Factor - direct (5 cm soil depth) (risk/yr per pCi/g)	Isotope-specific
External Exposure Slope Factor - dust (ground plane) (risk/yr per pCi/cm^2)	Isotope-specific
External Exposure Slope Factor - direct (infinite soil volume) (risk/yr per pCi/g)	Isotope-specific
Inhalation Slope Factor - air (risk/pCi)	Isotope-specific
Dust Ingestion Slope Factor - population (risk/pCi)	Isotope-specific
Dust Ingestion Slope Factor - adult only (risk/pCi)	Isotope-specific
External Exposure Slope Factor - submersion (risk/yr per pCi/m^3)	Isotope-specific

Dose and Decay Constant Variables	
Definition (units)	**Default**
Dissipation Rate Constant – (yr^{-1})	0.0
Time – indoor worker (yr)	25
Target Risk	1E-06
Time – resident (yr)	26
decay constant = 0.693/half-life ($year^{-1}$) where 0.693 = ln(2)	Isotope-specific

Inhalation and Ingestion Rates	
Definition (units)	**Default**
Age-Adjusted Inhalation Fraction – resident (m^3; based on IRIS default)	161,000
Dust Ingestion Factor – indoor worker (cm^2/day)	176.4

Age-Adjusted Dust Ingestion Fraction – resident (cm^2)	3,200,400
Inhalation Rate – indoor worker (m^3/day; based on a rate of 2.5m^3/hr for 24hr)	60
Inhalation Rate – adult resident (m^3/day; based on IRIS default)	20
Inhalation Rate – child resident (m^3/day; based on IRIS default)	10

Miscellaneous Variables	
Definition (units)	**Default**
Area and Material Factor (unitless)	1.0
Fraction of time spent in compartment (unitless)	1.0
Fraction time spent indoors (unitless)	1.0
Off-set Factor (unitless)	1.0
Frequency of Hand to Mouth - indoor worker (event/hr)	3
Frequency of Hand to Mouth - adult (event/hr)	3
Frequency of Hand to Mouth - child (event/hr)	17
Room Surfaces Factor for 15 cm Soil Volume (unitless)	Isotope-specific
Room Surfaces Factor for 1 cm Soil Volume (unitless)	Isotope-specific
Room Surfaces Factor for 5 cm Soil Volume (unitless)	Isotope-specific
Room Surfaces Factor for Ground Plane (unitless)	Isotope-specific
Room Surfaces Factor for Infinite Soil Volume (unitless)	Isotope-specific
Fraction Transferred Surface to Skin - hard surface (unitless)	0.5
Fraction Transferred Surface to Skin - soft surface (unitless)	0.1
Gamma Shielding Factor for air (unitless)	1 (assumes no shielding)
Gamma Shielding Factor for building surfaces (unitless)	1 (assumes no shielding)
Surface Area of Fingers - indoor worker (cm^2)	49
Surface Area of Fingers - adult (cm^2)	49
Surface Area of Fingers - child (cm^2)	16
Saliva Extraction Factor (unitless)	0.5

Exposure Frequency, Exposure Duration, and Exposure Time Variables

Definition (units)	Default
Exposure Duration - indoor worker (yr)	25
Exposure Duration - resident (yr)	26
Exposure Duration - adult resident (yr)	20
Exposure Duration - child resident (yr)	6
Exposure Frequency - indoor worker (days/yr)	250
Exposure Frequency - resident (day/yr)	350
Exposure Frequency - resident adult(day/yr)	350
Exposure Frequency - resident child(day/yr)	350
Air Exposure Time - indoor worker (hr/day)	8
Exposure Time - indoor worker hard surface (hr/day)	4
Exposure Time - indoor worker soft surface (hr/day)	4
Air Exposure Time - resident (hr/day)	24
Air Exposure Time - resident adult(hr/day)	24
Exposure Time - adult resident hard surface (hr/day)	6
Exposure Time - adult resident soft surface (hr/day)	10
Air Exposure Time - resident child(hr/day)	24
Exposure Time - child hard surface (hr/day)	6
Exposure Time - child soft surface (hr/day)	10

APPENDIX B: RESRAD-BUILD Parameters

Recommended default input parameters:

Parameter	Default
Exposure duration, d	365
Indoor fraction	0.5
Evaluation time, yr	0
Deposition velocity, m/s	0.01
Resuspension rate, 1/s	5.0E-07
Room height (room 1), m	2.5
Room height (room 2), m	2.5
Room area (room 1), m^2	36
Room area (room 2), m^2	36
Air exchange rate for building, 1/h	0.8
Air flow from outside to compartment 1	84
Air flow from outside to compartment 2	60
Air flow from compartment 1 to compartment 2	30
Air flow from compartment 2 to compartment 1	30
Number of receptors	1
Receptor inhalation rate, m^3/d	18
Receptor location, m	1,1,1
Receptor indirect ingestion rate, m^2/h	0.0001
Receptor time in room 1	1
Receptor time in room 2	1
Number of sources	1
Source location, m	0,0,0
Source length or area (m, m^2)	36
Air release fraction	0.1
Direct ingestion rate, g/h (volume source)	0
Direct ingestion rate, 1/h (area, line, and point)	0
Removable fraction	0.5

Parameter	Default
Time for source removal or source lifetime, d	365
Radionuclide concentration, pCi/g (volume); pCi/m^2 (surface); pCi/m (line); pCi (point)	1
Source material	Concrete
Number of regions in volume source	1
Contaminated region – volume source	1
Source thickness, cm	15
Source density, g/cm^3	2.4
Source erosion rate, cm/d	2.4E-08
Shielding material	NA
Shielding thickness, cm	0
Shielding density, g/cm3	NA
Dry zone thickness, cm	0
Wet + dry zone thickness, cm	10
Moisture content in the wet zone	0.03
Water fraction available for evaporation	1
Humidity, g/m^3	8
Source porosity	0.1
Radon release fraction	0.1