Overview of Radiation Risk Assessment Models for Radioactively Contaminated Outdoor Surfaces (SPRG/SDCC, RESRAD-RDD, ERMIN)

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I. Introduction:

The release of radioactive materials to the atmosphere can result in surface contamination on streets, building surfaces such as walls and roofs, and any other external surface. Events such as nuclear reactor accidents and radiological dispersal devices can cause the release of radioactive materials. The released radioactive contaminated dust particles deposit on the surface and can pose risk to people through external exposure, ingestion, and inhalation.

Radiation assessment models for contaminated surfaces have been developed by many agencies to support decision-making processes. These models have been developed for different main purposes but tackle the same issue, surface contamination. This paper addresses a review of the following models that are used to assess radioactively contaminated surfaces:

- The U.S. Environmental Protection Agency: SPRG/SDCC.
- The U.S. Department of Energy: RESRAD-RDD.
- The European Approach to Nuclear and Radiological Emergency Management and Rehabilitation Strategies (EURANOS): ERMIN.

II. Preliminary Remediation Goals for Radionuclides in Outdoor Surfaces (SPRG)

Superfund Preliminary Remediation Goals for Radionuclides on Outdoor Surfaces (SPRG) is an electronic calculator developed by the U.S. Environmental Protection Agency. The SPRG calculator presents risk-based standardized exposure parameters and equations that should be used for calculating radionuclide SPRGs at sites with contaminated outdoor hard surfaces such as building slabs, outside building roads, sidewalks, and roads. Recommended SPRGs are presented for resident and worker exposure in activity per area and mass per area units (Figure 1).

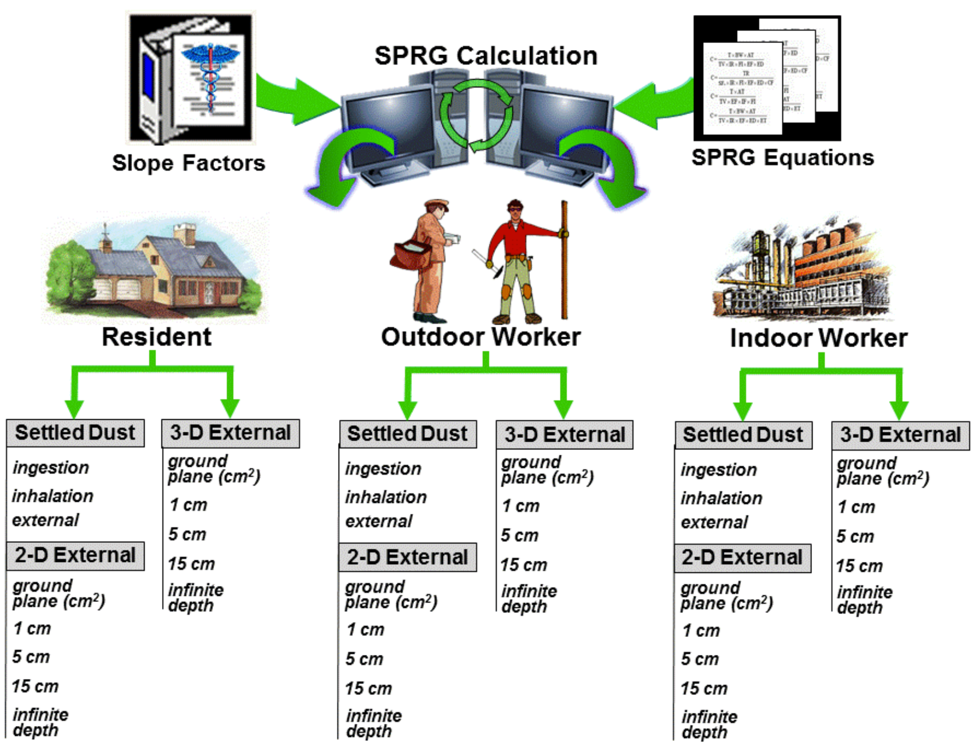

Figure 1: SPRG calculator website homepage.

The recommended SPRGs, which are considered to be protective for humans, including the most sensitive groups, can be produced using EPA recommended default input parameters or using site-specific data for 1255 radionuclides in the SPRG calculator. The SPRG calculator, found at: https://epa-sprg.ornl.gov/, was first issued in 2009 and was last updated in 2017. [1]

2.1 SPRG Exposure Pathways and Scenarios:

Scenario	Media
Resident	Exposure to Settled Dust (external, inhalation, and ingestion), 2-D external exposure, and 3-D external exposure.
Composite worker	Exposure to Settled Dust (external, inhalation, and ingestion), 2-D external exposure, and 3-D external exposure.
Outdoor worker	Exposure to Settled Dust (external, inhalation, and ingestion), 2-D external exposure, and 3-D external exposure.
Indoor worker	Exposure to Settled Dust (external, inhalation, and ingestion), 2-D external exposure, and 3-D external exposure.

III. Dose Compliance Concentrations for Radionuclides in Outdoor Surfaces (SDCC)

Superfund Dose Compliance Concentrations for Radionuclides on Outdoor Surfaces (SDCC), another electronic calculator developed by the U.S. Environmental Protection Agency, addresses ARARs that are expressed in terms of millirems per year. Similar to SPRGs, the SDCC calculates "compliance concentrations" based upon various methods of dose calculation (Figure 2).

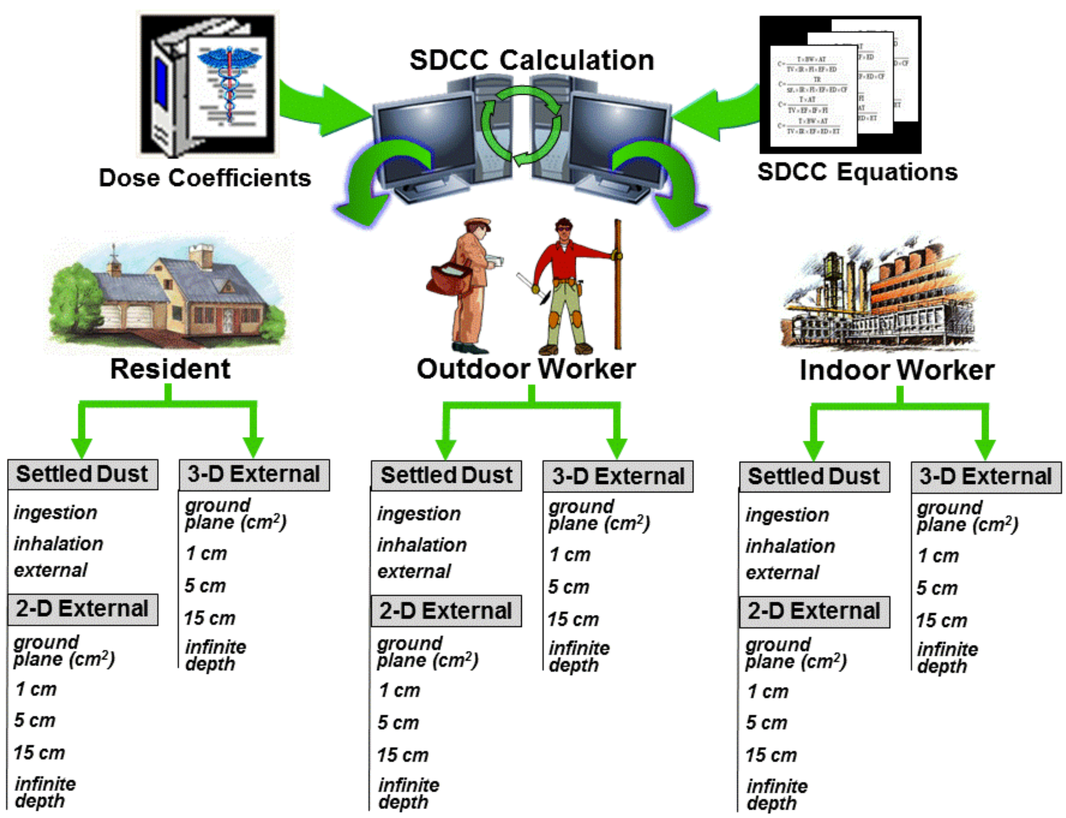

Figure 2: SDCC calculator website homepage.

The SDCC calculator equations are nearly identical to those in the SPRG. There are two key differences between the two tools: 1) the target dose rate (ARAR based) is substituted for the target cancer risk (1×10^{-6}), and 2) dose conversion factor (DCF) will be used in place of the slope factor. SDCCs may be calculated for 1255 radionuclides. The SDCC calculator may be found at the EPA website: https://epa-sdcc.ornl.gov/ . The SDCC calculator was first issued in 2009 and was last updated in 2017. [2]

3.1 SDCC Exposure Pathways and Scenarios:

Scenario	Media
Resident	Exposure to Settled Dust (external, inhalation, and ingestion), 2-D external exposure, and 3-D external exposure.
Composite worker	Exposure to Settled Dust (external, inhalation, and ingestion), 2-D external exposure, and 3-D external exposure.
Outdoor worker	Exposure to Settled Dust (external, inhalation, and ingestion), 2-D external exposure, and 3-D external exposure.
Indoor worker	Exposure to Settled Dust (external, inhalation, and ingestion), 2-D external exposure, and 3-D external exposure.

SPRG/SDCC calculators include two mechanisms for particulate resuspension: mechanically-driven resuspension and the traditional wind-driven resuspension. The state-specific option for mechanical resuspension is a unique modeling approach for an environmental remediation program that is used by the SPRG/SDCC calculators. The calculators assume that dust is being resuspended from the road surface by traffic; the amount of dust on an area of the road is called the Silt Loading Factor. This factor is specific for 50 U.S. States and is different for Rural or Urban areas by road class. Each rural roadway area includes six roadway classes (Interstate, Other Principal Arterial, Minor Arterial, Major Collector, Minor Collector, and Local). Each urban roadway area also includes six roadway classes (Interstate, Other Freeways and Expressways, Other Principal Arterial, Minor Arterial, Collector, and Local). Information about states and road class are obtained from the United States Department of Transportation's Federal Highway Administration. The default value of 0.015 g/m used in the calculators is based on California Urban Interstate average daily traffic volume (ADTV) that would result in the most conservative particulate emission value.

The site-specific option for mechanical resuspension in the SPRG/SDCC calculators are modeled for three types of roads: paved public roads, unpaved public roads, and unpaved industrial roads. All mechanical particulate emission factor (PEF) equations allow the user to input parameters to calculate mean vehicle weight, road dimensions, site dimensions, distance traveled, and time. In addition, the unpaved public roads mechanical PEF equation allows the user to input silt percentage, silt moisture content, mean vehicle speed, and fleet exhaust, brake and tire wear. The unpaved industrial roads equation also allows the user to input silt percentage and site dimensions. Unpaved and paved roads take into account the fugitive dust emissions that are generated by vehicle traffic. The difference between public and industrial unpaved roads is that the mechanical resuspension equation for industrial unpaved roads is based on weight while the equation for public unpaved roads is based on speed. SPRG/SDCC calculators assume that the contaminated area of surface soil (A_S) is a square and that the road divides the square evenly.

SPRG/SDCC calculators also assume that the surface contamination is already on multiple surfaces (building slabs, outside building walls, sidewalks, and roads). SPRG/SDCC calculators are applicable for the late-phase of a clean-up following a Radiological Dispersal Device (RDD) or Improvised Nuclear Device (IND) Incident. The SPRG/SDCC calculators output tables that contain guidelines in activity per area and mass per area units.

IV. RESRAD-Radiological Dispersal Device (RDD):

RESidual RADioactive material guidelines- Radiological Dispersal Device (RESRAD-RDD) is a computer model developed by Argonne National Laboratory for the U.S. Department of Energy (DOE). The model assists decision making after an RDD incident and assumes radionuclides deposit on multiple surfaces including street (urban), soil (rural), roof, exterior wall, interior floor (urban), interior floor (rural) and interior wall of buildings in the affected areas. RESRAD-RDD includes 11 radionuclides that are most likely involved in an RDD incident. RESRAD-RDD was issued in 2009 and can be downloaded at: http://resrad.evs.anl.gov/codes/resrad-rdd/. [3]

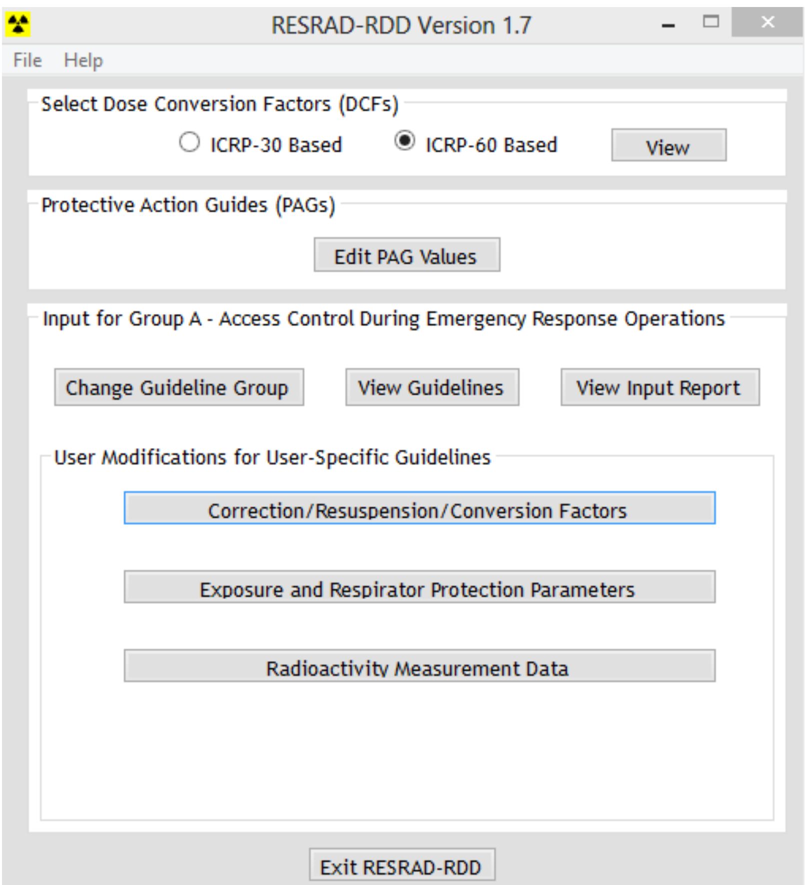

Figure 3: RESRAD-RDD Homepage.

4.1 RESRAD-RDD Exposure Pathways and Scenarios:

RESRAD-RDD contains seven groups (A-G) for operational guidelines following a nuclear incident. They are organized by the phase of emergency response in which the seven groups can be implemented after an incident or used for planning purposes. Each group is categorized into subgroups as follows:

A. Access control during emergency response operations:
   1. Life- and property-saving measures.
   2. Emergency worker demarcation.
B. Early-phase protective action:
   1. Evacuation.
   2. Sheltering.
C. Relocation from different areas and critical infrastructure utilization in relocation areas:
   1. Residential areas.
   2. Commercial and industrial areas.
   3. Other areas, such as parks and monuments.
   4. Hospitals and other health care facilities.
   5. Critical transport facilities.
   6. Water and sewer facilities.
   7. Power and fuel facilities.
D. Temporary access to relocation areas for essential activities:
   1. Worker access to businesses for essential actions.
   2. Public access to residences for retrieval of property, pets and records.

E. Transportation and access routes:

1. Bridges.

2. Streets and thoroughfares.

3. Sidewalks and walkways.

F. Release of property from radiologically controlled areas:

1. Personal property, except wastes.

2. Waste.

3. Hazardous waste.

4. Real property, such as lands and buildings.

G. Food consumption:

1. Early-phase food guidelines.

2. Early-phase soil guidelines.

3. Intermediate-phase soil guidelines.

4. Intermediate- to late-phase soil guidelines.

RESRAD-RDD considers the following 13 exposure pathways for a receptor:

1. External exposure (groundshine) to contaminants on streets/soils while staying outdoors.
2. External exposure to contaminants on exterior walls while staying indoors.
3. External exposure to contaminants on roofs while staying indoors.
4. External exposure to contaminants on interior walls while staying indoors.
5. External exposure to contaminants on interior floors while staying indoors.
6. External exposure to contaminants on streets/soils while staying indoors.

7. Inhalation exposure while staying outdoors (resuspension of contaminants from streets/soils only).
8. Inhalation exposure while staying indoors (indoor air contamination results from both outdoor air contamination and resuspension from contaminants on interior floors).
9. Submersion in contaminated air while staying outdoors.
10. Submersion in contaminated air while staying indoors.
11. Ingestion of dust particles on streets/soils while staying outdoors.
12. Ingestion of dust particles while staying indoors (assumed to be from the floors or walls, whichever is more conservative).
13. Radon inhalation while staying indoors.

RESRAD-RDD has general assumptions including:

- Radionuclides released in outdoor environments are deposited on multiple surfaces, and the surface concentrations are corrected for radioactive decay and weathering.
- The relative concentration ratios for soil (street)/outdoor walls/roof/indoor floor/indoor walls are 1: 0.5: 1: 0.1: 0.05.
- The outdoor resuspension factor decreases over time, and the indoor resuspension factor is constant at 1E-6 m^{-1}.
- For outdoor air concentration in an urban environment, the baseline resuspension factor was multiplied by a factor of 10 to account for vehicular traffic and a factor of 100 for one of the scenarios in Group E.

- A homogenously contaminated surface area of 10,000 m^2 was assumed for the outdoor street/soil source. This assumption is not applicable for Group E (bridges, streets, thoroughfares, sidewalks and walkways) because the street size is different.
- A surface roughness correction factor of 0.82 was applied for external dose calculation for an outdoor receptor.
- RESRAD-RDD assumes two buildings: residential buildings and commercial buildings. Three residential buildings are assumed: urban apartment, suburban house, and small rural house; two commercial buildings are assumed: large warehouse and small store/office. RESRAD-RDD also considers other constructions such as subway/train stations.

RESRAD-RDD outputs a report containing the calculated guideline results, input parameter values used, as well as scenarios considered and assumptions employed after each calculation.

V. The European Model for Inhabited Areas (ERMIN)

The European Model for Inhabited Areas (ERMIN) was developed by the multi-national project, European Approach to Nuclear and Radiological Emergency Management and Rehabilitation Strategies (EURANOS), funded by the European Commission. ERMIN can be used by decision-makers to assess different recovery options following radioactive contamination of an urban environment. ERMIN is a standalone tool but also designed to be implemented within other nuclear accident Decision Support Systems (DSS), such as the RODOS and ARGOS.

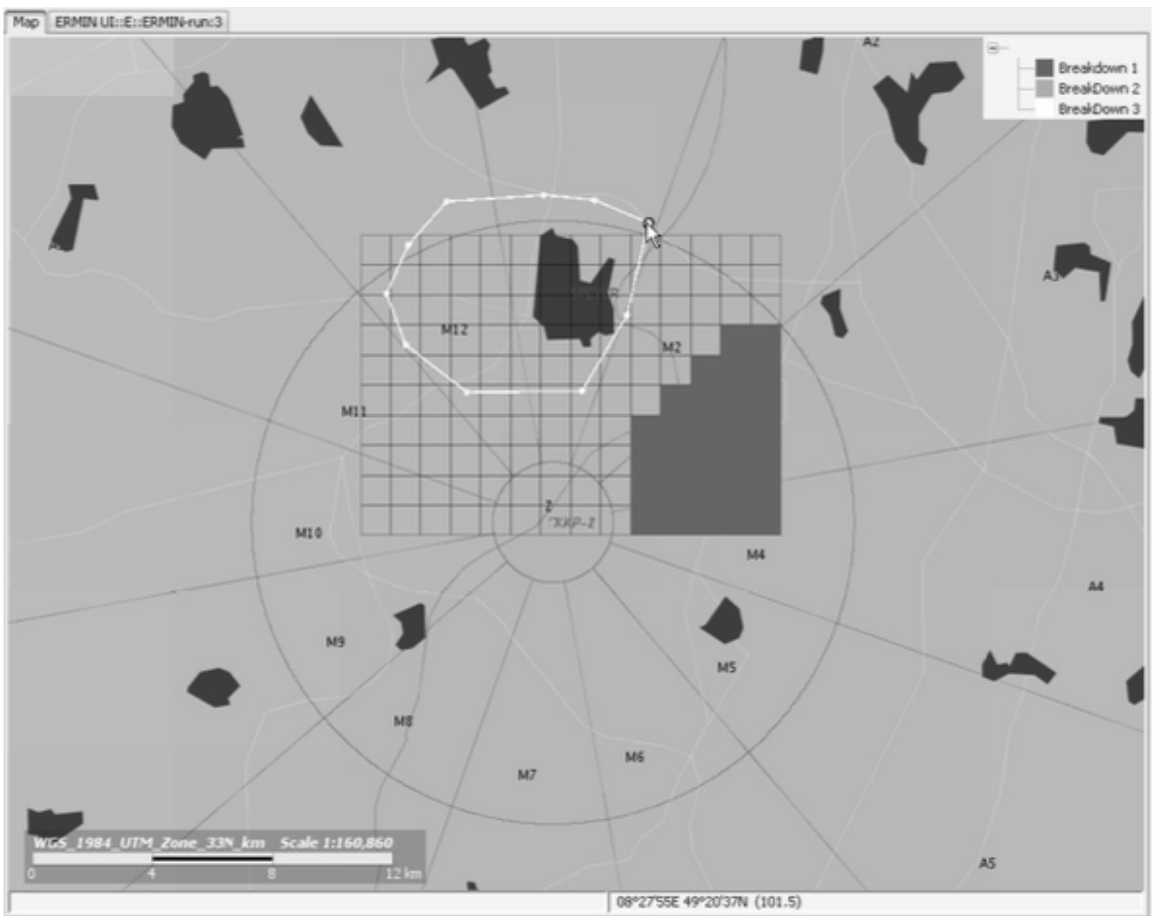

Figure 4: ERMIN screenshot.

ERMIN is designed with five input tabs:

1. "Init": contains basic ERMIN parameters.
2. Area of Interest: allows the user to specify 1) a grid defining the area, 2) radionuclides and 3) deposition data.
3. Environment breakdowns: allows the user to describe the inhabited environment.
4. Early countermeasures: allows the user to specify early countermeasures that have been applied and may have an impact on long-term dose calculations.
5. The Recovery Countermeasures: allows the user to specify countermeasures strategies.

The following tables present the surfaces included in ERMIN and their descriptions.

Parameter sets for the environment configuration:

<table>
<tr><th>Index</th><th>Parameter set name</th><th></th></tr>
<tr><td>1</td><td>Default</td><td rowspan="16">For all environments, the default configuration for the outside area that is not paved is 80% grass, 10% bare soil and 10% plants. The default area covered by trees depends on the environment, but the default mixture of tree types is that they are 80% deciduous and 20% coniferous.

In addition, each environment needs additional sets of parameters to describe different configurations (e.g, whether there are a lot of trees and a large paved area).

A'high paved' or 'high trees' environment has 50% larger area covered by paving or trees, respectively, than the default environment.

A 'low paved' or 'low trees' area has 50% smaller area covered by paving or trees, respectively, than the default environment.</td></tr>
<tr><td>2</td><td>High trees, default paved</td></tr>
<tr><td>3</td><td>Low trees, default paved</td></tr>
<tr><td>4</td><td>No trees, default paved</td></tr>
<tr><td>5</td><td>Default trees high paved</td></tr>
<tr><td>6</td><td>High trees, high paved</td></tr>
<tr><td>7</td><td>Low trees, high paved</td></tr>
<tr><td>8</td><td>No trees, high paved</td></tr>
<tr><td>9</td><td>Default trees, low paved</td></tr>
<tr><td>10</td><td>High trees, low paved</td></tr>
<tr><td>11</td><td>Low trees, low paved</td></tr>
<tr><td>12</td><td>No trees, low paved</td></tr>
<tr><td>13</td><td>Park</td></tr>
<tr><td>14</td><td>Playing fields</td></tr>
<tr><td>15</td><td>Car park</td></tr>
<tr><td>16</td><td>Ideal open area</td></tr>
</table>

Idealized urban environments and possible parameter sets:

Environment name	Possible parameter set
Street of detached prefabricated houses	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12
Street of semi-detached houses with basement	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12
Street of semi-detached houses without basement	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12
Street of terraced houses	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12
Multi-storey block of flats amongst other house blocks	1, 4, 5, 8, 9, 12
Multi-storey block of flats opposite parkland	1, 2, 4, 5, 6, 8
Industrial site	1
Large open area	13, 14, 15, 16

ERMIN output can be presented on maps. The output includes the following:

1. The average doses to members of the public from external exposure to gamma and beta radiation from deposited radionuclides and inhalation of resuspended radioactivity.
2. The contamination on urban surfaces.
3. The activity concentration in air from wind resuspension.
4. The doses to workers undertaking the recovery work.
5. The quantity and activity of waste generated.
6. The cost and work required to implement the countermeasure.

References:

1. US EPA. [2002 (last updated in 2017)]. *Preliminary Remediation Goals for Radionuclides in Outdoor Surfaces (SPRG)*. Retrieved from: https://epa-sprg.ornl.gov/.

2. US EPA. [2004 (last updated in 2017)]. *Dose Compliance Concentrations for Radionuclides in Outdoor Surfaces (SDCC)*. Retrieved from: https://epa-sdcc.ornl.gov/.

3. ANL. (2009). *User's manual for RESRAD-RDD version 3.1. Environmental Assessment Division, Argonne National Laboratory, Argonne.* Retrieved from: http://resrad.evs.anl.gov/codes/resrad-rdd/.

4. EURANOS, (2009), *ERMIN user's manual*.