SAND2020-8608PE

U.S.NRC
UNITED STATES NUCLEAR REGULATORY COMMISSION
Protecting People and the Environment

A Proposed Methodology for Estimating Decontamination Costs in MACCS 3.10

PRESENTED BY

N. E. Bixler (Sandia National Labs)

Coauthor: A. J. Nosek (USNRC)

Tech. Monitor: K. Compton (USNRC)

Presented at 2020 Virtual International MACCS Users' Group Meeting, August 31 to September 2, 2020

Sandia National Laboratories is a multimission laboratory managed and operated by National Technology & Engineering Solutions of Sandia, LLC, a wholly owned subsidiary of Honeywell International Inc., for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-NA0003525. SAND2019-XXXX C

Objectives

- Develop a documented, traceable, and transparent methodology for the development of decontamination parameters for MACCS 3.10
- Present overview of key elements of the proposed methodology
- Illustrate proposed methodology using a mixture of
  - Documented data sources
  - Reasonable assumptions
- Provide examples of resulting MACCS decontamination parameters by applying the proposed methodology

MACCS Parameters Evaluated

- Number of Decontamination Levels (LVLDEC)
- Decontamination Factors (DSRFCT)
- Non-Farmland Decontamination Cost (CDNFRM), per capita
- Farmland Decontamination Cost (CDFRM), per hectare

Development of Decontamination Levels (LVLDEC and DSRFCT)

- Selected values based on BNL 2009
  - DFs of 1-4 can be achieved using mechanical methods such as sweeping and washing
  - DFs of 5-10 can be achieved by additional more aggressive methods such as high pressure washing, sand blasting, and selective surface replacement.
- Currently Proposed Decontamination Levels:

Decontamination Level (DF)	Percentage of the Initial Dose Remaining After Decontamination	Total Dose Reduction Percentage
2	50%	50%
4	25%	75%
8	12.5%	87.5%

Overall Framework for Estimating Decontamination Costs

- Total decontamination costs include:
  - Cost for local decontamination activities (CD_{Decon})
  - Cost for waste characterization (CD_{Char})
  - Cost for waste storage, transportation, and disposal (CD_{Waste})

$$CD_{Tot} = CD_{Decon} + CD_{Char} + CD_{Waste}$$

Decontamination Cost Estimation

- Estimation of decontamination costs should consider
  - Types of surfaces (e.g., lawns, roads) requiring decontamination
  - Decontamination method applied to a given surface (e.g. topsoil removal, pressure washing, etc.)
    - Effectiveness
    - Unit cost
    - Unit waste generated
  - The total amount of decontamination target surfaces to be decontaminated for each type of land use
  - The fraction of land dedicated to each land use category
  - The extent of decontamination in each land use category
  - The population density of populated areas in each land use category

Cost Estimation
Decontamination Activities

Estimate decontamination costs as a weighted sum

Non-Farmland ($/person)

$$CDNFRM_{DECON,n} = \left(\frac{AREA_{TOTAL}}{POP_{TOTAL}}\right) \cdot \sum_{l} \sum_{i} f_l \cdot F_l^{DECON} \cdot \left(SURF_{i,l} \cdot COST_{i,n}\right)$$

Farmland ($/ha)

$$CDFRM_{DECON,n} = \sum_{i} F_{Farm}^{DECON} \cdot \left(SURF_{i,Farm} \cdot COST_{i,n}\right)$$

Where:

f_l	Average fraction of area dedicated to land use l (dimensionless)
F_l^{DECON}	Fraction of area dedicated to land use l that is decontaminated (dimensionless)
$SURF_{i,l}$	Average decontamination surface area i per land area dedicated to land use l (square yards per acre)
$COST_{i,n}$	Average unit cost to decontaminate surface area i to achieve an overall decontamination level n ($ per square yard)
$AREA_{TOTAL}$	Total area (acres)
POP_{TOTAL}	Total population (people)

Cost Estimation
Waste Management Activities

Estimate waste management costs as a weighted sum:

Non-Farmland ($/person)

$$CDNFRM_{WASTE,n} = WASTE\_COST_{NONFARM} \cdot \left(\frac{AREA_{TOTAL}}{POP_{TOTAL}}\right) \cdot \sum_{l}\sum_{i} f_l \cdot F_l^{DECON} \cdot \left(SURF_{i,l} \cdot WASTE_{i,n}\right)$$

Farmland ($/ha)

$$CDFRM_{WASTE,n} = WASTE\_COST_{FARM} \cdot \sum_{i} F_{Farm}^{DECON} \cdot \left(SURF_{i,Farm} \cdot WASTE_{i,n}\right)$$

Where:

$WASTE\_COST$	Total waste management cost for storage, transportation, and disposal ($ per cubic yard)
f_l	Average fraction of area dedicated to land use l (dimensionless)
F_l^{DECON}	Fraction of area dedicated to land use l that is decontaminated (dimensionless)
$SURF_{i,l}$	Average decontamination surface area i per land area dedicated to land use l (square yards per acre)
$WASTE_{i,n}$	Average unit waste volume generated in decontaminate surface area i to achieve an overall decontamination level n (cubic yard per square yard)
$AREA_{TOTAL}$	Total area (acres)
POP_{TOTAL}	Total population (people)

Selection of Decontamination Technologies

- JAEA 2015 (*Remediation of contaminated areas in the aftermath of the accident at the Fukushima Daiichi Nuclear Power station: Overview, analysis and lessons learned Part 1: A report on the "Decontamination Pilot Project" (Review No. 2014-051)*) is the primary reference for decontamination methods and their associated costs, effectiveness, and waste generation rates
- Multiple types of surfaces require decontamination
- Each type of surface contributes a different amount to the dose received by an individual
- Each type of surface has a different unit cost and decontamination effectiveness
- Tables to follow show source of values used for $COST_{i,n}$ and $WASTE_{i,n}$

Examples of Residential Decontamination Methods (adapted from Appendix A of JAEA, 2015)

Reference	Type of Surface	Method	Unit cost* ($/SY unless otherwise noted)	Dose Reduction Factor	Solid waste volume (L/m2 unless otherwise noted) and type
Residential-1a	Residential Houses: tile roof, iron roof	Surface brushing and washing (iron roof)	9.11	1.1 - 1.5	almost none (sludge & solids)
Residential-2	Residential Houses: gutter	Removal of debris and wiping	3.35 $/lf	1.4 - 10	1 m^3 per house on average (litter, soil)
Residential-5	Residential Land: garden	Thin-layer topsoil stripping	4.93	1.1 - 10	20 – 40 (thickness of stripping 2-3 cm) (vegetation, soil)
Residential-8	Residential Land: turf	Turf stripping	12.54	5	20 - 50 (stripping 2-5cm) (turf)
Residential-12	Concrete/asphalt surfaces: hard-packed floors, scarcement, flat roofs, stairs, terraced areas, car parks, pavements	Ultra-high-pressure water jet	9.62	5	~3 (Concrete & asphalt)
Residential-14	Concrete surfaces: concrete walls, scarcement	Brushing followed by high pressure water jet washing	8.03	1.3 - 3.3	almost none (sludge)
Residential-15	Concrete surfaces: hard floors, scarcement, roof, stairs, balcony	High-pressure washing	8.03	1.3 - 3.3	almost none (sludge)

**Assumed conversion of 100 Yen per dollar*

Examples of Non-Residential Decontamination Methods (adapted from Appendix A of JAEA 2015)

Reference	Type of Surface	Method	Unit cost* ($/SY unless otherwise noted)	Dose Reduction Factor	Solid waste volume (L/m^2 unless otherwise noted) and type
Public Infrastructure-1b	Asphalt roads	Road Sweeper (On-board road sweeper)	0.17	1 - 2	1 - 1.5 (soil, road dust, vegetation)
Public Infrastructure-3	Asphalt roads	Water-jet vehicle	1.25	1 - 3	few (sludge)
Public Infrastructure-8	Asphalt roads	Asphalt removal by surface stripping machine	3.26	22	~8 (stripping ~5mm) (Asphalt)
Forest-2	Forested flat ground	Humus and thin-layer topsoil removal (stripping)	7.44	1.3 - 5	20 - 90 (litter, humus, soil)
Forest-3	Forested flat ground	Strimming	1.34	-	5 - 10 (grasses, shrubs, litter)
Agricultural land-1	Paddy fields, vegetable fields	Reversal tillage	0.28	1.4 - 2.5	-
Agricultural land-2	Paddy fields, vegetable fields	Interchanging topsoil with subsoil	2.59	~3	-
Agricultural land-6	Paddy fields, vegetable fields	Mowing	0.59	-	9 -12 (vegetation)
Agricultural land-7	Paddy fields, vegetable fields, fruit farm	Strimming	0.84	-	9 - 12 (crops)

**Assumed conversion of 100 Yen per dollar*

Farmland Decontamination

- Decontamination of farmland in MACCS does not affect contamination levels in crops produced on the land.
- Preliminary work showed that methods involving farmland soil removal are cost-prohibitive in MACCS due to the cost of removing contaminated soil.
- It is appropriate to consider only methods that are based on mixing or exchanging surface and subsoil, providing shielding.
- Reversal Tillage and Interchanging Topsoil with Subsoil are therefore included in all three farmland decontamination levels.
- Waste management costs are therefore zero for farmland.
- High costs associated with soil interchange methods may be cost-ineffective due to relatively low typical farmland values.

Non-Farmland Decontamination Methods Selected to achieve targeted dose reduction

Decontamination Surface	DF=2	DF=4	DF=8	Approximate Dose Contribution[1]	
				dry	wet
Asphalt	Public infrastructure-1b, -3	Public Infrastructure-1b, -8, seal coat	Public Infrastructure-1b, -8, seal coat	4%	7.5%
Concrete	Residential-14	Residential-12	Residential-12	4%	7.5%
Roof area	Residential-1a	Residential-1a 50% of surface Remove & Replace 50% of surface	Remove & replace 100% of surface	11%	9%
Roof gutters[2]	Residential-2	Residential-2	Residential-2		
Wall area - exterior	Residential-15	Residential-15 50% of surface Remove & Replace 50% of surface	Remove & replace	9%	1%
Wall area - interior	Wash	Wash 50% Replace 50%	Remove & replace	8%	0%
Floor area	Scrub floors and shampoo carpets	Scrub floors and shampoo carpets 50%, Replace 50%	Remove & replace	8%	0%
Landscape - trees	Forest-2	Forest-2	Forest-2 with increased topsoil removal	10%	0.5%
Landscape - shrubs	Forest-2	Forest-2	Forest-2 with increased topsoil removal	10%	0.5%
Landscape - lawn	Residential-8, 3.5 cm, 67% of surface	Residential-8, 3.5 cm	Residential-8, 3.5 cm Residential-5, 3.5 cm	32%	74%

1. ***Values are inferred from Appendix B of [Brown et al. 2007]. When the relative contribution between two surface types is unknown (e.g., interior walls and floors), each surface is assumed to contribute an equal amount. Information on the contribution to dose from roof gutters was not available in Appendix B of [Brown et al. 2007].***

Assumed Surface Areas Associated with Each Housing Intensity ($SURF_{i,l}$)

Assumptions:

- High Density Residential Areas: two two-story 10-unit structures on one acre, each unit consisting of 1000 ft^2 of floor space
- Medium Density Residential Areas: four single-level 2000-ft^2 houses on one acre (one unit per quarter-acre).
- Low Density Residential Areas: one single-level 2000-ft^2 house on 2.68 acres
- All land uses include assumptions for roads (asphalt) and driveways and sidewalks (concrete)
- Remaining landscape (excluding the areas occupied by the house, concrete, and asphalt) is assumed to be 2/3 lawn, 1/6 trees, and 1/6 shrubs/bushes/plants.

Decontamination Surface Area (SY/acre)	High Intensity Urban Areas	Medium Intensity Urban Areas	Low Intensity Urban Areas
Asphalt	1316	696	205
Concrete	383	470	45
Roof area	1111	1026	96
Roof gutters (lf/acre)	560	400	37
Wall area - exterior	1562	1005	94
Wall area - interior	15967	3129	292
Floor area	2222	889	83
Landscape - trees	338	464	752
Landscape - shrubs	338	464	752
Landscape - lawn	1353	1857	3010

Land Use (f_l) and Decontamination (F_l^{DECON}) Fractions

Assumptions:

- All developed areas (urban, rural residential, and rural roads) are decontaminated.
- For DF=4 and DF=8, strips of land adjacent to rural roadways are also decontaminated.

Land use fractions derived based on data from:

- U.S. Census Bureau, "2013 National - Housing Unit Characteristics - All Housing Units"
- U.S. Census Bureau, "American Community Survey 2013"
- U.S. Department of Agriculture 2017, "Major Land Uses 2012"
- D. P. Bigelow and A. Borchers 2017, "Major Uses of Land in the United States, 2012 (EIB-178)"

Land Use and Decontamination Fractions

Land Use	High-Intensity Urban	Medium-Intensity Urban	Low-Intensity Urban	Low-Intensity Rural Residential	Rural Roads (Not Included with Housing)	Other (Treated as Forest)
Estimated Land-Use Fraction (f_l)*	0.069%	1.6%	2.0%	5.6%	1.2%	69%
Fraction Decontaminated (F_l^{DECON})	100%	100%	100%	71%**	100%	0 or 4.5%***
CONUS-averaged fraction decontaminated	0.069%	1.6%	2.0%	4.0%	1.2%	0 or 3.1%***

* Total sums to less than 100% because agricultural land is treated separately and decontamination of water bodies is not considered.
** Assumes decontamination of 2.68 acres per household
*** Assumes decontamination of a 20 m buffer area on each side of rural roads; assumes no decontamination for level 1

Waste Management Costs

Unit Costs ($/CY)	Temporary Storage	Transportation	Disposal	Total
Non-Farmland	$216	$254	$241	$711

Assumptions:

- Onsite temporary storage in soft-sided bags (Yasutaka and Naito, 2016)
- Waste is 61% debris and 39% soil (JMOE 2014)
- Transportation costs based on Feizollahi et al. (1995) assuming shipping 1000 miles using 20 ton flatbed trucks
- Low-level waste facility unit disposal costs assumed to be $250/CY for soil and $630/CY for debris (assumption, consistent with Carilli et al. 2009)
- Disposal costs assumed reduced by half to account for the potential for hazardous waste disposal facilities rather than low-level waste disposal facilities

Characterization Costs

- Non-Farmland Characterization Assumptions:
  - One sample is collected per household (per housing unit).
  - The cost to collect a sample is $750 and the cost to analyze it is $900.
  - The number is adjusted to a per acre basis accounting for land-use-specific population density.
  - Resulting values range from $400 per acre for rural residential areas to $22,000 per acre for urban high density land use.
  - On a per acre basis, the cost of waste characterization for Roads and Other land-use categories is assumed to be the same as for rural housing, but Other is adjusted lower to account for the small fraction that would be decontaminated (4.5%).
- Farmland: $330/ha
  - Assumes one sample is collected for every five hectares of farmland at a cost of $750 for acquisition and $900 for analysis.

Summary of Potential Decontamination Costs

- Non-Farmland decontamination costs averaged over all land

	Decontamination	Waste Generation	Waste Management	Waste Characterization	Total Cost to Decontaminate	
	$/acre	CY/acre	$/acre	$/acre	$/acre	$/person
Level 1 (DF 2)	$5,200	15	$11,000	$170	$16,000	$78,000
Level 2 (DF 4)	$11,000	38	$27,000	$170	$38,000	$180,000
Level 3 (DF 8)	$15,000	57	$40,000	$170	$56,000	$270,000

- Farmland decontamination costs

	Decontamination	Waste Generation	Waste Management	Soil Characterization	Total Cost to Decontaminate
	$/ha	CY/ha	$/ha	$/ha	$/ha
Level 1 (DF 2)	$3,349	0	$0	$330	$3,679
Level 2 (DF 4)	$38,032	0	$0	$330	$38,362
Level 3 (DF 8)	$38,032	0	$0	$330	$38,362

Observations

- Majority of dose arises from land areas surrounding structures
  - Mainly lawns, forest, asphalt, and concrete
  - Especially so for wet deposition
- Decontamination of land areas requiring vegetation, humus, and topsoil removal tend to generate large amounts of waste.
- Per-capita decontamination costs are highest for low population density.
- Some non-farmland decontamination costs are greater than CDNFRM parameter limit of $100,000/person in MACCS 3.10.
- High non-farmland decontamination costs coupled with extended interdiction periods may result in increased condemnation.
- High farmland decontamination costs may result in increased condemnation of farmland.

Summary

- A methodology has been developed by Sandia National Laboratories that provides a documented, traceable, and transparent method for estimating decontamination costs in MACCS.
- Values have been estimated using unit cost, waste, and dose reduction data from Fukushima cleanup experience coupled with generic US-average land use statistics.

Selected References

- BNL 2009, "Decontamination Technologies Task 3. Urban Remediation and Response Project Prepared for New York City Department of Health and Mental Hygiene," Brookhaven National Laboratory, Upton, NY, 2009.
- J. Brown, K. Mortimer, K. Andersson, T. Duranova, A. Mrskova, R. Hänninen, T. Ikäheimonen, G. Kirchner, V. Bertsch, F. Gallay and N. Reales, "Generic handbook for assisting in the management of contaminated inhabited areas in Europe following a radiological emergency: Part II - Compendium of Information on Countermeasure Options, Version 1.0 (EURANOS(CAT1)-TN(07)-02)," Health Protection Agency, Chilton, Didcot, UK, 2007.
- T. Yasutaka and W. Naito, "Assessing cost and effectiveness of radiation decontamination in Fukushima Prefecture, Japan," *Journal of Environmental Radioactivity,* vol. 151, pp. 512-520, 2016
- Japan Atomic Energy Agency, "Remediation of contaminated areas in the aftermath of the accident at the Fukushima Daiichi Nuclear Power station: Overview, analysis and lessons learned Part 1: A report on the "Decontamination Pilot Project" (Review No. 2014-051)," Fukushima Environmental Safety Center, Japan Atomic Energy Agency, Tokai-Mura, Japan, 2015.
- U.S. Census Bureau, "2013 National - Housing Unit Characteristics - All Housing Units," 2013. [Online]. Available: https://www.census.gov/programs-surveys/ahs/data/interactive/ahstablecreator.html.
- U.S. Census Bureau, "American Community Survey, 2013," 2013. [Online]. Available: https://www.census.gov/programs-surveys/acs.
- U.S. Department of Agriculture, "Major Land Uses, 2012," 2017. [Online]. Available: https://www.ers.usda.gov/data-products/major-land-uses/major-land-uses/.
- D. P. Bigelow and A. Borchers, "Major Uses of Land in the United States, 2012 (EIB-178)," U.S. Department of Agriculture, 2017.
- Japan Ministry of the Environment, "Jokyo Dojou tou no Chuukan Chozou Shisetsu no An ni tsuite [Draft Plan of Interim Storage Facility for Removed Soil and Waste] (in Japanese)," Fukushima Headquarters for Interim Storage Facilities, 2014.
- F. Feizollahi, D. Shropshire and D. Burton, "Waste Management Facilities Cost Information for Transportation of Radioactive and Hazardous Materials (INEL-95/0300)," Idaho National Engineering Laboratory, Idaho Falls, ID, 1995.
- J. T. Carilli, S. K. Krenzien, R. G. Geisinger, S. J. Gordon and B. Quinn, "Overview of Nevada Test Site Radioactive and Mixed Waste Disposal Operations - 9117," in WM2009 Conference, Phoenix, AZ, 2009.