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Comparison of waste estimation capabilities of the models, WEST and ERMIN

Comparison of waste estimation capabilities of the models, WEST and ERMIN

Jun Hirouchi and Tom Charnock

Abstract

When developing a recovery strategy following a radiation emergency, decision makers need to know predicted doses and the likely dose reduction for different clean-up options, as well as estimates of the costs, effort, amount of waste and radioactive concentration of that waste for those options.

This study compares two tools that can address these needs. The European Model for Inhabited Areas (ERMIN) developed collaboratively by UK Health Security Agency (UKHSA), and other organisations provides estimates of all this information. Whereas the Waste Estimation Support Tool (WEST), developed by the US Environmental Protection Agency, is focussed on estimating the potential volume and levels of radioactive waste generated by a radiological incident and subsequent decontamination efforts. This document describes an exercise to compare the waste calculation approaches of the ERMIN and WEST models to inform how both could be used operationally by UKHSA and to inform further development of the ERMIN tool.

ERMIN represents the built environment as proportions of hypothetical or idealised built environments that the user selects from the database to represent the real area of concern. The ERMIN database contains eight hypothetical environments, and these have different proportions of urban surfaces (grass, paved, road etc) and specific building coverage. WEST instead adopts a tabular approach that allows the user to directly specify the amount of different urban surfaces and the building coverage. Both tools have sets of clean-up operations with parameters that describe their efficacy from which the user can select.

A comparison of ERMIN and WEST decontamination options found that some options were only included in either ERMIN or WEST. The decontamination operations for grass and trees are not included in WEST. The options for indoor floors and walls are grouped in ERMIN as interior surfaces and consequently the indoor options for ERMIN are broad and generic compared to the WEST options. In addition, waste rates for some contamination operations differed by a factor of more than 10 between ERMIN and WEST. The reasons for these large differences are the different consideration of liquid wastes. For example, the waste for washing interior surfaces and cleaning with pressurised hot water in ERMIN contains only solid wastes such as contaminated filters and not contaminated water.

The waste quantity, the radioactivity concentration in the waste, and removed radioactivity were calculated in a hypothetical deposition scenario using ERMIN and WEST. The ratios of waste quantity and removed radioactivity between ERMIN and WEST differed depending on the zone and built-environment. In addition, the ratio of waste quantity in WEST to ERMIN depended on the decontamination option. These differences were mainly due to the difference in the waste rate, the amount of land covered by building (building coverage ratio, or ratio of building footprint to total area), and the surface area ratios between ERMIN and WEST. On

the other hand, the ratio of radioactivity concentration in waste between ERMIN and WEST, which was calculated as the ratio of the deposition on the surface to the mass of waste rate, was constant regardless of the zone and built-environment; in other words, it was independent of the area of decontamination surface.

From these comparisons between ERMIN and WEST, the following potential improvements in ERMIN have been identified: 1) Develop a better representation of interiors to allow for the evaluation of decontamination options for walls and ceilings; 2) Subdivide waste endpoints into liquid and solid components. This may resolve some of the large differences in the production of waste rates identified in the comparison of the models as some of the ERMIN options assume the waste is filtered and the water discarded; 3) Addition of high-pressure washing and firehosing on concrete surfaces; and 4) Addition of more variability in building density or coverage in different built environments.

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1 Introduction

This document describes an exercise to compare the waste calculation approaches of the ERMIN (European Model for Inhabited Areas) and WEST (Waste Estimation Support Tool) tools. Lessons learnt from the comparison inform how both models could be used operationally by UKHSA and identify possible further developments of the ERMIN tool.

ERMIN is a code developed by UKHSA to explore recovery options following the contamination of an urban environment with radioactive material following an atmospheric release. It calculates effective doses to the public and to workers undertaking the recovery work, the quantity and activity of waste generated, and the cost and work required to implement the recovery option.

WEST was developed by US Environmental Protection Agency (EPA). It calculates only waste related endpoints but is not limited to radiological airborne contamination scenarios.

1.1 ERMIN

ERMIN (Charnock et al, 2009) was developed through several European collaborative projects to provide a module for the two European nuclear accident decision support systems RODOS and ARGOS (Ievdin et al, 2010; Jacobsen et al, 2010), that could address questions during the recovery phase of an incident. Decision making in recovery is about reconciling the views and needs of disparate stakeholders and about building consensus. To help underpin the process, ERMIN attempts to provide robust figures on the technical aspects of proposed strategies, that can help rank and eliminate options. Technical aspects include long-term surface contamination, estimated projected and residual public doses, predicted doses to those implementing the recovery strategy for different options, costs, effort, amount of waste and radioactive concentration of that waste for different options. The calculations of waste quantities use waste rates as specified in the European Recovery Handbook (Nisbet et al, 2010).

RODOS and ARGOS are map-based systems, and ERMIN was developed to conform to that approach. The user delineates zones to indicate different built environments, different levels of contamination and different decontamination activities being applied. Alternatively, an atmospheric dispersion model can provide input on the spatial distribution of contamination.

1.2 WEST

The Waste Estimation Support Tool (WEST) was developed by the US Environmental Protection Agency (US EPA, 2012) and is focussed on estimating the potential volume and radioactivity levels of waste generated by a radiological incident and subsequent decontamination efforts. WEST can also be applied to biological contamination incidents but not chemical ones.

The WEST developers recognised that while monitoring and sampling will better characterise and delineate a contaminated area, this will inevitably involve time and that initial development of remediation strategies needs to start immediately following the event to minimise economic and health consequences to the affected communities. The development process includes identification and quantification of contaminated surfaces found indoors and outdoors in terms

of material and contamination levels, and identification of optimal clean-up options for those surfaces.

The WEST developers envisage that, initially in an incident, WEST users will use deposition maps derived from plume models such as those distributed by the National Atmospheric Release Advisory Committee (NARAC), together with land cover classifications and building stock information generated by the Federal Emergency Management Agency (FEMA) Hazus-MH software. But the modular approach means that as characterisation proceeds, the inputs from these tools can be replaced if better information becomes available.

WEST was developed to exploit infrastructure databases developed for the US, and the developers recognised that use outside of the United States would be hampered. Nevertheless because of WEST's modular approach, it is possible to use it outside of the United States as demonstrated in Section 3.1.

2 Functional comparison of WEST and ERMIN

There are both similarities and differences in the conceptual models and approaches used by ERMIN and WEST and these are explored in this section.

2.1 Representation of the built environment

ERMIN divides the landscape into a grid, and the user defines built environment zones by grouping grid squares. To represent the built environment in a zone, the user selects proportions of hypothetical environments from the database that most closely match the real situation. Hypothetical environments were developed in studies that used Monte Carlo particle transport modelling to evaluate dose rates in contaminated settlements. For computational efficiency, 'idealised' environments are developed in which a single type of building is regularly spaced.

ERMIN represents each of the idealised environments as proportions of urban surfaces: roads, pavements, other paved areas, interior surfaces, deciduous trees, coniferous trees, roofs, exterior walls, small areas of bare soil, small areas of grass, small areas of plants, large area of bare soil, large areas of grass and large areas of plants. The ERMIN database contains several idealised environments containing different proportions of these surfaces. The proportions of interior surfaces, external walls and roofs are fixed for each environment, though the user has some flexibility to modify the relative proportions of paved and soil surface and of trees. The choice of idealised environment is limited by the availability of studies for which sufficiently complete exposure modelling has been performed with Monte Carlo codes. Currently there are eight environments in the database: six built environments of various kinds, another built environment but limited to purely ^{137}Cs contamination, and an open area environment with no buildings.

WEST adopts a tabular approach. The landscape is divided into up to ten deposition zones of constant deposition level and divided into administrative units or tracts. The amount of each deposition zone is entered into WEST for each tract as a table (Figure 1). Similarly, the WEST user provides the asphalt, concrete, and soil ground surface directly for each deposition zone as a table and, for each tract, the infrastructure (buildings) are listed with a footprint area, type,

and number of floors. To each building type, the user assigns an 'occupancy class'. The 'occupancy class' defines what the building is used for, for example 'single family dwelling', 'multi-family dwelling', 'grade school' or 'bank'. This allows decontamination options to be targeted to different sorts of building. The 'occupancy class' is comprised of a mix of 'model building types'. The 'model building type' defines the construction material and so the amount of waste if the building is removed.

The ERMIN approach is constrained by the need to use the limited set of idealised environments in the dose library, so that the doses to the population can also be calculated. Unfortunately, the total amount of different kinds of surface in the idealised environment may be different from the real environment if the idealised environment is not a good match. The WEST approach is generally more precise in this respect. However, it should be noted that in WEST, buildings are specified by tract and not deposition zone, and so to calculate the amount of buildings within each deposition zone, WEST assumes they are uniformly distributed across the tract, which may not be the case.

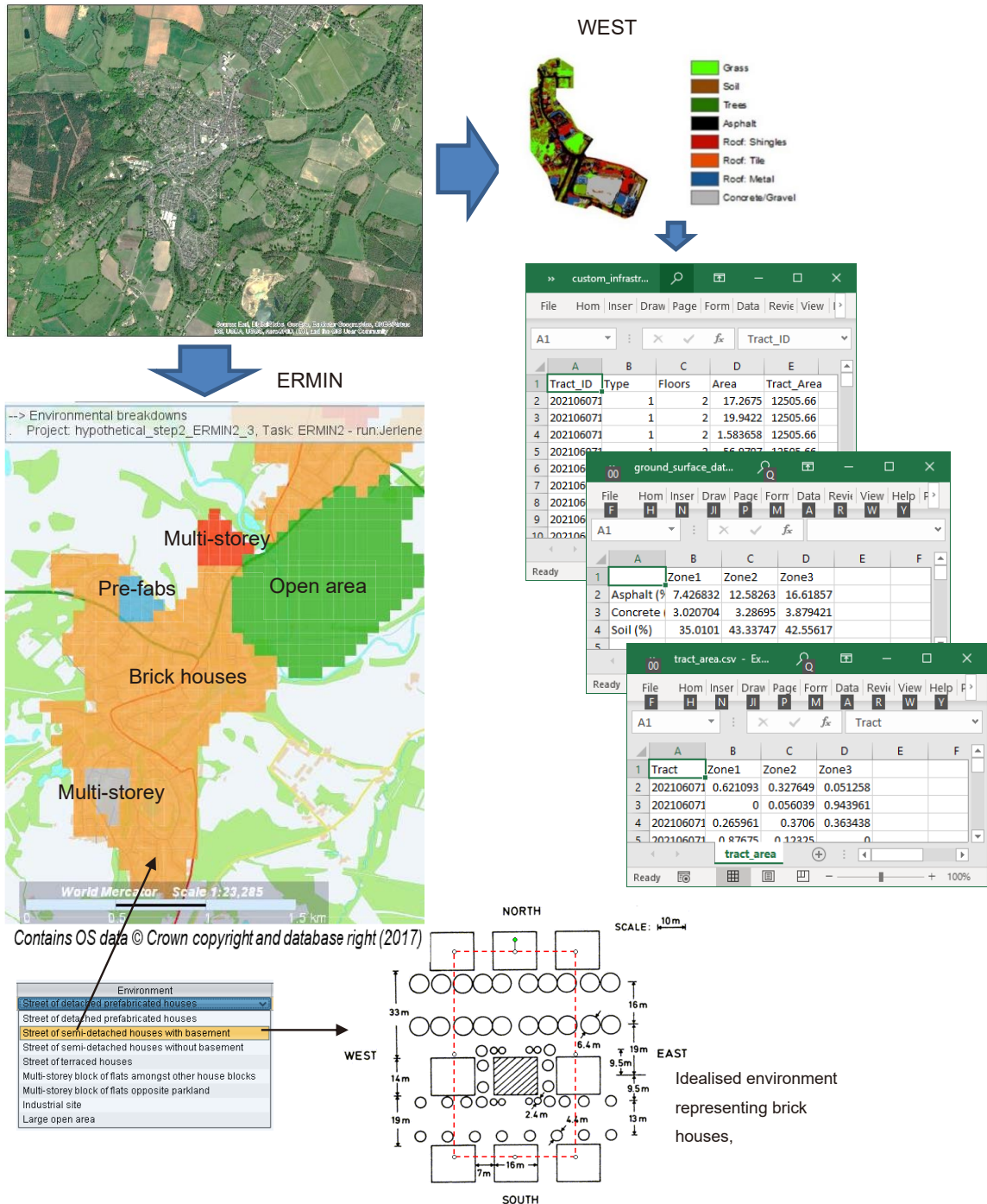


Figure 1 Representation of the built environment in ERMIN and WEST (Contains OS data © Crown copyright 2022 and material from Lemieux and Boe (2018) and Meckbach et al. (1988).

2.2 Representation of decontamination options

The decontamination options in ERMIN and WEST are summarized in Table 1, with similar options between ERMIN and WEST being listed in the same row. Some options are only included in either ERMIN or WEST. The decontamination operations for grass and trees are not included in WEST. Those for indoor floors and walls are grouped together in ERMIN as that for interior surfaces and consequently the indoor options for ERMIN are broad and generic compared to the WEST options. As ERMIN calculates more than waste endpoints, the range of options it considers are broader and includes those that do not create waste, such as options that fix contamination in place and that shield or bury the contamination. WEST does include some options for these types, such as “Reversal tillage”, which is treated as a removal process that generates zero waste. In contrast, a similar technique in ERMIN such as ploughing, does not remove activity but moves it lower in the soil column profile where it still contributes to doses and could be subsequently removed by other options.

To calculate the amount of waste generated by an option, both ERMIN and WEST apply a waste rate. This is the amount of waste produced per unit area of the surface to which the option is applied (kg m^{-2}). The waste rates for each decontamination option are shown in Table 2. WEST lists solid and liquid waste rates, while ERMIN does not distinguish between solid and liquid waste rates. The waste rates in WEST are based on observations by EPA and JAEA (Japan Atomic Energy Agency, 2015), while those in ERMIN are based on the Generic European Handbook (Nisbet et al, 2010). Waste rates for some decontamination operations differ by a factor of more than 10 between ERMIN and WEST. The reasons for this large difference are the different consideration of liquid wastes and the different thickness of surface removal. The waste for washing interior surfaces and cleaning with pressurised hot water in ERMIN contains only solid wastes such as contaminated filters and not the contaminated water. The thickness of surface removal on concrete in ERMIN is set to be 40 mm, while the WEST option of surface abrasion of the surface is set at approximately 1.5–3 mm.

The decontamination options that have a waste rate are compared in Table 2.

To calculate the concentration of radionuclides in waste, both ERMIN and WEST use factors that relate the amount deposited on a reference surface. For ERMIN this is on short grass away from buildings and trees. For WEST it is the average deposition of the area. WEST assumes that subsequently the activity on the surface does not change, whereas ERMIN accounts for weathering and radioactive decay and therefore the timing of the application of decontamination will affect the waste activity concentrations in the waste. ERMIN and WEST both use a factor to calculate the amount of activity on the surface removed by an option. In ERMIN these are termed decontamination factors (DF) and are defined as the activity on the surface before the option is applied divided by activity on the surface afterwards. WEST has a contamination removal factor (Fr) which is the proportion of the surface activity removed. The relationship between DF and Fr is expressed as $Fr = 1 - 1/DF$. For some techniques the DF in ERMIN is reduced over time to represent the radioactive material becoming more fixed to the surface and the technique becoming less effective, so again there is a time dependency in ERMIN.

Table 1 List of decontamination options in WEST and ERMIN

WEST		ERMIN	
Decontamination option	Surface	Decontamination option	Surface
Foam/Rinse	Wall	Firehosing	Wall
Grinding	Wall	Mechanical abrasion	Wall
Grit Blasting	Wall	Sandblasting	Wall
Strippable coating	Wall	Peelable coatings	Wall
Water blasting	Wall	High pressure hosing	Wall
Low volume foam/rinse	Wall	-	-
Non-strippable coating	Wall	-	-
Polymer/Gel	Wall	-	-
Surface brushing	Wall	-	-
Low pressure mould remover spray with terry towels	Wall	-	-
-	-	Tie-down	Wall
Dry vacuum	Interior floors	Vacuum cleaning	Interior surfaces
Foam/Rinse	Interior floors	Washing	Interior surfaces
Grinding	Interior floors	-	-
Grit Blasting	Interior floors	-	-
Low volume foam/rinse	Interior floors	-	-
Non-strippable coating	Interior floors	-	-
Polymer/Gel	Interior floors	-	-
Strippable coating	Interior floors	-	-
Grinding	Interior wall	-	-
Grit Blasting	Interior wall	-	-
Polymer/Gel	Interior wall	-	-
Strippable coating	Interior wall	-	-
Brushing & High-pressure washing	Roof	High pressure hosing	Roof
		Brushing	Roof
Foam/Rinse	Roof	Firehosing	Roof
Strippable coating	Roof	Peelable coatings	Roof
Water blasting	Roof	Cleaning with pressurised hot water	Roof
2.25 HP shop-vac	Roof	-	-
Grinding	Roof	-	-
Grit Blasting	Roof	-	-
Low volume foam/rinse	Roof	-	-
Non-strippable coating	Roof	-	-
Polymer/Gel	Roof	-	-
-	-	Replacement	Roof

Table 1 List of decontamination options in WEST and ERMIN (continued)

WEST		ERMIN	
Decontamination option	Surface	Decontamination option	Surface
		Mechanical topsoil and turf or plant removal	Soil
Excavation/Physical removal - Machine Assisted	Soil	Mechanical topsoil and turf or plant removal and soil replacement	Soil
		Mechanical topsoil and turf removal, soil replacement and returf	Soil
		Mechanical topsoil and turf or plant removal, soil replacement and reseed	Soil
		Manual topsoil and turf or plant removal	Soil
		Manual topsoil and turf or plant removal and soil replacement	Soil
Excavation/Physical removal - Manual Removal	Soil	Manual topsoil and turf removal and soil replacement and returf	Soil
		Manual topsoil and turf removal and soil replacement and reseed	Soil
		Rotovating	Soil
Reversal tillage	Soil	Ploughing	Soil
Soil inversion	Soil	Deep ploughing	Soil
		Triple digging	Soil
Excavation/Physical removal with solidification agent - Machine assisted	Soil	-	-
-	-	Skim and burial ploughing	Soil
-	-	Cover with clean soil	Soil
-	-	Cover with asphalt	Soil
-	-	Manual digging	Soil
-	-	Turf harvesting and reseed	Soil
-	-	Mechanised snow removal	Soil
-	-	Turf harvesting	Grass
-	-	Turf harvesting and returf	Grass
-	-	Grass cutting	Grass
-	-	Plant removal	Grass
-	-	Tree removal	Tree
-	-	Tree removal and replacement	Tree

Table 1 List of decontamination options in WEST and ERMIN (continued)

WEST		ERMIN	
Decontamination option	Surface	Decontamination option	Surface
Excavation/Physical removal - Machine Assisted	Paved, Asphalt	Surface removal	Paved
Foam/Rinse	Paved, Asphalt	Firehosing	Paved
Road sweeper	Paved, Asphalt	Vacuum sweeping	Paved
Strippable coating	Paved, Asphalt	Peelable coatings	Paved
Ultra-high pressure washing	Paved, Asphalt	High pressure hosing	Paved
Grinding	Paved, Asphalt	-	-
Grit Blasting	Paved, Asphalt	-	-
Low volume foam/rinse	Paved, Asphalt	-	-
Media blasting (Dry ice)	Paved, Asphalt	-	-
Media blasting (Sand)	Paved, Asphalt	-	-
Media blasting (Shot)	Paved, Asphalt	-	-
Polymer/Gel	Paved, Asphalt	-	-
Water blasting	Paved, Asphalt	-	-
-	-	Tie-down	Paved
-	-	Turning	Paved
-	-	Surface removal and replacement	Paved
Abrasion	Concrete	Surface removal	Concrete
Foam/Rinse	Concrete	-	-
Grinding	Concrete	-	-
Grit Blasting	Concrete	-	-
High-pressure washing	Concrete	-	-
Low volume foam/rinse	Concrete	-	-
Media blasting (Shot)	Concrete	-	-
Polymer/Gel	Concrete	-	-
Strippable coating	Concrete	-	-
Ultra-high pressure washing	Concrete	-	-
Water blasting	Concrete	-	-
-	-	Surface removal and replacement	Concrete

Table 2 Rate of waste production rate of decontamination options in WEST and ERMIN

Decontamination option	WEST				ERMIN				WEST/ERMIN
	Surface	Waste rate (kg m ⁻²)		DF	Decontamination option	Surface	Waste rate (kg m ⁻²)	DF	Ratio of Waste rate
		Solid	Liquid						
Foam/Rinse	Wall	0	26.7	1.9	Firehosing	Wall	50	1.3	0.5
Grinding	Wall	0 ^a	0 ^a	2.2	Mechanical abrasion	Wall	0.1	2.0	0.0
Grit Blasting	Wall	56	0	25	Sandblasting	Wall	53	4.0	1.1
Strippable coating	Wall	0.26	0	2.3	Peelable coatings	Wall	1	3.0	0.3
Water blasting	Wall	0	217.3	1.6	High pressure hosing	Wall	20	1.8	10.9
Dry vacuum	Interior floors	0.23	0	3.7	Vacuum cleaning	Interior surfaces	0.005	3.5	46.0
Foam/Rinse	Interior floors	0	26.7	1.9	Washing	Interior surfaces	0.0015	2.5	17800.0 ^b
Brushing & High-pressure washing	Roof	1.7	25	1.8	High pressure hosing	Roof	20	1.8	1.3
Foam/Rinse	Roof	0	26.7	1.9	Brushing	Roof	0.2	2.0	0.5
Strippable coating	Roof	0.26	0	2.3	Firehosing	Roof	50	1.3	0.3
Water blasting	Roof	0	217.3	1.6	Peelable coatings	Roof	1	3.0	1086.5 ^b
					Cleaning with pressurised hot water	Roof	0.2	2.0	

a The WEST application indicates no waste, whereas the report, US EPA (2006), states a small amount of waste.

b The very large difference is because the ERMIN figure assumes that the water is filtered and the waste rate only includes the solid component.

Table 2 Rate of waste production rate of decontamination options in WEST and ERMIN (continued)

Decontamination option	WEST			ERMIN			WEST/ERMIN		
	Surface	Waste rate (kg m ⁻²)		Decontamination option	Surface	Waste rate (kg m ⁻²)	DF		
		Solid	Liquid					DF	Waste rate
Excavation/Physical removal - Machine Assisted	Soil	76.1	0	1.8	Mechanical topsoil and turf removal (with/without soil replacement)	Soil	60	20	1.3
Excavation/Physical removal - Manual Removal	Soil	83.7	0	2	Mechanical topsoil and turf removal, (with/without soil replacement and return or reseed)	Soil	60	20	1.3
Reversal tillage	Soil	0	0	1.8	Manual topsoil and turf or plant removal (with/without soil replacement, return or reseed)	Soil	60	10	1.4
Soil inversion	Soil	0	0	3 ^c	Rotovating	Soil	0	0	-
Excavation/Physical removal - Machine Assisted	Paved, Asphalt	64.7	0	5.3	Ploughing	Soil	0	0	-
Foam/Rinse	Paved, Asphalt	0	26.7	1.9	Deep ploughing	Soil	0	0	-
Road sweeper	Paved, Asphalt	1	0	1.3	Triple digging	Soil	0	0	-
Strippable coating	Paved, Asphalt	0.26	0	2.3	Surface removal	Paved	60	8.0	1.1
Ultra-high pressure washing	Paved, Asphalt	2.5	45	5	Firehosing	Paved	50	2.0	0.5
Abrasion ^d	Concrete	2.2	0	3.3	Vacuum sweeping	Paved	0.2	2.5	5.0
					Peelable coatings	Paved	1	3.0	0.3
					High pressure hosing	Paved	20	4.0	2.4
					Surface removal ^e	Concrete	120	8.0	0.0 ^e

^c The WEST DF applies to the surface concentration before and after the options. The radioactivity in the soil column is not changed by the option, but the surface concentration is decreased.

^d In the WEST model, the option of surface removal is not included. Since the abrasion is the most similar technology to the surface removal, the abrasion was compared to the surface removal in this study, although they are different.

^e The large difference is due to different surface removal and abrasion depth, approximately 1.5–3 mm for WEST and 40 mm for ERMIN

2.3 Waste Endpoints

ERMIN calculates the waste amount (kg) and radioactivity concentration in waste for each radionuclide for each option at the time of application (Bq kg^{-1}). It also sums the radionuclides to give the total concentration of alpha-emitting radionuclides and of beta/gamma-emitting radionuclides (Bq kg^{-1}). When a package of clean-up operations has been applied, ERMIN allows the user to define zones. Within each zone, ERMIN calculates a single amount of waste (kg) and a single average waste radioactivity concentration for each radionuclide (Bq kg^{-1}). In addition, the total average waste radioactivity concentration of two groups of radionuclides, alpha-emitting and of beta/gamma-emitting, averaged over all techniques applied within the zone is calculated.

WEST is more sophisticated and comprehensive in that it distinguishes between solid and liquid waste and for a decontamination scenario (a package of decontamination options) it calculates six endpoints: total solid waste radioactivity (Bq), total liquid waste radioactivity (Bq), total solid waste mass (kg), total liquid waste mass (kg), total solid waste volume (m^3) and total liquid waste volume (m^3).

For decontamination of buildings, WEST provides for each contamination zone, building decontamination option and administrative tract, the same six endpoints, plus the amount of surface within the zone/option/tract combination that is decontaminated.

For building demolition, WEST provides for each contamination zone, administrative tract and occupancy class, the same six endpoints, assuming that buildings of the occupancy class are demolished.

For decontamination of ground surfaces, WEST provides for each contamination zone, surface type (soil, asphalt and concrete), each administrative tract, and each ground surface decontamination option, the same six endpoints.

WEST allows all results to be exported to an excel spreadsheet for further analysis.

3 Development of a scenario for comparison

To explore the capabilities of WEST and to compare it with ERMIN, a scenario was developed. To keep the scenario simple and avoid the complications of a complex urban area with different building types, an arbitrary residential area was chosen with a homogeneous building stock of brick detached and semi-detached houses. ArcGIS geographic information software was chosen as the platform to handle the spatial input data and to support the analysis.

One of the WEST tools is an ArcGIS script that generates WEST input from the ESRI world imagery base map using an image classification process. Unfortunately, this could not be applied to the UK situation, and it was also noted that the ESRI imagery does not always align well with UK features such as roads and buildings. Instead, building and surface data was extracted from the UK Ordnance Survey OS MasterMap® Topographic Layer (Ordnance Survey, 2018). The OS MasterMap® Topographic Layer is the most detailed topographic dataset covering Great Britain. Features of the physical environment down to a few metres are represented, including building footprints, roads, pavements, and house plots, see Figure 2 as an example.

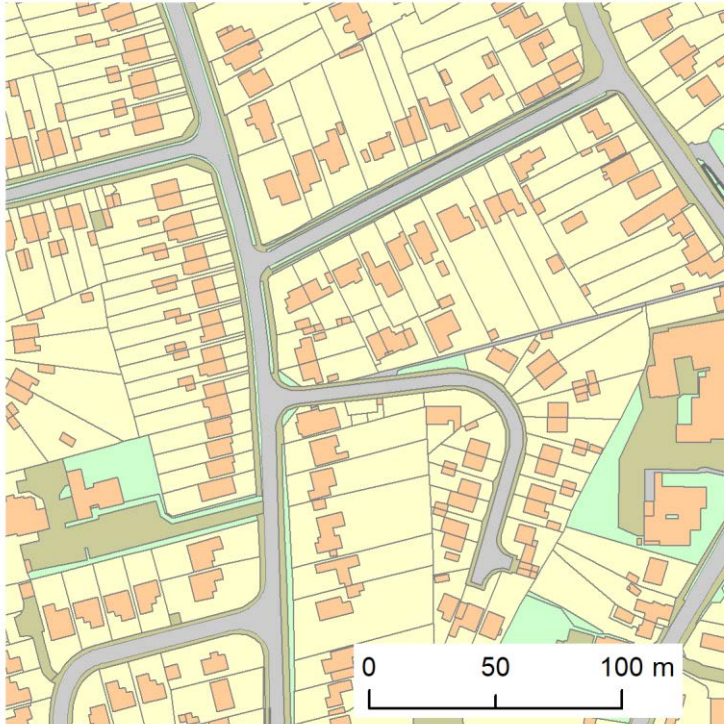


Figure 2 An example of Ordnance Survey MasterMap® Crown Copyright.

A hypothetical plume of ^{137}Cs contamination was generated using a simple gaussian atmospheric dispersion model giving deposition in 100 m grid-squares across the area as shown in Figure 3.

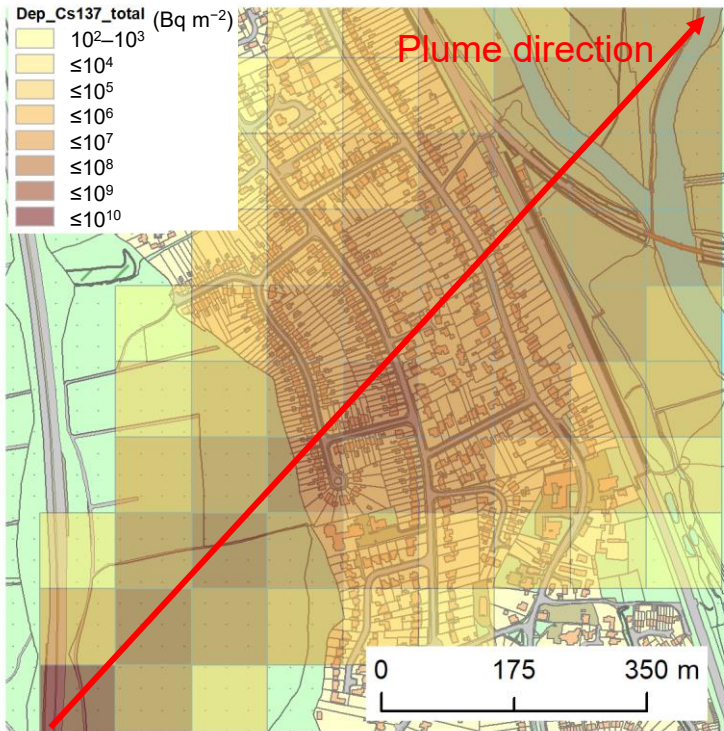


Figure 3 A hypothetical plume directed across the scenario area

ArcGIS scripts were written to generate inputs for both ERMIN and WEST from the MasterMap and plume data.

3.1 WEST scenario script

WEST uses a tabular approach to structure the input. The area is divided into zones based on deposition and the amount of buildings, asphalt, concrete and soil surfaces within those zones are specified. To generate the required input files for WEST, the script uses two MasterMap® fields, *featcode* and *make*, to establish the surface material of each of the relevant features in the MasterMap. For example, *Featcode* "10172" is described as "Road or Track" and can take the *make* values of either "Manmade" (for paved roads) or "Natural" (for dirt roads). The script assumes that a "10172/Manmade" combination is 100% asphalt and a "10172/Natural" combination is 100% soil. Some combinations are less clear, for example the combination "10053/Multiple" is frequently used for the plot of land surrounding residential houses. The "multiple" *make* value indicates it is made up of different surface materials so to resolve this the script assumes this is 80% soil, 10% asphalt and 10% concrete. The *featcode/make* combinations used in the script are given in Table 3.

Table 3 Surface material assumptions in the WEST script

MasterMap® Combination	Description	%Asphalt	%Soil	%Concrete
10183/Manmade	Roadside	100	0	0
10183/Natural	Roadside	0	100	0
10056/Manmade	General Surface	100	0	0
10056/Natural	General Surface	0	100	0
10172/Manmade	Road or Track	100	0	0
10172/Natural	Road or Track	0	100	0
10053/Multiple	General Surface	10	80	10
10021	Buildings			

There is only one MasterMap® *featcode* to represent buildings (10021), so MasterMap® is not able to distinguish between different building types and therefore the script labels every building as type 1, which, because of the simplicity of the area chosen, can be assumed to be a brick-built home.

3.2 ERMIN scenario script

ERMIN uses a spatial grid to structure input. Users of ERMIN are required to select standard built environments from the database to represent the real environment within those grid squares. The standard environments consist of a single building type (e.g. a brick semi-detached house) surrounded by fixed proportions of grass and paved surfaces. The MasterMap® data gives building footprints but does not give building types or use. However, because a simple residential area was used, it is reasonable to assume a single built environment type. Therefore, the script assumes that any grid square containing 5% or more building-footprint is 100% of a single environment and other grid squares are assumed to be uninhabited and excluded from the calculation. The "street of semi-detached houses" environment most closely matches the dimensions and shielding properties of the buildings

within the example region, but the use of the “street of prefabricated house” environment was also explored as the proportions of external surface more closely matched the spacing within the sample region.

Figure 4 shows the area identified as residential when applying this simple algorithm to the scenario, the area being subdivided into three different deposition zones. Rather than using deposition zones, ERMIN can accommodate distinct values of deposition in every square. However, for comparison with WEST, constant deposition across the zones was assumed.

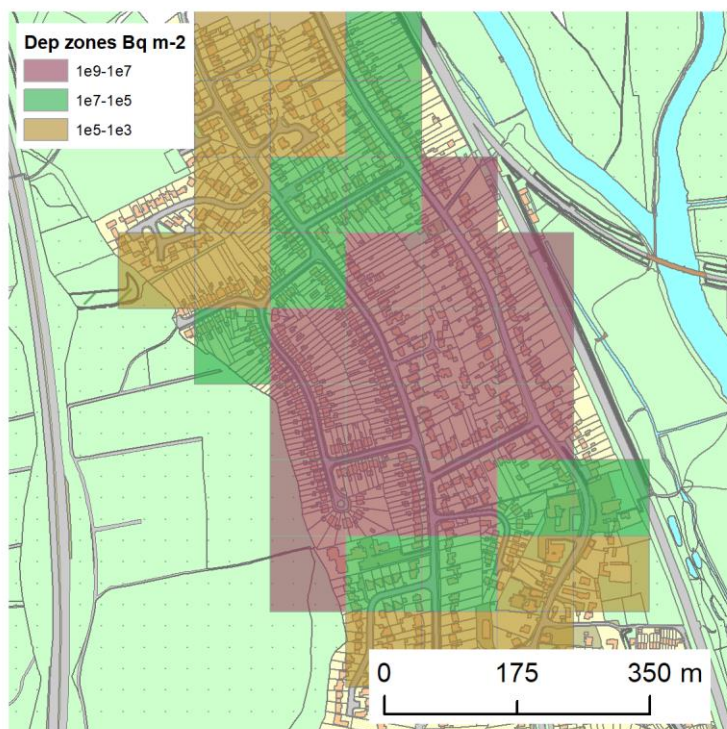


Figure 4 Areas identified as containing residential housing divided into three deposition zones.

3.3 Comparison

The deposition concentration, radionuclide considered, and ratio of deposition to surface relative to the reference surface (soil) are shown in Table 4. For this study, these parameters were set to be the same for ERMIN and WEST.

Table 4 Parameter set

Parameter	Value
Deposition (Bq m ⁻²)	Zone 1: 1×10 ⁹
	Zone 2: 1×10 ⁷
	Zone 3: 1×10 ⁵
Radionuclide	Cs-137/Ba-137m
Deposition-Exterior wall	0.03
Deposition -Roof	0.7
Deposition -Interior floor	1
Deposition -Soil	1
Deposition -Asphalt	0.25
Deposition -Concrete	0.25

As mentioned previously, the surface area of outdoor ground media is based directly on the MasterMap® data in WEST. On the other hand, ERMIN uses a representative built environment. Therefore, the surface area ratio of outdoor ground media can differ between ERMIN and WEST. Furthermore, ERMIN has three classes of paved surface: road, pavement and other paved, divided by size and use, and these could be either concrete or asphalt, or a less common material such as paving stones. However, WEST distinguishes between asphalt and concrete but does not categorise further.

In this report, the ratios of surface material of 10053/Multiple shown in Table 3 were changed to adjust the surface area ratio of outdoor ground media in WEST to be closer to that in ERMIN. The adjusted surface area ratios are shown in Table 5 and Table 6. As shown in Table 5 and Table 6, the surface area ratio in zone 3 gave the best agreement between ERMIN and WEST, while in zones 1 and 2 WEST had less of each surface than ERMIN. The road in ERMIN is assumed to be the same as asphalt in WEST, while pavement and other paved areas in ERMIN are assumed to be the same as concrete in WEST.

The building coverage ratio (ratio of building footprint to total area) in WEST is taken directly from MasterMap® and can be assumed to be more precise and cannot be adjusted. The building coverage ratio in ERMIN is different among the built environments that can be chosen. To investigate the influence of different building coverage ratio, two built environments (“street of detached prefabricated houses” and “street of semi-detached houses without basement”) were chosen. The building coverage ratios are shown in Table 7. The building coverage ratio for detached prefabricated houses for ERMIN was similar to the sample region and those entered into WEST. However, those for semi-detached houses without basement were approximately three times larger than the sample region and entered into WEST. This is unfortunate since the shielding properties of the “street of semi-detached” more closely matched the construction materials and shielding properties of typical UK housing seen in the sample region.

The decontamination operations chosen were those in which waste rates were greater than zero: firehosing for walls; sandblasting for walls; peelable coatings for walls; high pressure hosing for walls; vacuum cleaning for interior surfaces; washing for interior surfaces; high pressure hosing for roofs; peelable coating for roofs; cleaning with pressurised hot water for roofs; manual topsoil and turf removal and soil replacement and reseed-small scale; mechanical topsoil and turf or plant removal; surface removal for roads; firehosing for roads; vacuum sweeping for roads; peelable coating for roads; high pressure hosing for roads; and removal-small scale for concrete.

As described before, WEST assumes that the activity on a surface does not change, whereas ERMIN accounts for weathering and radioactivity decay. Additionally, the DF for some techniques in ERMIN reduces over time to represent the radioactive material becoming more fixed to the surface. To avoid the effect of any difference due to the timing of the application of the decontamination option on the waste activity, the timing was assumed to be one week after the deposition for all options.

Table 5 Surface area ratios (%) for detached prefabricated houses

ERMIN		WEST			WEST/ERMIN			
		Zone1	Zone2	Zone3	Zone1	Zone2	Zone3	
Default								
Road	14.4	Asphalt	7.4	12.6	16.6	0.52	0.87	1.15
Paved area	3.6	Concrete	3.0	3.3	3.9	0.42	0.46	0.54
Other paved	3.6							
Grass								
Plant	54.8	Soil	35.0	43.3	42.6	0.51	0.63	0.62
Bare	6.9							
	6.9							
High paved								
Road	21.6	Asphalt	10.4	15.9	20.5	0.48	0.73	0.95
Paved area	5.4	Concrete	6.0	6.6	7.8	0.56	0.61	0.72
Other paved	5.4							
Grass								
Plant	46.2	Soil	29.0	36.8	34.8	0.50	0.64	0.60
Bare	5.8							
	5.8							
Low paved								
Road	7.2	Asphalt	3.1	6.9	8.7	0.43	0.96	1.21
Paved area	1.8	Concrete	1.3	2.4	4.0	0.37	0.67	1.12
Other paved	1.8							
Grass								
Plant	63.5	Soil	41.1	49.9	50.3	0.52	0.63	0.63
Bare	7.9							
	7.9							

Table 6 Surface area ratios (%) for semi-detached house without basement

ERMIN		WEST			WEST/ERMIN			
		Zone1	Zone2	Zone3	Zone1	Zone2	Zone3	
Default								
Road	13.2	Asphalt	7.4	12.6	16.6	0.56	0.95	1.26
Paved area	8.8	Concrete	18.1	19.7	23.3	0.82	0.89	1.05
Other paved	13.4							
Grass	22.4							
Plant	2.8	Soil	19.9	26.9	23.2	0.71	0.96	0.83
Bare	2.8							
High paved^a								
Road	19.9	Asphalt	10.4	15.9	20.5	0.53	0.80	1.03
Paved area	13.2	Concrete	24.2	26.3	31.0	0.73	0.79	0.93
Other paved	20.1							
Grass	8.2							
Plant	1	Soil	10.8	17.0	11.5	1.06	1.67	1.13
Bare	1							
Low paved^a								
Road	6.6	Asphalt	1.8	3.7	5.1	0.27	0.56	0.77
Paved area	4.4	Concrete	4.2	7.2	9.6	0.38	0.65	0.86
Other paved	6.7							
Grass	36.5							
Plant	4.6	Soil	39.5	48.3	48.4	0.86	1.06	1.06
Bare	4.6							

^a ERMIN allows some refinement of the proportion of ground surfaces with high paved meaning approximately a 50% increase in paving with a corresponding reduction in grass surface, and low paved meaning approximately 50% reduction in paving and a corresponding increase in grass surface.

Table 7 Building coverage ratio (%)

Type of housing	ERMIN	WEST			WEST/ERMIN		
		Zone 1	Zone 2	Zone 3	Zone 1	Zone 2	Zone 3
Detached prefabricated house	12.6	12.6	11.5	14.5	1.00	0.91	1.15
Semi-detached house	36.7	12.6	11.5	14.5	0.34	0.31	0.40

4 Results and analysis

Examples of comparisons of waste quantity, radioactivity concentrations in waste, and removed radioactivity between ERMIN and WEST are shown in Table 8–Table 12. The complete set of comparisons are given in Appendix A.

Waste quantity

Table 8 and Table 9 show the waste quantities (kg) calculated by WEST and ERMIN and ratios between the two sets of calculations.

Both ERMIN and WEST calculate the waste quantity by multiplying the surface area by the waste rate shown in Table 2. Differences in surface area between ERMIN and WEST in different zones and built environments, identified in Table 5 and Table 6, explain some of the differences in ratios in the “WEST/ERMIN” columns in Table 8 and Table 9 when comparing the same decontamination option. The waste quantity on the outdoor ground media varied by changing the surface area ratio of the outdoor ground media. In a comparison of different building environments, the waste quantity from building media (walls, interior surfaces, and roofs) was lower for detached prefabricated houses because their building coverage ratio is smaller than that for semi-detached houses without basements.

The largest ratio of waste quantity between ERMIN and WEST was for washing interior surfaces with concrete paving stone removal being the smallest as shown in Table 8 and Table 9. The “WEST/ERMIN” ratio in Table 8 and Table 9, and the “Ratio of waste rate” in Table 2 are very consistent. This indicates that the difference in the waste rate between ERMIN and WEST was the largest contributor to the difference in the waste quantity between ERMIN and WEST.

To eliminate the influence of the difference in the waste rate between ERMIN and WEST, the ratios of waste quantity in Table 8 and Table 9 were normalized by the ratios of waste rate. The resulting normalized ratios of waste quantity are shown in Table 13 and Table 14. The ratios of building coverage and surface area for each surface type between ERMIN and WEST are also shown in Table 13 and Table 14. These normalized ratios of waste quantity largely reproduced the ratios of surface area for each surface type, except for outdoor walls. This indicates that the differences in the building coverage ratio and surface area between ERMIN and WEST also contribute to the difference in the waste quantity between ERMIN and WEST.

The normalized ratio of waste quantity of firehosing outdoor walls was more than twice the ratio of building coverage ratio, as shown in Table 13 and Table 14. This is because the surface area of wall depends on the building height and the shape of building floor as well as the building coverage ratio. In ERMIN, the ratio of roof to wall surface area for detached prefabricated houses and semi-detached houses are 0.79 and 0.61 respectively. In WEST, the ratio of roof to wall surface area ranged from 0.13–0.70, with an average value of 0.30 in this case. The difference in the ratio of roof to wall surface area between ERMIN and WEST was similar to the difference in the normalized ratio of waste quantity on walls.

These results show that it is important to reproduce the building coverage ratio and surface area of each media, to calculate accurately the waste quantity. In ERMIN, the prefabricated environment is the better match to the example region in this respect. However, as previously discussed, the semi-detached house is a better match in terms of shielding properties.

Waste activity and waste activity concentration

Table 10 and Table 11 give the total waste radioactivity (Bq), and Table 12 gives the radioactivity concentration (Bq kg⁻¹) calculated by WEST and ERMIN and ratios between the WEST and ERMIN calculations for detached prefabricated house only.

Like waste quantity, the differences in total waste radioactivity calculated by WEST and ERMIN for the same decontamination method depend on the differences in surface area in the different zones and ERMIN environments. Because the two models had the same deposition on the same surfaces (see Table 4) and because the application times were too short for the weathering in ERMIN to have a great effect, the differences in predicted amounts between ERMIN and WEST for the same decontamination option are also due to the differences in the DF (Table 2).

The ratio of radioactivity concentration in waste between ERMIN and WEST, which was calculated as the ratio of the deposition on the surface to the mass of waste rate was independent of the area of decontamination surface and the differences are due to the combined effect of differences in the waste rate and the DF.

Table 8 Waste quantity for detached prefabricated house. The surface area ratio assumed for ERMIN is the default case in Table 5.

Waste quantity (kg)	ERMIN			WEST			WEST/ERMIN			Ratio of waste rate ^a
	Zone 1	Zone 2	Zone 3	Zone 1	Zone 2	Zone 3	Zone 1	Zone 2	Zone 3	
Firehosing walls (walls)	1.22E+06	7.60E+05	6.08E+05	2.11E+06	1.42E+06	9.83E+05	1.73	1.86	1.62	0.53
Washing interior surfaces (internal surfaces)	7.08E+01	4.43E+01	3.54E+01	1.21E+06	8.60E+05	6.19E+05	17028.89	19427.00	17477.76	17800.00
Roof cleaning with pressurised hot water (roof)	3.84E+03	2.40E+03	1.92E+03	4.91E+06	3.50E+06	2.52E+06	1279.14	1459.27	1312.86	1086.50
Manual topsoil and turf removal and soil replacement and reseed-small scale (soil)	6.66E+06	5.18E+06	2.96E+06	4.61E+06	4.46E+06	2.46E+06	0.69	0.86	0.83	1.39
Firehosing paved (road)	1.30E+06	1.01E+06	5.76E+05	2.94E+05	4.29E+05	3.10E+05	0.23	0.43	0.54	0.53
Concrete paving stone removal-small scale (pavement)	1.56E+06	1.21E+06	6.91E+05	1.02E+04	8.03E+03	5.91E+03	0.01	0.01	0.01	0.02

^a Equivalent to the column "WEST/ERMIN" in Table 2

Table 9 Waste quantity for semi-detached house. The surface area ratio assumed for ERMIN is the default case in Table 6.

Waste quantity (kg)	ERMIN			WEST			WEST/ERMIN			Ratio of waste rate ^a
	Zone 1	Zone 2	Zone 3	Zone 1	Zone 2	Zone 3	Zone 1	Zone 2	Zone 3	
Firehosing walls (walls)	5.26E+06	3.29E+06	2.63E+06	2.11E+06	1.42E+06	9.83E+05	0.40	0.43	0.37	0.53
Washing interior surfaces (internal surfaces)	1.76E+02	1.10E+02	8.78E+01	1.21E+06	8.60E+05	6.19E+05	6862.74	7829.19	7043.63	17800.00
Roof cleaning with pressurised hot water (roof)	1.27E+04	7.96E+03	6.37E+03	4.91E+06	3.50E+06	2.52E+06	385.67	439.98	395.84	1086.50
Manual topsoil and turf removal and soil replacement and reseed-small scale (soil)	2.72E+06	2.12E+06	1.21E+06	2.63E+06	2.80E+06	1.32E+06	0.97	1.32	1.09	1.39
Firehosing paved (road)	1.19E+06	9.24E+05	5.28E+05	2.94E+05	4.29E+05	3.10E+05	0.25	0.46	0.59	0.53
Concrete paving stone removal-small scale (pavement)	4.79E+06	3.73E+06	2.13E+06	6.12E+04	5.35E+04	3.40E+04	0.01	0.01	0.02	0.02

^a Equivalent to the column "WEST/ERMIN" in Table 2

Table 10 Waste activity for detached prefabricated house. The surface area ratio assumed for ERMIN is the default case in Table 5.

Waste activity (Bq)	ERMIN			WEST			WEST/ERMIN		
	Zone 1	Zone 2	Zone 3	Zone 1	Zone 2	Zone 3	Zone 1	Zone 2	Zone 3
Firehosing walls (walls)	1.68E+11	1.05E+09	8.39E+06	1.08E+12	7.27E+09	5.03E+07	6.42	6.93	6.00
Washing interior surfaces (internal surfaces)	9.63E+12	6.02E+10	4.81E+08	2.01E+13	1.43E+11	1.03E+09	2.09	2.37	2.13
Roof cleaning with pressurised hot water (roof)	6.68E+12	4.18E+10	3.34E+08	5.70E+12	4.06E+10	2.92E+08	0.85	0.97	0.88
Manual topsoil and turf removal and soil replacement and reseed-small scale (soil)	1.21E+14	9.38E+11	5.36E+09	2.74E+13	2.65E+11	1.46E+09	0.23	0.28	0.27
Firehosing paved (road)	3.17E+12	2.46E+10	1.41E+08	1.22E+12	1.78E+10	1.29E+08	0.39	0.72	0.92
Concrete paving stone removal-small scale (pavement)	2.75E+12	2.13E+10	1.22E+08	7.93E+11	6.24E+09	4.59E+07	0.29	0.29	0.38

Table 11 Waste activity for semi-detached house. The surface area ratio assumed for ERMIN is the default case in Table 6.

Waste activity (Bq)	ERMIN			WEST			WEST/ERMIN		
	Zone 1	Zone 2	Zone 3	Zone 1	Zone 2	Zone 3	Zone 1	Zone 2	Zone 3
Firehosing walls (walls)	7.26E+11	4.54E+09	3.63E+07	1.08E+12	7.27E+09	5.03E+07	1.49	1.60	1.39
Washing interior surfaces (internal surfaces)	2.39E+13	1.50E+11	1.19E+09	2.01E+13	1.43E+11	1.03E+09	0.84	0.95	0.86
Roof cleaning with pressurised hot water (roof)	2.21E+13	1.39E+11	1.11E+09	5.70E+12	4.06E+10	2.92E+08	0.26	0.29	0.26
Manual topsoil and turf removal and soil replacement and reseed-small scale (soil)	4.92E+13	3.84E+11	2.19E+09	1.56E+13	1.67E+11	7.85E+08	0.32	0.43	0.36
Firehosing paved (road)	2.90E+12	2.25E+10	1.29E+08	1.22E+12	1.78E+10	1.29E+08	0.42	0.79	1.00
Concrete paving stone removal-small scale (pavement)	8.43E+12	6.56E+10	3.75E+08	4.76E+12	4.16E+10	2.64E+08	0.56	0.63	0.70

Table 12 Waste activity concentration for detached prefabricated house. The surface area ratio assumed for ERMIN is the default case in Table 5.

Waste activity concentration (Bq kg ⁻¹)	ERMIN			WEST			WEST/ERMIN		
	Zone 1	Zone 2	Zone 3	Zone 1	Zone 2	Zone 3	Zone 1	Zone 2	Zone 3
Firehosing walls (walls)	1.38E+05	1.38E+03	1.38E+01	5.12E+05	5.12E+03	5.12E+01	3.71	3.71	3.71
Washing interior surfaces (internal surfaces)	1.36E+11	1.36E+09	1.36E+07	1.66E+07	1.66E+05	1.66E+03	0.00	0.00	0.00
Roof cleaning with pressurised hot water (roof)	1.74E+09	1.74E+07	1.74E+05	1.16E+06	1.16E+04	1.16E+02	<0.005	<0.005	<0.005
Manual topsoil and turf removal and soil replacement and reseed-small scale (soil)	1.81E+07	1.81E+05	1.81E+03	5.95E+06	5.95E+04	5.95E+02	0.33	0.33	0.33
Firehosing paved (road)	2.44E+06	2.44E+04	2.44E+02	4.16E+06	4.16E+04	4.16E+02	1.70	1.70	1.70
Concrete paving stone removal-small scale (pavement)	1.76E+06	1.76E+04	1.76E+02	7.77E+07	7.77E+05	7.77E+03	44.08	44.08	44.08

Table 13 Waste quantity ratio normalized by the ratio of waste rate for detached prefabricated house.

Waste quantity ratio / Waste rate ratio	Default			High paved			Low paved		
	Zone 1	Zone 2	Zone 3	Zone 1	Zone 2	Zone 3	Zone 1	Zone 2	Zone 3
	Firehosing walls	3.25	3.49	3.03	3.25	3.49	3.03	3.25	3.49
Washing interior surfaces (internal surfaces)	0.96	1.09	0.98	0.96	1.09	0.98	0.96	1.09	0.98
Roof cleaning with pressurised hot water (roof)	1.18	1.34	1.21	1.18	1.34	1.21	1.18	1.34	1.21
Ratio of building coverage ratio (WEST/ERMIN)	1.00	0.91	1.15	1.00	0.91	1.15	1.00	0.91	1.15
Manual topsoil and turf removal and soil replacement and reseed-small scale (soil)	0.50	0.62	0.60	0.49	0.63	0.58	0.50	0.62	0.60
Ratio of soil area ratio (WEST/ERMIN)	0.51	0.63	0.62	0.50	0.64	0.60	0.52	0.63	0.63
Firehosing paved (road)	0.42	0.80	1.01	0.40	0.65	0.79	0.36	0.86	1.07
Ratio of asphalt area ratio (WEST/ERMIN)	0.52	0.87	1.15	0.48	0.73	0.95	0.43	0.96	1.21
Concrete paving stone removal-small scale (pavement)	0.36	0.37	0.47	0.49	0.57	0.63	0.24	0.49	0.95
Ratio of concrete area ratio (WEST/ERMIN)	0.42	0.46	0.54	0.56	0.61	0.72	0.37	0.67	1.12

Table 14 Waste quantity ratio normalized by the ratio of waste rate for semi-detached house.

Waste quantity ratio / Waste rate ratio	Default			High paved			Low paved		
	Zone 1	Zone 2	Zone 3	Zone 1	Zone 2	Zone 3	Zone 1	Zone 2	Zone 3
	Firehosing walls	0.75	0.81	0.70	0.75	0.81	0.70	0.75	0.81
Washing interior surfaces (internal surfaces)	0.39	0.44	0.40	0.39	0.44	0.40	0.39	0.44	0.40
Roof cleaning with pressurised hot water (roof)	0.35	0.40	0.36	0.35	0.40	0.36	0.35	0.40	0.36
Ratio of building coverage ratio (WEST/ERMIN)	0.34	0.31	0.40	0.34	0.31	0.40	0.34	0.31	0.40
Manual topsoil and turf removal and soil replacement and reseed-small scale (soil)	0.69	0.95	0.78	1.05	1.63	1.12	0.85	1.03	1.00
Ratio of soil area ratio (WEST/ERMIN)	0.71	0.96	0.83	1.06	1.67	1.13	0.86	1.06	1.06
Firehosing paved (road)	0.46	0.87	1.10	0.44	0.71	0.86	0.26	0.54	0.65
Ratio of asphalt area ratio (WEST/ERMIN)	0.56	0.95	1.26	0.53	0.80	1.03	0.27	0.56	0.77
Concrete paving stone removal-small scale (pavement)	0.71	0.80	0.89	0.63	0.69	0.80	0.32	0.56	0.77
Ratio of concrete area ratio (WEST/ERMIN)	0.82	0.89	1.05	0.73	0.79	0.93	0.38	0.65	0.86

5 Recommendations

Although both models address waste arising from a radiation emergency, WEST and ERMIN are very different tools and in some ways complementary. The breadth of outputs from ERMIN suit it to supporting a decision-making process to develop a strategy, whereas WEST's greater precision on waste amounts and endpoints makes it suitable for capacity analysis both for planning default strategies and budgeting a developed strategy that emerges from a decision-making process.

This study allows several recommendations to be made regarding:

- the use of WEST operationally,
- sources of surface and building data to use with either model,
- recommendation for further developments of the scripts used to drive both models, and
- improvements in the ERMIN model.

5.1 Making WEST operational for UK applications

WEST is a powerful tool for estimating waste from clean-up. In some respects, it is simpler than ERMIN, as it does not include weathering, decay or dose modelling. However this means it is much easier to apply in an ad hoc way, to a wider range of contamination scenarios. For interior surfaces it has particularly advantages over ERMIN because it distinguishes between floors, walls, and ceilings. It also has a building demolish option which was not explored in this study.

WEST is capable of being used on a small scale such as a few contaminated buildings, or a very large scale for example a city and its surroundings. However, WEST is fairly laborious to use. The user must first generate a set of input files to describe the decontamination zones, the amount of outdoor ground surfaces and the building types within those zones and within administrative units termed "tracts". It might be possible to generate some very simple inputs files by hand, but it would be preferable to have tools available to do this. The script used for this report could be a starting point, but it depends on the assumption that all the buildings can be treated as brick residential properties. Therefore, further development would be required so that it could be used operationally. In this study the WEST Image classification tool could not be applied, and it is not likely to be as accurate as inputs based on MasterMap®, which is the definitive topological description of Great Britain.

Within WEST, the input files are imported to create a "contamination scenario". By default, a set of "partitioning factors" (relating average deposition to deposition on different urban surfaces) are assumed but these can be easily modified to match measured values. For operational use it would be useful to have guidance on appropriate factors for different scenarios (for example different chemical forms of radionuclides and different deposition conditions) for occasions when measurements are not available. These could be based on those compiled for ERMIN.

Before the "contamination scenario" can be analysed, each building type in the input files needs to be mapped onto an "occupancy class". There are sufficient occupancy classes in WEST that are suitable for the UK situation. However, each "occupancy class" has a given default set of

proportions of “model building types”. For example, it is assumed that the “single family dwelling” consists of approximately 85% “wood, light frame (< 5,000 sq. ft.)”, 11% “unreinforced masonry bearing walls”, 3% “reinforced masonry bearing walls with wood or metal deck diaphragms” and 1% “concrete shear walls”. The defaults will need to be changed because they are unsuitable for the UK (where, for residential buildings, brick construction predominates). Therefore, guidance needs to be developed to ascertain which, if any, “model building types” in the WEST database are suitable for the UK and in what proportions they should be used for different “occupancy classes”.

The WEST model allows a package of decontamination options to be applied to a contamination scenario. Different sets of decontamination options (called “decontamination technologies” in WEST) can be applied independently to “occupancy classes” and outdoor ground surfaces in different contamination zones. Each option is described by six parameters: the percentage of the surface treated (0-100%), the mass of soil waste generated per unit area (kg/m^2) the volume of solid waste generated per unit area (m^3/m^2), the mass of liquid waste generated per unit area (kg/m^2), the volume of liquid waste generated per unit area (m^3/m^2) and a contamination removal factor (the proportion of the activity in the surface that is removed). WEST provides default values for all these (except the percentage of surface treated), but there is a need to ensure these are appropriate for the UK.

The sum of the percentages of the surface decontaminated using options must not exceed 100%, and different options can be applied to different parts of the same surface, but no part of the surface can have more than one option applied. This differs from ERMIN which assumes that a technique is applied to 100% of a given surface, and does allow, with many restrictions, more than one option to be applied to the same surface.

It would be quite difficult to use WEST to develop a strategy by exploring different strategies and comparing them; it is both laborious to use and does not include additional endpoints (for example, public dose reduction, worker dose, cost, manpower etc) that are important for decisions. The process of exploring and discarding options would be more easily performed using the approach in the UK Radiation Recovery Handbook (Nisbet and Watson, 2015), which provided useful decision trees and look-up tables, possibly in conjunction with ERMIN to produce indicative technical numbers.

The strength of WEST is the precision that can be achieved, because firstly the areas of urban surfaces can be specified precisely, secondly there is a better representation of interiors as different strategies can be applied to different kinds of building (e.g. residences or public buildings) and thirdly different proportions of the surfaces can be tackled with different options. Another strength is that it can be applied to a wider range of decontamination situations and be based directly on measurements, by varying the partitioning factors as appropriate. Therefore, WEST is particularly useful for generating realistic data for planning and budgeting purposes for default strategies.

In summary the tasks that need to be performed to prepare WEST for operational use in the UK are:

- Develop a robust tool and procedure for generating WEST input files from MasterMap® and other supporting information.
- Develop sets of “partitioning factors” appropriate for different scenarios in UK.

-
- Examine the “occupancy classes” and the “model building types” available in WEST to develop guidance about how to select and proportion the most appropriate for the UK situation.
 - Make sure the available decontamination options and parameters are appropriate for the UK and develop new values if they are not.
 - Develop guidance on using WEST operationally.

It is not clear if WEST has a facility to add additional “occupancy classes”, “model building types” or “decontamination technologies”. However, as WEST is built on an Access™ database platform, this should be possible. If this eventually proves necessary, then the original developers could be approached for advice on this.

5.2 Sources of surface and building data

This study used Ordnance Survey OS MasterMap® Topographic Layer (Ordnance Survey 2018), to provide the surface and building data for both WEST and ERMIN. The OS MasterMap® Topographic Layer is the most detailed topographic dataset covering the whole of Great Britain. Features of the physical environment down to a few metres are represented, including building footprints, roads, pavements, and house plots. There is unlikely to be a better available dataset that covers the whole of Great Britain¹. However, it has the following weaknesses;

- It does not cover Northern Ireland, or areas outside the UK including Isle of Man and the Channel Islands.
- While it contains building footprints, it does not identify types of building either in terms of use or construction.
- It does not distinguish between asphalt and concrete, and in some cases soil surfaces. It does not include tree coverage needed for ERMIN.

In this study, the scripts used were kept simple by using an area where all buildings could be assumed to be residential. A more sophisticated algorithm could have been devised that used for example the building footprint size to make a more informed assumption about the type of building in the case of WEST or the type of urban environment in the case of ERMIN. It is possible to obtain building height as an addition to MasterMap and this too could be used to inform the assumptions about buildings and environments. Information about zoning (e.g. residential, commercial, industrial activity zones) could be used to further inform the assumptions. However, UK is heterogeneous in this regard, with industrial, residential, and commercial activities being mixed. No national dataset has been identified that could provide this information.

If there is a need to use either tool outside Great Britain, more effort could be expended on using the WEST image processing tool to generate input files for WEST and a similar approach could be adopted for ERMIN. Alternatively, a tool could be developed that uses

¹ The UK CEH land-cover map which, also includes Great Britain, was considered but found to be too coarse for this purpose, and the categories of urban land cover were too broad.

OpenStreetMap™ which identifies building footprints and increasingly classifies the construction materials used and tags other features with landcover.

5.3 Further development of scripts

In the development of scripts to provide information for both WEST and ERMIN, several opportunities for improvement were identified. For scripts for both models these are:

- Develop a more sophisticated algorithm to better define either building type for WEST or built environment for ERMIN
- Identify national datasets that could improve the classification of buildings and ground surfaces.

For the WEST script:

- Re-examine the assumptions about ground surface material more critically. The current script makes a simplistic assumption about the division between asphalt, concrete and soil that could be refined.

For the ERMIN script:

- Develop a more sophisticated algorithm that selects proportions of idealised environments including the open area environment, to more closely match the proportions of buildings and ground surfaces provided by MasterMap®
- Retrieve the results from ERMIN and reimport into ArcGIS for mapping
- Improve the flexibility of the interface to allow the user to more easily apply when and where decontamination options are applied.

5.4 Recommendations for ERMIN improvements

From this work, several potential improvements in ERMIN have been identified:

- Develop a better representation of interiors to allow decontamination options for walls and ceilings to be evaluated.
- Subdivision of waste endpoints into liquid and solid components. This may resolve the large differences in the waste-rate identified in the comparison as some of the ERMIN options assume the waste is filtered and the water discarded.
- Examine and resolve remaining differences in the waste-rate between WEST and ERMIN that have been identified, e.g. washing and surface removal of concrete.
- Addition of various building coverage ratios for different built environments.
- ERMIN does not include decontamination options for interior walls and high-pressure washing and firehosing of concrete surfaces. In particular, the omission of high-pressure washing and firehosing of concrete surfaces is important as these were applied after the Fukushima Daiichi nuclear power station accident.
- Since the waste is not partitioned into liquid and solid in ERMIN, it was found that for some water-based decontamination options, the total waste quantity was

underestimated compared to WEST. Liquid wastes are important in assessing the total waste quantity after a nuclear accident.

- The waste rate for surface removal of concrete may need to be modified as technology advances and removal of thinner layers become possible.
- As ERMIN has only one building coverage ratio for each built environment, it is not possible to assess doses and waste quantities under different surrounding building conditions. However, it is not practical to calculate doses for all possible building densities as this would be too time-consuming. Instead, the preparation of several building coverage ratios in each built environment, such as high density, middle density, and low density, would be useful for more rigorous dose assessment as well as for waste quantity estimation. This would necessitate further time-consuming Monte-Carlo particle transport calculations.

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Appendix A Dataset of waste quantity, waste activity, and radioactivity in waste

Table A1 Waste quantity for detached prefabricated house. The surface area ratio assumed for ERMIN is the default case in Table 5.

Waste quantity (kg)	ERMIN			WEST			WEST/ERMIN			Ratio of waste rate ^a
	Zone 1	Zone 2	Zone 3	Zone 1	Zone 2	Zone 3	Zone 1	Zone 2	Zone 3	
Firehosing walls (walls)	1.22E+06	7.60E+05	6.08E+05	2.11E+06	1.42E+06	9.83E+05	1.73	1.86	1.62	0.53
Sandblasting walls (walls)	1.29E+06	8.06E+05	6.44E+05	4.42E+06	2.97E+06	2.06E+06	3.43	3.69	3.20	1.06
Peelable coatings (walls)	2.43E+04	1.52E+04	1.22E+04	2.05E+04	1.38E+04	9.58E+03	0.84	0.91	0.79	0.26
High pressure hosing walls (walls)	4.86E+05	3.04E+05	2.43E+05	1.72E+07	1.15E+07	8.01E+06	35.27	37.93	32.93	10.87
Vacuum cleaning interior surfaces (internal surfaces)	2.36E+02	1.48E+02	1.18E+02	1.05E+04	7.49E+03	5.39E+03	44.53	50.80	45.70	46.49
Washing interior surfaces (internal surfaces)	7.08E+01	4.43E+01	3.54E+01	1.21E+06	8.60E+05	6.19E+05	17028.89	19427.00	17477.76	17800.00
High pressure hosing roofs (roof)	3.84E+05	2.40E+05	1.92E+05	6.04E+05	4.31E+05	3.10E+05	1.57	1.80	1.62	1.32
Firehosing roofs (roof)	9.60E+05	6.00E+05	4.80E+05	6.03E+05	4.30E+05	3.09E+05	0.63	0.72	0.64	0.53
Peelable coatings (roof)	1.92E+04	1.20E+04	9.60E+03	5.88E+03	4.19E+03	3.02E+03	0.31	0.35	0.31	0.26
Roof cleaning with pressurised hot water (roof)	3.84E+03	2.40E+03	1.92E+03	4.91E+06	3.50E+06	2.52E+06	1279.14	1459.27	1312.86	1086.50
Manual topsoil and turf removal and soil replacement and reseed-small scale (soil)	6.66E+06	5.18E+06	2.96E+06	4.61E+06	4.46E+06	2.46E+06	0.69	0.86	0.83	1.39
Mechanical topsoil and turf or plant removal (soil)	6.66E+06	5.18E+06	2.96E+06	4.19E+06	4.05E+06	2.24E+06	0.63	0.78	0.76	1.27
Road surface removal (road)	1.56E+06	1.21E+06	6.91E+05	7.13E+05	1.04E+06	7.52E+05	0.46	0.86	1.09	1.08
Firehosing paved (road)	1.30E+06	1.01E+06	5.76E+05	2.94E+05	4.29E+05	3.10E+05	0.23	0.43	0.54	0.53
Vacuum sweeping paved (road)	5.18E+03	4.03E+03	2.30E+03	1.13E+04	1.65E+04	1.19E+04	2.18	4.09	5.17	5.00
Peelable coatings (road)	2.59E+04	2.02E+04	1.15E+04	2.86E+03	4.19E+03	3.02E+03	0.11	0.21	0.26	0.26
High pressure hosing paved (road)	5.18E+05	4.03E+05	2.30E+05	5.23E+05	7.64E+05	5.52E+05	1.01	1.89	2.40	2.38
Concrete paving stone removal-small scale (pavement)	1.56E+06	1.21E+06	6.91E+05	1.02E+04	8.03E+03	5.91E+03	0.01	0.01	0.01	0.02

^a Equivalent to the column "WEST/ERMIN" in Table 2

Table A2 Waste quantity for detached prefabricated house. The surface area ratio assumed for ERMIN is the high paved case in Table 5.

Waste quantity (kg)	ERMIN			WEST			WEST/ERMIN			Ratio of waste rate ^a
	Zone 1	Zone 2	Zone 3	Zone 1	Zone 2	Zone 3	Zone 1	Zone 2	Zone 3	
Firehosing walls (walls)	1.22E+06	7.60E+05	6.08E+05	2.11E+06	1.42E+06	9.83E+05	1.73	1.86	1.62	0.53
Sandblasting walls (walls)	1.29E+06	8.06E+05	6.44E+05	4.42E+06	2.97E+06	2.06E+06	3.43	3.69	3.20	1.06
Peelable coatings (walls)	2.43E+04	1.52E+04	1.22E+04	2.05E+04	1.38E+04	9.58E+03	0.84	0.91	0.79	0.26
High pressure hosing walls (walls)	4.86E+05	3.04E+05	2.43E+05	1.72E+07	1.15E+07	8.01E+06	35.27	37.93	32.93	10.87
Vacuum cleaning interior surfaces (internal surfaces)	2.36E+02	1.48E+02	1.18E+02	1.05E+04	7.49E+03	5.39E+03	44.53	50.80	45.70	46.49
Washing interior surfaces (internal surfaces)	7.08E+01	4.43E+01	3.54E+01	1.21E+06	8.60E+05	6.19E+05	17028.89	19427.00	17477.76	17800.00
High pressure hosing roofs (roof)	3.84E+05	2.40E+05	1.92E+05	6.04E+05	4.31E+05	3.10E+05	1.57	1.80	1.62	1.32
Firehosing roofs (roof)	9.60E+05	6.00E+05	4.80E+05	6.03E+05	4.30E+05	3.09E+05	0.63	0.72	0.64	0.53
Peelable coatings (roof)	1.92E+04	1.20E+04	9.60E+03	5.88E+03	4.19E+03	3.02E+03	0.31	0.35	0.31	0.26
Roof cleaning with pressurised hot water (roof)	3.84E+03	2.40E+03	1.92E+03	4.91E+06	3.50E+06	2.52E+06	1279.14	1459.27	1312.86	1086.50
Manual topsoil and turf removal and soil replacement and reseed-small scale (soil)	5.62E+06	4.37E+06	2.50E+06	3.82E+06	3.83E+06	2.00E+06	0.68	0.88	0.80	1.39
Mechanical topsoil and turf or plant removal (soil)	5.62E+06	4.37E+06	2.50E+06	3.47E+06	3.49E+06	1.82E+06	0.62	0.80	0.73	1.27
Road surface removal (road)	2.33E+06	1.82E+06	1.04E+06	1.02E+06	1.28E+06	8.85E+05	0.44	0.71	0.85	1.08
Firehosing paved (road)	1.94E+06	1.51E+06	8.64E+05	4.20E+05	5.29E+05	3.65E+05	0.22	0.35	0.42	0.53
Vacuum sweeping paved (road)	7.78E+03	6.05E+03	3.46E+03	1.61E+04	2.03E+04	1.40E+04	2.07	3.35	4.05	5.00
Peelable coatings (road)	3.89E+04	3.03E+04	1.73E+04	4.09E+03	5.15E+03	3.56E+03	0.11	0.17	0.21	0.26
High pressure hosing paved (road)	7.78E+05	6.05E+05	3.46E+05	7.47E+05	9.41E+05	6.49E+05	0.96	1.55	1.88	2.38
Concrete paving stone removal-small scale (pavement)	2.33E+06	1.82E+06	1.04E+06	2.04E+04	1.87E+04	1.18E+04	0.01	0.01	0.01	0.02

^a Equivalent to the column "WEST/ERMIN" in Table 2

Table A3 Waste quantity for detached prefabricated house. The surface area ratio assumed for ERMIN is the low paved case in Table 5.

Waste quantity (kg)	ERMIN			WEST			WEST/ERMIN			Ratio of waste rate ^a
	Zone 1	Zone 2	Zone 3	Zone 1	Zone 2	Zone 3	Zone 1	Zone 2	Zone 3	
Firehosing walls (walls)	1.22E+06	7.60E+05	6.08E+05	2.11E+06	1.42E+06	9.83E+05	1.73	1.86	1.62	0.53
Sandblasting walls (walls)	1.29E+06	8.06E+05	6.44E+05	4.42E+06	2.97E+06	2.06E+06	3.43	3.69	3.20	1.06
Peelable coatings (walls)	2.43E+04	1.52E+04	1.22E+04	2.05E+04	1.38E+04	9.58E+03	0.84	0.91	0.79	0.26
High pressure hosing walls (walls)	4.86E+05	3.04E+05	2.43E+05	1.72E+07	1.15E+07	8.01E+06	35.27	37.93	32.93	10.87
Vacuum cleaning interior surfaces (internal surfaces)	2.36E+02	1.48E+02	1.18E+02	1.05E+04	7.49E+03	5.39E+03	44.53	50.80	45.70	46.49
Washing interior surfaces (internal surfaces)	7.08E+01	4.43E+01	3.54E+01	1.21E+06	8.60E+05	6.19E+05	17028.89	19427.00	17477.76	17800.00
High pressure hosing roofs (roof)	3.84E+05	2.40E+05	1.92E+05	6.04E+05	4.31E+05	3.10E+05	1.57	1.80	1.62	1.32
Firehosing roofs (roof)	9.60E+05	6.00E+05	4.80E+05	6.03E+05	4.30E+05	3.09E+05	0.63	0.72	0.64	0.53
Peelable coatings (roof)	1.92E+04	1.20E+04	9.60E+03	5.88E+03	4.19E+03	3.02E+03	0.31	0.35	0.31	0.26
Roof cleaning with pressurised hot water (roof)	3.84E+03	2.40E+03	1.92E+03	4.91E+06	3.50E+06	2.52E+06	1279.14	1459.27	1312.86	1086.50
Manual topsoil and turf removal and soil replacement and reseed-small scale (soil)	7.71E+06	6.00E+06	3.43E+06	5.40E+06	5.18E+06	2.86E+06	0.70	0.86	0.83	1.39
Mechanical topsoil and turf or plant removal (soil)	7.71E+06	6.00E+06	3.43E+06	4.91E+06	4.71E+06	2.60E+06	0.64	0.79	0.76	1.27
Road surface removal (road)	7.78E+05	6.05E+05	3.46E+05	3.06E+05	5.61E+05	3.98E+05	0.39	0.93	1.15	1.08
Firehosing paved (road)	6.48E+05	5.04E+05	2.88E+05	1.26E+05	2.31E+05	1.64E+05	0.19	0.46	0.57	0.53
Vacuum sweeping paved (road)	2.59E+03	2.02E+03	1.15E+03	4.83E+03	8.88E+03	6.30E+03	1.87	4.40	5.47	5.00
Peelable coatings (road)	1.30E+04	1.01E+04	5.76E+03	1.23E+03	2.25E+03	1.60E+03	0.09	0.22	0.28	0.26
High pressure hosing paved (road)	2.59E+05	2.02E+05	1.15E+05	2.24E+05	4.12E+05	2.92E+05	0.86	2.04	2.54	2.38
Concrete paving stone removal-small scale (pavement)	7.78E+05	6.05E+05	3.46E+05	3.40E+03	5.35E+03	5.91E+03	0.00	0.01	0.02	0.02

^a Equivalent to the column "WEST/ERMIN" in Table 2

Table A4 Waste quantity for semi-detached house. The surface area ratio assumed for ERMIN is the default case in Table 6.

Waste quantity (kg)	ERMIN			WEST			WEST/ERMIN			Ratio of waste rate ^a
	Zone 1	Zone 2	Zone 3	Zone 1	Zone 2	Zone 3	Zone 1	Zone 2	Zone 3	
Firehosing walls (walls)	5.26E+06	3.29E+06	2.63E+06	2.11E+06	1.42E+06	9.83E+05	0.40	0.43	0.37	0.53
Sandblasting walls (walls)	5.57E+06	3.48E+06	2.79E+06	4.42E+06	2.97E+06	2.06E+06	0.79	0.85	0.74	1.06
Peelable coatings (walls)	1.05E+05	6.57E+04	5.26E+04	2.05E+04	1.38E+04	9.58E+03	0.20	0.21	0.18	0.26
High pressure hosing walls (walls)	2.10E+06	1.31E+06	1.05E+06	1.72E+07	1.15E+07	8.01E+06	8.16	8.78	7.62	10.87
Vacuum cleaning interior surfaces (internal surfaces)	5.86E+02	3.66E+02	2.93E+02	1.05E+04	7.49E+03	5.39E+03	17.95	20.47	18.42	46.49
Washing interior surfaces (internal surfaces)	1.76E+02	1.10E+02	8.78E+01	1.21E+06	8.60E+05	6.19E+05	6862.74	7829.19	7043.63	17800.00
High pressure hosing roofs (roof)	1.27E+06	7.96E+05	6.37E+05	6.04E+05	4.31E+05	3.10E+05	0.47	0.54	0.49	1.32
Firehosing roofs (roof)	3.18E+06	1.99E+06	1.59E+06	6.03E+05	4.30E+05	3.09E+05	0.19	0.22	0.19	0.53
Peelable coatings (roof)	6.37E+04	3.98E+04	3.18E+04	5.88E+03	4.19E+03	3.02E+03	0.09	0.11	0.09	0.26
Roof cleaning with pressurised hot water (roof)	1.27E+04	7.96E+03	6.37E+03	4.91E+06	3.50E+06	2.52E+06	385.67	439.98	395.84	1086.50
Manual topsoil and turf removal and soil replacement and reseed-small scale (soil)	2.72E+06	2.12E+06	1.21E+06	2.63E+06	2.80E+06	1.32E+06	0.97	1.32	1.09	1.39
Mechanical topsoil and turf or plant removal (soil)	2.72E+06	2.12E+06	1.21E+06	2.39E+06	2.54E+06	1.20E+06	0.88	1.20	0.99	1.27
Road surface removal (road)	1.43E+06	1.11E+06	6.34E+05	7.13E+05	1.04E+06	7.52E+05	0.50	0.94	1.19	1.08
Firehosing paved (road)	1.19E+06	9.24E+05	5.28E+05	2.94E+05	4.29E+05	3.10E+05	0.25	0.46	0.59	0.53
Vacuum sweeping paved (road)	4.75E+03	3.70E+03	2.11E+03	1.13E+04	1.65E+04	1.19E+04	2.37	4.46	5.64	5.00
Peelable coatings (road)	2.38E+04	1.85E+04	1.06E+04	2.86E+03	4.19E+03	3.02E+03	0.12	0.23	0.29	0.26
High pressure hosing paved (road)	4.75E+05	3.70E+05	2.11E+05	5.23E+05	7.64E+05	5.52E+05	1.10	2.07	2.61	2.38
Concrete paving stone removal-small scale (pavement)	4.79E+06	3.73E+06	2.13E+06	6.12E+04	5.35E+04	3.40E+04	0.01	0.01	0.02	0.02

^a Equivalent to the column "WEST/ERMIN" in Table 2

Table A5 Waste quantity for semi-detached house. The surface area ratio assumed for ERMIN is the high paved case in Table 6.

Waste quantity (kg)	ERMIN			WEST			WEST/ERMIN			Ratio of waste rate
	Zone 1	Zone 2	Zone 3	Zone 1	Zone 2	Zone 3	Zone 1	Zone 2	Zone 3	
Firehosing walls (walls)	5.26E+06	3.29E+06	2.63E+06	2.11E+06	1.42E+06	9.83E+05	0.40	0.43	0.37	0.53
Sandblasting walls (walls)	5.57E+06	3.48E+06	2.79E+06	4.42E+06	2.97E+06	2.06E+06	0.79	0.85	0.74	1.06
Peelable coatings (walls)	1.05E+05	6.57E+04	5.26E+04	2.05E+04	1.38E+04	9.58E+03	0.20	0.21	0.18	0.26
High pressure hosing walls (walls)	2.10E+06	1.31E+06	1.05E+06	1.72E+07	1.15E+07	8.01E+06	8.16	8.78	7.62	10.87
Vacuum cleaning interior surfaces (internal surfaces)	5.86E+02	3.66E+02	2.93E+02	1.05E+04	7.49E+03	5.39E+03	17.95	20.47	18.42	46.49
Washing interior surfaces (internal surfaces)	1.76E+02	1.10E+02	8.78E+01	1.21E+06	8.60E+05	6.19E+05	6862.74	7829.19	7043.63	17800.00
High pressure hosing roofs (roof)	1.27E+06	7.96E+05	6.37E+05	6.04E+05	4.31E+05	3.10E+05	0.47	0.54	0.49	1.32
Firehosing roofs (roof)	3.18E+06	1.99E+06	1.59E+06	6.03E+05	4.30E+05	3.09E+05	0.19	0.22	0.19	0.53
Peelable coatings (roof)	6.37E+04	3.98E+04	3.18E+04	5.88E+03	4.19E+03	3.02E+03	0.09	0.11	0.09	0.26
Roof cleaning with pressurised hot water (roof)	1.27E+04	7.96E+03	6.37E+03	4.91E+06	3.50E+06	2.52E+06	385.67	439.98	395.84	1086.50
Manual topsoil and turf removal and soil replacement and reseed-small scale (soil)	9.93E+05	7.73E+05	4.42E+05	1.45E+06	1.76E+06	6.87E+05	1.46	2.28	1.55	1.39
Mechanical topsoil and turf or plant removal (soil)	9.93E+05	7.73E+05	4.42E+05	1.32E+06	1.60E+06	6.24E+05	1.33	2.07	1.41	1.27
Road surface removal (road)	2.15E+06	1.67E+06	9.55E+05	1.02E+06	1.28E+06	8.85E+05	0.47	0.77	0.93	1.08
Firehosing paved (road)	1.79E+06	1.39E+06	7.96E+05	4.20E+05	5.29E+05	3.65E+05	0.23	0.38	0.46	0.53
Vacuum sweeping paved (road)	7.16E+03	5.57E+03	3.18E+03	1.61E+04	2.03E+04	1.40E+04	2.25	3.64	4.40	5.00
Peelable coatings (road)	3.58E+04	2.79E+04	1.59E+04	4.09E+03	5.15E+03	3.56E+03	0.11	0.18	0.22	0.26
High pressure hosing paved (road)	7.16E+05	5.57E+05	3.18E+05	7.47E+05	9.41E+05	6.49E+05	1.04	1.69	2.04	2.38
Concrete paving stone removal-small scale (pavement)	7.19E+06	5.60E+06	3.20E+06	8.16E+04	6.96E+04	4.58E+04	0.01	0.01	0.01	0.02

Table A6 Waste quantity for semi-detached house. The surface area ratio assumed for ERMIN is the low paved case in Table 6.

Waste quantity (kg)	ERMIN			WEST			WEST/ERMIN			Ratio of waste rate
	Zone 1	Zone 2	Zone 3	Zone 1	Zone 2	Zone 3	Zone 1	Zone 2	Zone 3	
Firehosing walls (walls)	5.26E+06	3.29E+06	2.63E+06	2.11E+06	1.42E+06	9.83E+05	0.40	0.43	0.37	0.53
Sandblasting walls (walls)	5.57E+06	3.48E+06	2.79E+06	4.42E+06	2.97E+06	2.06E+06	0.79	0.85	0.74	1.06
Peelable coatings (walls)	1.05E+05	6.57E+04	5.26E+04	2.05E+04	1.38E+04	9.58E+03	0.20	0.21	0.18	0.26
High pressure hosing walls (walls)	2.10E+06	1.31E+06	1.05E+06	1.72E+07	1.15E+07	8.01E+06	8.16	8.78	7.62	10.87
Vacuum cleaning interior surfaces (internal surfaces)	5.86E+02	3.66E+02	2.93E+02	1.05E+04	7.49E+03	5.39E+03	17.95	20.47	18.42	46.49
Washing interior surfaces (internal surfaces)	1.76E+02	1.10E+02	8.78E+01	1.21E+06	8.60E+05	6.19E+05	6862.74	7829.19	7043.63	17800.00
High pressure hosing roofs (roof)	1.27E+06	7.96E+05	6.37E+05	6.04E+05	4.31E+05	3.10E+05	0.47	0.54	0.49	1.32
Firehosing roofs (roof)	3.18E+06	1.99E+06	1.59E+06	6.03E+05	4.30E+05	3.09E+05	0.19	0.22	0.19	0.53
Peelable coatings (roof)	6.37E+04	3.98E+04	3.18E+04	5.88E+03	4.19E+03	3.02E+03	0.09	0.11	0.09	0.26
Roof cleaning with pressurised hot water (roof)	1.27E+04	7.96E+03	6.37E+03	4.91E+06	3.50E+06	2.52E+06	385.67	439.98	395.84	1086.50
Manual topsoil and turf removal and soil replacement and reseed-small scale (soil)	4.44E+06	3.45E+06	1.97E+06	5.27E+06	4.97E+06	2.75E+06	1.19	1.44	1.39	1.39
Mechanical topsoil and turf or plant removal (soil)	4.44E+06	3.45E+06	1.97E+06	4.79E+06	4.52E+06	2.50E+06	1.08	1.31	1.27	1.27
Road surface removal (road)	7.13E+05	5.55E+05	3.17E+05	2.04E+05	3.21E+05	2.21E+05	0.29	0.58	0.70	1.08
Firehosing paved (road)	5.94E+05	4.62E+05	2.64E+05	8.39E+04	1.32E+05	9.12E+04	0.14	0.29	0.35	0.53
Vacuum sweeping paved (road)	2.38E+03	1.85E+03	1.06E+03	3.22E+03	5.07E+03	3.50E+03	1.36	2.74	3.32	5.00
Peelable coatings (road)	1.19E+04	9.24E+03	5.28E+03	8.18E+02	1.29E+03	8.89E+02	0.07	0.14	0.17	0.26
High pressure hosing paved (road)	2.38E+05	1.85E+05	1.06E+05	1.49E+05	2.35E+05	1.62E+05	0.63	1.27	1.54	2.38
Concrete paving stone removal-small scale (pavement)	2.40E+06	1.87E+06	1.07E+06	1.36E+04	1.87E+04	1.48E+04	0.01	0.01	0.01	0.02

Table A7 Waste activity concentration for detached prefabricated house. The surface area ratio assumed for ERMIN is the default case in Table 5.

	ERMIN			WEST			WEST/ERMIN		
	Zone 1	Zone 2	Zone 3	Zone 1	Zone 2	Zone 3	Zone 1	Zone 2	Zone 3
Waste activity concentration (Bq kg ⁻¹)									
Firehosing walls (walls)	1.38E+05	1.38E+03	1.38E+01	5.12E+05	5.12E+03	5.12E+01	3.71	3.71	3.71
Sandblasting walls (walls)	4.24E+05	4.24E+03	4.24E+01	5.06E+05	5.06E+03	5.06E+01	1.20	1.20	1.20
Peelable coatings (walls)	2.00E+07	2.00E+05	2.00E+03	6.36E+07	6.36E+05	6.36E+03	3.19	3.19	3.19
High pressure hosing walls (walls)	6.41E+05	6.41E+03	6.41E+01	4.89E+04	4.89E+02	4.89E+00	0.08	0.08	0.08
Vacuum cleaning interior surfaces (internal surfaces)	4.85E+10	4.85E+08	4.85E+06	3.01E+09	3.01E+07	3.01E+05	0.06	0.06	0.06
Washing interior surfaces (internal surfaces)	1.36E+11	1.36E+09	1.36E+07	1.66E+07	1.66E+05	1.66E+03	<0.005	<0.005	<0.005
High pressure hosing roofs (roof)	1.49E+07	1.49E+05	1.49E+03	1.18E+07	1.18E+05	1.18E+03	0.79	0.79	0.79
Firehosing roofs (roof)	3.21E+06	3.21E+04	3.21E+02	1.21E+07	1.21E+05	1.21E+03	3.77	3.77	3.77
Peelable coatings (roof)	4.64E+08	4.64E+06	4.64E+04	1.50E+09	1.50E+07	1.50E+05	3.24	3.24	3.24
Roof cleaning with pressurised hot water (roof)	1.74E+09	1.74E+07	1.74E+05	1.16E+06	1.16E+04	1.16E+02	<0.005	<0.005	<0.005
Manual topsoil and turf removal and soil replacement and reseed-small scale (soil)	1.81E+07	1.81E+05	1.81E+03	5.95E+06	5.95E+04	5.95E+02	0.33	0.33	0.33
Mechanical topsoil and turf or plant removal (soil)	1.91E+07	1.91E+05	1.91E+03	5.89E+06	5.89E+04	5.89E+02	0.31	0.31	0.31
Road surface removal (road)	3.56E+06	3.56E+04	3.56E+02	3.00E+06	3.00E+04	3.00E+02	0.84	0.84	0.84
Firehosing paved (road)	2.44E+06	2.44E+04	2.44E+02	4.16E+06	4.16E+04	4.16E+02	1.70	1.70	1.70
Vacuum sweeping paved (road)	7.32E+08	7.32E+06	7.32E+04	5.86E+07	5.86E+05	5.86E+03	0.08	0.08	0.08
Peelable coatings (road)	1.63E+08	1.63E+06	1.63E+04	5.16E+08	5.16E+06	5.16E+04	3.18	3.18	3.18
High pressure hosing paved (road)	9.14E+06	9.14E+04	9.14E+02	3.41E+06	3.41E+04	3.41E+02	0.37	0.37	0.37
Concrete paving stone removal-small scale (pavement)	1.76E+06	1.76E+04	1.76E+02	7.77E+07	7.77E+05	7.77E+03	44.08	44.08	44.08

Table A8 Waste activity for detached prefabricated house. The surface area ratio assumed for ERMIN is the default case in Table 5.

Waste activity (Bq)	ERMIN			WEST			WEST/ERMIN		
	Zone 1	Zone 2	Zone 3	Zone 1	Zone 2	Zone 3	Zone 1	Zone 2	Zone 3
Firehosing walls (walls)	1.68E+11	1.05E+09	8.39E+06	1.08E+12	7.27E+09	5.03E+07	6.42	6.93	6.00
Sandblasting walls (walls)	5.47E+11	3.42E+09	2.73E+07	2.24E+12	1.50E+10	1.04E+08	4.09	4.40	3.82
Peelable coatings (walls)	4.86E+11	3.04E+09	2.44E+07	1.30E+12	8.78E+09	6.09E+07	2.68	2.89	2.50
High pressure hosing walls (walls)	3.12E+11	1.95E+09	1.56E+07	8.41E+11	5.62E+09	3.92E+07	2.70	2.89	2.51
Vacuum cleaning interior surfaces (internal surfaces)	1.14E+13	7.18E+10	5.72E+08	3.16E+13	2.25E+11	1.62E+09	2.76	3.14	2.83
Washing interior surfaces (internal surfaces)	9.63E+12	6.02E+10	4.81E+08	2.01E+13	1.43E+11	1.03E+09	2.09	2.37	2.13
High pressure hosing roofs (roof)	5.72E+12	3.58E+10	2.86E+08	7.13E+12	5.09E+10	3.66E+08	1.25	1.42	1.28
Firehosing roofs (roof)	3.08E+12	1.93E+10	1.54E+08	7.30E+12	5.20E+10	3.74E+08	2.37	2.70	2.43
Peelable coatings (roof)	8.91E+12	5.57E+10	4.45E+08	8.82E+12	6.29E+10	4.53E+08	0.99	1.13	1.02
Roof cleaning with pressurised hot water (roof)	6.68E+12	4.18E+10	3.34E+08	5.70E+12	4.06E+10	2.92E+08	0.85	0.97	0.88
Manual topsoil and turf removal and soil replacement and reseed-small scale (soil)	1.21E+14	9.38E+11	5.36E+09	2.74E+13	2.65E+11	1.46E+09	0.23	0.28	0.27
Mechanical topsoil and turf or plant removal (soil)	1.27E+14	9.89E+11	5.65E+09	2.47E+13	2.39E+11	1.32E+09	0.19	0.24	0.23
Road surface removal (road)	5.55E+12	4.31E+10	2.46E+08	2.14E+12	3.12E+10	2.26E+08	0.39	0.72	0.92
Firehosing paved (road)	3.17E+12	2.46E+10	1.41E+08	1.22E+12	1.78E+10	1.29E+08	0.39	0.72	0.92
Vacuum sweeping paved (road)	3.79E+12	2.95E+10	1.68E+08	6.62E+11	9.67E+09	6.97E+07	0.17	0.33	0.41
Peelable coatings (road)	4.22E+12	3.29E+10	1.87E+08	1.48E+12	2.16E+10	1.56E+08	0.35	0.66	0.83
High pressure hosing paved (road)	4.73E+12	3.68E+10	2.10E+08	1.78E+12	2.61E+10	1.88E+08	0.38	0.71	0.90
Concrete paving stone removal-small scale (pavement)	2.75E+12	2.13E+10	1.22E+08	7.93E+11	6.24E+09	4.59E+07	0.29	0.29	0.38

Table A9 Waste activity for semi-detached house The surface area ratio assumed for ERMIN is the default case in Table 6.

Waste activity (Bq)	ERMIN			WEST			WEST/ERMIN		
	Zone 1	Zone 2	Zone 3	Zone 1	Zone 2	Zone 3	Zone 1	Zone 2	Zone 3
Firehosing walls (walls)	7.26E+11	4.54E+09	3.63E+07	1.08E+12	7.27E+09	5.03E+07	1.49	1.60	1.39
Sandblasting walls (walls)	2.36E+12	1.48E+10	1.18E+08	2.24E+12	1.50E+10	1.04E+08	0.95	1.02	0.88
Peelable coatings (walls)	2.10E+12	1.31E+10	1.05E+08	1.30E+12	8.78E+09	6.09E+07	0.62	0.67	0.58
High pressure hosing walls (walls)	1.35E+12	8.40E+09	6.73E+07	8.41E+11	5.62E+09	3.92E+07	0.62	0.67	0.58
Vacuum cleaning interior surfaces (internal surfaces)	2.84E+13	1.78E+11	1.42E+09	3.16E+13	2.25E+11	1.62E+09	1.11	1.27	1.14
Washing interior surfaces (internal surfaces)	2.39E+13	1.50E+11	1.19E+09	2.01E+13	1.43E+11	1.03E+09	0.84	0.95	0.86
High pressure hosing roofs (roof)	1.89E+13	1.19E+11	9.49E+08	7.13E+12	5.09E+10	3.66E+08	0.38	0.43	0.39
Firehosing roofs (roof)	1.02E+13	6.39E+10	5.10E+08	7.30E+12	5.20E+10	3.74E+08	0.71	0.81	0.73
Peelable coatings (roof)	2.96E+13	1.85E+11	1.48E+09	8.82E+12	6.29E+10	4.53E+08	0.30	0.34	0.31
Roof cleaning with pressurised hot water (roof)	2.21E+13	1.39E+11	1.11E+09	5.70E+12	4.06E+10	2.92E+08	0.26	0.29	0.26
Manual topsoil and turf removal and soil replacement and reseed-small scale (soil)	4.92E+13	3.84E+11	2.19E+09	1.56E+13	1.67E+11	7.85E+08	0.32	0.43	0.36
Mechanical topsoil and turf or plant removal (soil)	5.20E+13	4.05E+11	2.31E+09	1.41E+13	1.50E+11	7.07E+08	0.27	0.37	0.31
Road surface removal (road)	5.09E+12	3.95E+10	2.26E+08	2.14E+12	3.12E+10	2.26E+08	0.42	0.79	1.00
Firehosing paved (road)	2.90E+12	2.25E+10	1.29E+08	1.22E+12	1.78E+10	1.29E+08	0.42	0.79	1.00
Vacuum sweeping paved (road)	3.48E+12	2.71E+10	1.54E+08	6.62E+11	9.67E+09	6.97E+07	0.19	0.36	0.45
Peelable coatings (road)	3.88E+12	3.02E+10	1.73E+08	1.48E+12	2.16E+10	1.56E+08	0.38	0.72	0.90
High pressure hosing paved (road)	4.34E+12	3.38E+10	1.93E+08	1.78E+12	2.61E+10	1.88E+08	0.41	0.77	0.98
Concrete paving stone removal-small scale (pavement)	8.43E+12	6.56E+10	3.75E+08	4.76E+12	4.16E+10	2.64E+08	0.56	0.63	0.70

Table A10 Waste quantity ratio normalized by the ratio of waste rate for detached prefabricated house.

Waste quantity ratio / Waste rate ratio	Default			High paved			Low paved		
	Zone 1	Zone 2	Zone 3	Zone 1	Zone 2	Zone 3	Zone 1	Zone 2	Zone 3
	Firehosing walls (walls)	3.25	3.49	3.03	3.25	3.49	3.03	3.25	3.49
Sandblasting walls (walls)	3.25	3.49	3.03	3.25	3.49	3.03	3.25	3.49	3.03
Peelable coatings (walls)	3.25	3.49	3.03	3.25	3.49	3.03	3.25	3.49	3.03
High pressure hosing walls (walls)	3.25	3.49	3.03	3.25	3.49	3.03	3.25	3.49	3.03
Vacuum cleaning interior surfaces (internal surfaces)	0.96	1.09	0.98	0.96	1.09	0.98	0.96	1.09	0.98
Washing interior surfaces (internal surfaces)	0.96	1.09	0.98	0.96	1.09	0.98	0.96	1.09	0.98
High pressure hosing roofs (roof)	1.18	1.34	1.21	1.18	1.34	1.21	1.18	1.34	1.21
Firehosing roofs (roof)	1.18	1.34	1.21	1.18	1.34	1.21	1.18	1.34	1.21
Peelable coatings (roof)	1.18	1.34	1.21	1.18	1.34	1.21	1.18	1.34	1.21
Roof cleaning with pressurised hot water (roof)	1.18	1.34	1.21	1.18	1.34	1.21	1.18	1.34	1.21
Ratio of building coverage ratio (WEST/ERMIN)	1.00	0.91	1.15	1.00	0.91	1.15	1.00	0.91	1.15
Manual topsoil and turf removal and soil replacement and reseed-small scale (soil)	0.50	0.62	0.60	0.49	0.63	0.58	0.50	0.62	0.60
Mechanical topsoil and turf or plant removal (soil)	0.50	0.62	0.60	0.49	0.63	0.58	0.50	0.62	0.60
Ratio of soil area ratio (WEST/ERMIN)	0.51	0.63	0.62	0.50	0.64	0.60	0.52	0.63	0.63
Road surface removal (road)	0.43	0.80	1.01	0.40	0.66	0.79	0.36	0.86	1.07
Firehosing paved (road)	0.42	0.80	1.01	0.40	0.65	0.79	0.36	0.86	1.07
Vacuum sweeping paved (road)	0.44	0.82	1.03	0.41	0.67	0.81	0.37	0.88	1.09
Peelable coatings (road)	0.43	0.80	1.01	0.40	0.66	0.79	0.36	0.86	1.07
High pressure hosing paved (road)	0.42	0.80	1.01	0.40	0.65	0.79	0.36	0.86	1.07
Ratio of asphalt area ratio (WEST/ERMIN)	0.52	0.87	1.15	0.48	0.73	0.95	0.43	0.96	1.21
Concrete paving stone removal-small scale (pavement)	0.36	0.37	0.47	0.49	0.57	0.63	0.24	0.49	0.95
Ratio of concrete area ratio (WEST/ERMIN)	0.42	0.46	0.54	0.56	0.61	0.72	0.37	0.67	1.12

Table A11 Waste quantity ratio normalized by the ratio of waste rate for semi-detached house.

Waste quantity ratio / Waste rate ratio	Default			High paved			Low paved		
	Zone 1	Zone 2	Zone 3	Zone 1	Zone 2	Zone 3	Zone 1	Zone 2	Zone 3
Firehosing walls (walls)	0.75	0.81	0.70	0.75	0.81	0.70	0.75	0.81	0.70
Sandblasting walls (walls)	0.75	0.81	0.70	0.75	0.81	0.70	0.75	0.81	0.70
Peelable coatings (walls)	0.75	0.81	0.70	0.75	0.81	0.70	0.75	0.81	0.70
High pressure hosing walls (walls)	0.75	0.81	0.70	0.75	0.81	0.70	0.75	0.81	0.70
Vacuum cleaning interior surfaces (internal surfaces)	0.39	0.44	0.40	0.39	0.44	0.40	0.39	0.44	0.40
Washing interior surfaces (internal surfaces)	0.39	0.44	0.40	0.39	0.44	0.40	0.39	0.44	0.40
High pressure hosing roofs (roof)	0.35	0.40	0.36	0.35	0.40	0.36	0.35	0.40	0.36
Firehosing roofs (roof)	0.35	0.40	0.36	0.35	0.40	0.36	0.35	0.40	0.36
Peelable coatings (roof)	0.35	0.40	0.36	0.35	0.40	0.36	0.35	0.40	0.36
Roof cleaning with pressurised hot water (roof)	0.35	0.40	0.36	0.35	0.40	0.36	0.35	0.40	0.36
Ratio of building coverage ratio (WEST/ERMIN)	0.34	0.31	0.40	0.34	0.31	0.40	0.34	0.31	0.40
Manual topsoil and turf removal and soil replacement and reseed-small scale (soil)	0.69	0.95	0.78	1.05	1.63	1.12	0.85	1.03	1.00
Mechanical topsoil and turf or plant removal (soil)	0.69	0.95	0.78	1.04	1.63	1.11	0.85	1.03	1.00
Ratio of soil area ratio (WEST/ERMIN)	0.71	0.96	0.83	1.06	1.67	1.13	0.86	1.06	1.06
Road surface removal (road)	0.46	0.87	1.10	0.44	0.71	0.86	0.27	0.54	0.65
Firehosing paved (road)	0.46	0.87	1.10	0.44	0.71	0.86	0.26	0.54	0.65
Vacuum sweeping paved (road)	0.47	0.89	1.13	0.45	0.73	0.88	0.27	0.55	0.66
Peelable coatings (road)	0.46	0.87	1.10	0.44	0.71	0.86	0.27	0.54	0.65
High pressure hosing paved (road)	0.46	0.87	1.10	0.44	0.71	0.86	0.26	0.54	0.65
Ratio of asphalt area ratio (WEST/ERMIN)	0.56	0.95	1.26	0.53	0.80	1.03	0.27	0.56	0.77
Concrete paving stone removal-small scale (pavement)	0.71	0.80	0.89	0.63	0.69	0.80	0.32	0.56	0.77
Ratio of concrete area ratio (WEST/ERMIN)	0.82	0.89	1.05	0.73	0.79	0.93	0.38	0.65	0.86

About the UK Health Security Agency

UKHSA is responsible for protecting every member of every community from the impact of infectious diseases, chemical, biological, radiological and nuclear incidents and other health threats. We provide intellectual, scientific and operational leadership at national and local level, as well as on the global stage, to make the nation health secure.

UKHSA is an executive agency, sponsored by the [Department of Health and Social Care](#).

www.gov.uk/government/organisations/uk-health-security-agency

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For queries relating to this document, please contact: Tom.Charnock@ukhsa.gov.uk

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UKHSA supports the Sustainable Development Goals



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