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Environmental Programs Directorate

Standard Operating Procedure

for **AIR EMISSIONS FROM ENVIRONMENTAL FIRES**

APPROVAL SIGNATURES:

Subject Matter Expert:	**Organization**	**Signature**	**Date**
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1.0 PURPOSE AND SCOPE

This procedure describes the process for estimating airborne emissions from environmental fires, for example in the case of a controlled burn, a wildfire, or the re-suspension of ash or dust from contaminated soil.

This procedure integrates the criteria of the Quality Assurance Plan for the Environmental Programs, hereinafter referred to as the Quality Assurance Plan.

WES-EDA personnel may implement this procedure when estimating airborne releases from a controlled burn, a wildfire, re-suspension of ash or dust from contaminated soil, or other airborne releases from the environment.

2.0 OVERVIEW

2.1 Introduction

There are well established techniques for calculating airborne releases from operational facilities; for example, see ENV-EAQ-RN http://int.lanl.gov/orgs/env/eaq/docs/qa/EAQ-RN-R4.pdf and supporting procedures. Generally, these techniques involve the use of standard computer models such as CAP88, Hotspot, NARAC, etc. These models require a source term, which is the amount or rate of release, typically in curies, or in curies per year.

However, for releases from environmental fires, ash, or dust, there is no readily available source term. This procedure provides techniques and tools for such cases.

The techniques described here are essentially the same as those used in the RESRAD family of codes. The basic method is illustrated by the mass-loading calculation. In RESRAD, the default mass loading of particulates in air is 0.0001 g/m^3 (1E-4 g/m^3). If the airborne particulates come from material with a concentration of 1 pCi/g (for example), the airborne activity is obtained by multiplying the two numbers and combining or canceling the units:

$$(1 \text{ pCi/g})(0.0001 \text{ g/m}^3) = 0.0001 \text{ pCi/m}^3.$$

The material that contributes air particulates may be soil, burning vegetation, or ash. Each of these is discussed below.

2.2 Airborne mass loading (g/m^3)

The mass loading is the mass of solid particulates suspended in the air. Typical data are available from the LANL "Tapered Element Oscillating Microbalance," TEOM, http://newnet.lanl.gov/Teom/teom.asp . The airborne mass loading is usually within an order of magnitude of the RESRAD default value of 0.0001 g/m^3 (100 μg/m^3) as shown in the following table.

Airborne mass loading (g/m^3)	Airborne mass loading (μg/m^3)	Visibility (miles)	Comment
0.00001	10	50	very clear
0.00002	20	25	New Mexico average
0.0001	100	5	hazy; RESRAD default
0.00015	150	3	24-hour PM-10 standard
0.001	1000	0.5	smoke from nearby fires
0.002	2000		London, December 6-8, 1952

On a clear day in New Mexico, it is about 0.00001 g/m^3, which is 0.1 times the RESRAD default. On such a day, the Sangre de Christo mountains are clearly visible from Los Alamos and it may be possible to see Sandia Peak. Visibility is about 50 miles.

The RESRAD-default mass loading of 0.0001 g/m^3 corresponds to hazy or dusty conditions, for example when there are regional fires. In this case, the visibility is about 5 miles.

Ten times the default, 0.001 g/m^3, corresponds to dense smoke from a fire in the immediate vicinity. For example, refer to the TEOM data of May 13, 2000, during the Cerro Grande Fire. In this case, the visibility is about 0.5 miles.

For comparison, the 24-hour National Ambient Air Monitoring Standard for PM10 is 0.00015 g/m^3, slightly higher than the RESRAD default.

As another point of comparison, during the exceptional London smog of December 6-8, 1952, the smoke concentration was 0.002 g/m^3. (If the smoke were the only particulate, the visibility would be 0.25 miles; in this case it was less because the smog included both smoke and fog.)

2.3 Soil concentration (pCi/g)

A fire is often accompanied by strong winds that may cause soil to be re-suspended as dust. Typical values of soil concentrations are listed in Attachment 1. Data should be averaged over a distance of about 100 to 300 m or an area of about 1 to 10 ha.

For example, consider the transuranics in Mortandad Canyon. The average concentrations are taken from the Mortandad Canyon Investigation Report, LA-UR-06-6752, and are listed in the table below. Reaches E1 and M2 are much narrower than 100 m so the concentration in M3 is the most appropriate.For simplicity, you may select the value for transuranics in Attachment 1: 50 pCi/g.

Reach	width (m)	Pu-238 (pCi/g)	Pu-239 (pCi/g)	Am241 (pCi/g)	total (pCi/g)
E1	3	10	34	36	80
M2	10	14	21	21	56
M3	75	8	18	21	47

2.4 Concentration in vegetation (pCi/g)

In the case of a wildfire or a controlled burn, calculate the concentration in the burning vegetation in place of the soil concentration. See Attachment 2. The wet-weight concentration ratios listed in Attachment 2 are used to calculate the wet-weight concentration (pCi/g-wet), which is used in Section 2.9.

For smoke, use the ash-weight concentration (pCi/g-ash), which is typically 30 to 50 times the wet-weight concentration (see Attachment 2.) The ash/wet ratio is essentially the same as the ratio of particulate emissions to the wet-weight of fuel, as documented in the EPA Emission Factors compilation, AP42: http://www.epa.gov/ttn/chief/ap42/ch13/final/c13s01.pdf .

For example, for transuranics, the worst-case transuranic concentration ratio is 1.5E-2 and the wet/ash ratio is about 50, so if the soil concentration is 50 pCi/g the concentration in wet vegetation is:

$$(50 \text{ pCi/g})(1.5\text{E-}2) = 0.75 \text{ pCi/g-wet}$$

and the concentration in ash is

$$(0.75 \text{ pCi/g-wet})(50 \text{ g-wet/g-ash}) = 38 \text{ pCi/g-ash}$$

2.5 Concentration in air (pCi/m^3)

The air concentration in units of pCi/m^3 is calculated by multiplying the concentration of particulate matter in air (g/m^3) by the average concentration in the underlying medium (e.g., soil or vegetation) (pCi/g). for example:

$$(0.0001 \text{ g/m}^3)(1 \text{ pCi/g}) = 0.0001 \text{ pCi/m}^3.$$

2.6 Re-suspension factors

In some applications, the airborne concentration is calculated using a re-suspension factor, *K*, in units of m^{-1}. This method is used in occupational health physics when the surface contamination in a building is measured in units of activity per unit area. However, it is generally better to use the mass-loading method described above. For reference, resuspension factors are compared with the mass loading method in Attachment 3.

2.7 Dose and dose rate (mrem and mrem/h)

Note that airborne concentrations (pCi/m^3) correspond to a dose rates (mrem/h), whereas source terms (pCi) correspond to dose (mrem).

The dose rate may be calculated by comparing the airborne concentration of a radionuclide with tables such as those in 40 CFR 61 Appendix E Table 2, 10 CFR 835, DOE Order 5400.5, or EPA 400R92001. For example, according to 40 CFR 61, a transuranic concentration of 2 fCi/g corresponds to a dose rate of 10 mrem/year. For details, refer to Attachment 4.

2.8 Downwind airborne concentration as a function of distance

The mass-loading methods described above are used to estimate airborne concentrations at the contaminated area. The relative concentration downwind may be calculated by using Hotspot or NARAC. Note that Hotspot and NARAC report dose, which is proportional to both concentration and dose rate. For example, if the downwind dose is 10% of that at the contaminated area, the downwind concentration and dose rate will also be 10% of that at the contaminated area.

Refer to the Attachment 5 for an example.

2.9 Calculating a source term

The calculations described above result in an airborne concentration (pCi/m^3) and correspond to a dose rate (mrem/h). It is not usually necessary to calculate a source term. However, a source term may be calculated as follows.

For resuspension of dust, use the method of RESRAD-Offsite: the re-suspension rate is the product of the airborne concentration, the source area, and the average vertical component of the particulate velocity.

During normal conditions, the average vertical component of the particulate velocity is the re-suspension velocity. As a default value for respirable particulates, use 3E-3 m/s from Hotspot and Napier PNNL-14599 http://www.pnl.gov/main/publications/external/technical_reports/PNNl-14599Rev0.pdf .

(For comparison, CAP88 uses 1.8 mm/s; Resrad-Offsite uses 1 mm/s; Till and Grogan 2008 suggest 1 mm/s. The largest value, 3E-3 m/s, is the most conservative. Non-respirable dust has a larger deposition velocity.)

For example, if the area is 1E4 m^2, the airborne concentration is 1E-4 pCi/m^3, and the re-suspension velocity is 3E-3 m/s, the emission rate is

$$(1E4\ m^2)(1E\text{-}4\ pCi/m^3)(3E\text{-}3\ m/s) = 3E\text{-}3\ pCi/s.$$

If the emissions persist for 1E5 s, the source term is

$$(3E\text{-}3\ pCi/s)(1E5\ s) = 300\ pCi.$$

During a fire, the vertical particulate velocity is the updraft velocity, which can be as high as 60 m/s http://box.mmm.ucar.edu/asr97/coupled_atmosphere_fire.html . However, velocities on the order of 10 m/s are more typical.

For a wildfire, you may multiply the wet-weight concentration by the mass of (wet) vegetation per unit area and the area of the fire to calculate a source term (see example in Attachment 6.) The concentration ratios of radionuclides in biota to those in soil may be obtained from RESRAD-BIOTA and Attachment 2.

Alternatively, you may use the ash-weight concentration and the RESRAD-Offsite method, as in the example of Attachment 6.

2.10 Chemicals

The same techniques may be used to calculate chemical concentrations. To do so, substitute milligrams (mg) of contaminant for pCi of radioactive material. The resulting airborne concentrations may be compared with TEEL, ERPG, or AEGL values. Note: 1 $mg/m^3 \approx$ 1 mg/kg of air $\approx$ 1 ppm by mass.

3.0 EQUIPMENT AND TOOLS

None

4.0 STEP-BY-STEP PROCESS DESCRIPTION

4.1		
WES-EDA personnel	1.	Estimate the average concentration of contamination in the underlying material such as soil, vegetation, or ash. Typical units are pCi/g. See Attachments 1and 2.
	2.	Estimate the average concentration of particulates in air (g/m^3.) Begin with the RESRAD-default value of 0.0001 g/m^3 and increase or decrease it by up to a factor of 10 as discussed in Section 2.2.
	3.	Multiply the results of items 1 and 2 and combine or cancel the units to obtain the concentration in air (typically pCi/m^3.)
	4.	Estimate the dose rate (mrem/h) at the contaminated area by comparing with the concentrations in EPA 400R92001 or other tables, see Attachment 4.
4.2 Records Management		
WES-EDA personnel	1.	Maintain and submit records and/or documents according to the Records Processing Facility, EP-DIR-SOP-4004, Records Transmittal and Retrieval Process and as required by the Emergency Operations Center.

5.0 DEFINITIONS

N/A.

6.0 PROCESS FLOW CHART

N/A.

7.0 ATTACHMENTS

Attachment 1 Typical Soil Concentrations

Attachment 2 Typical Vegetation Concentration Ratios

Attachment 3 Resuspension

Attachment 4 Converting Concentration to Dose Rate

Attachment 5 Use of Hotspot for Downwind Concentration and Dose

Attachment 6 Example

8.0 REVISION HISTORY

Revision No. *[Enter current revision number, beginning with Rev.0]*	Effective Date *[DCC inserts effective date for revision]*	Description of Changes *[List specific changes made since the previous revision]*	Type of Change *[Technical (T) or Editorial (E)]*
0	5/19/2009	New procedure.	E

ATTACHMENT 1	
SOP-5242-1 **TYPICAL SOIL CONCENTRATIONS**	Records Use only Los Alamos NATIONAL LABORATORY EST. 1943

If specific data are readily available, average the data over a distance of about 100 m or more, or an area of about 3 ha. If data are not readily available, use the following data as guidance to the worst case surface-soil contamination; note that these cases represent < 1% of the total area of LANL.

Typical Background

Nuclide	**Concentrations**
U-238 and decay products	1-3 pCi/g for each decay product
Th-232 and decay products	1-3 pCi/g for each decay product
K-40	10-30 pCi/g
transuranics	0.01 to 0.03 pCi/g
tritium	1 pCi/mL
Cs-137	1 pCi/g
Sr-90	1 pCi/g

The following tables only list the nuclides that are significantly above the typical backgound listed above.

Mortandad Canyon surface soil (Reach M3)

Nuclide	**Concentrations**
transuranics	50 pCi/g
Cs-137	70 pCi/g
Sr-90	4 pCi/g

TA-10 surface soil

Nuclide	**Concentrations**
U-238	10 pCi/g
Sr-90	10 pCi/g

TA-15 surface soil (EF Site)

Nuclide	**Concentrations**
U-234	100 pCi/g
U-238	300 pCi/g

TA-21 surface soil (MDA T)

Nuclide	Concentrations
transuranics	400 pCi/g
Cs-137	60 pCi/g
Sr-90	15 pCi/g

TA-35 surface soil (Pratt Canyon)

Nuclide	Concentrations
Sr-90	100 pCi/g

TA-49 surface soil (Area AB)

Nuclide	Concentrations
transuranics	10 pCi/g

TA-54 surface soil (Area G)

Nuclide	Concentrations
transuranics	3 pCi/g
tritium	10,000 pCi/mL

REFERENCES

LA-UR-05-4699: "Biota Dose Assessment at LANL," M McNaughton (2005)
http://www.lanl.gov/environment/compliance/docs/LA-UR-05-4699.pdf

LA-UR-0802947: "Notes on the Mortandad Canyon Biota Dose Assessment," M McNaughton (2007)
http://www.lanl.gov/environment/compliance/docs/LA-UR-08-2947.pdf

ATTACHMENT 2

SOP-5242-2

TYPICAL VEGETATION CONCENTRATION RATIOS

Records Use only

Los Alamos NATIONAL LABORATORY EST.1943

The 95% upper limit concentrations of uranium and the transuranics in vegetation can be calculated using the wet-weight concentration ratios in RESRAD-Biota as follows. (In RESRAD-Biota, these are called B_{iv}, which means the bioaccumulation factor for the i^{th} element in vegetation.)

Element	Wet-weight concentration ratio
Americium	8E-3
Plutonium	1.5E-2
Uranium	4E-3

For cesium and strontium, use the wet-weight concentration ratios in LA-14284 and LA-UR-08-2783, which are as follows.

Element	Wet-weight concentration ratio
cesium	0.01 to 0.06
strontium	0.1 to 0.5

To calculate dry-weight and ash concentrations, use the ratios in LA-UR-07-0280, which are as follows.

Material	Dry/Wet	Ash/Dry	Ash/Wet	Wet/Ash
Undertory	0.32	0.10	0.032	30
Overstory	0.45	0.050	0.023	45
Chamisa	0.59	0.033	0.020	50

References

LA-14284: "Concentration Ratios for Cesium and Strontium in Produce near Los Alamos," S. Salazar, M. McNaughton, P.R. Fresquez (2006) http://www.osti.gov/bridge/servlets/purl/881275-5L3oK8/881275.pdf

LA-UR-07-0280: "Moisture Conversion Ratios for the Foodstuffs and Nonfoodstuffs Biota Environmental Surveillance Programs at LANL," PR Fresquez, JK Ferenbaugh, L Naranjo (2007).

LA-UR-08-2783: "Site Representative Biota concentration Guides at Los Alamos," Mike McNaughton, Phil Fresquez, Bill Eisele (2008) http://www.lanl.gov/environment/compliance/docs/LA-UR-08-2783.pdf

ATTACHMENT 3	
SOP-5242-3 **RESUSPENSION**	Records Use only Los Alamos NATIONAL LABORATORY EST. 1943

Introduction

There are two approaches to the calculation of resuspension.

Some authors use the re-suspension factor, *K*, with units of m^{-1}, defined as:

$$K = (\text{Activity/m}^3 \text{ of air})/(\text{Activity/m}^2 \text{ of ground})$$

Others, such as the RESRAD team, use the mass-loading method:

$$\text{Activity/m}^3 \text{ of air} = (\text{Activity/g of soil})*(\text{g/m}^3 \text{ of air})$$

The publications of Anspaugh 1975, Garland 1994, Garger 1999, and Wagenpfeil 1999 recommend a value of K = 1E-9 m^{-1} for contamination that has weathered, migrated into the soil, and bound to the soil matrix. Estimates of how long this process takes range from 3 to 18 years. Almost all contamination at LANL is older than this so the value of K = 1E-9 m^{-1} is usually appropriate. The following calculations show that this value produces results that are consistent with the mass-loading method.

Sample calculation

As an example, assume the soil concentration is 1 pCi/g, and assume this was measured in the usual way by averaging over a depth of 5 cm of soil with a density of 1.6 g/cm^3. Then the activity per unit area is

$$(5 \text{ cm})(1.6 \text{ g/cm}^3) = 8 \text{ pCi/cm}^2 = 8\text{E}4 \text{ pCi/m}^2.$$

Using K = 1E-9 m^{-1}, the air concentration is

$$(1\text{E-}9 \text{ m}^{-1})(8\text{E}4 \text{ pCi/m}^2) = 8\text{E-}5 \text{ pCi/m}^3 \approx 1\text{E-}4 \text{ pCi/m}^3.$$

Alternatively, using the RESRAD-default mass-loading of soil in air of 1E-4 g/m^3, the air concentration is

$$(1\text{E-}4 \text{ g/m}^3)(1 \text{ pCi/g}) = 1\text{E-}4 \text{ pCi/m}^3.$$

The two results are close so we could use either method.

Reality Check

The typical concentration of ^{239}Pu in soil is ~0.01 pCi/g so the above calculations both predict an air concentration of about 1E-6 pCi/m^3. This is about an order of magnitude greater than the AIRNET data so it is conservative.

If we use the TEOM data, the mass loading is about an order of magnitude lower than the RESRAD-default value of 1E-4 g/m^3 assumed above. In this case the mass-loading calculation would be in reasonable agreement with the AIRNET data.

References

Anspaugh 1975: LR Anspaugh, JH Shinn, PL Phelps, NC Kennedy, "Resuspension and Redistribution of Plutonium in Soils," Health Physics Vol. 29 pp 571-582 (1975).

Garland 1994: JA Garland and IR Pomeroy, "Resuspension of Fallout Material Following the Chernobyl Accident," J. Aerosol Sci., Vol 25 No. 5 pp 793-806 (1994).

Garger 1999: EK Garger et al., "Test of existing mathematical models for atmospheric resuspension of radionuclides," Journal of Environmental Radioactivity 42 (1999) 157-175.

Wagenpfeil 1999: F Wagenpfeil, HG Paretzke, JM Peres, J. Tschiersch, "Resuspension of coarse particles in the region of Chernobyl," Atmospheric Environment 33 (1999) 3313-3323.

ATTACHMENT 4

SOP-5242-4

CONVERTING CONCENTRATION TO DOSE RATE

Records Use only

40 CFR 61 App. E Table 2 lists the concentrations that would result in **10 mrem/year** as follows. For ease of comparison, the right-hand column lists the concentrations that correspond to **1 mrem/year**.

	for **10 mrem/y**	for **1 mrem/y**
transuranics	2E-15 Ci/m^3	2E-16 Ci/m^3
uranium	7E-15 Ci/m^3	7E-16 Ci/m^3
tritium	1.5E-9 Ci/m^3	1.5E-10 Ci/m^3
strontium-90	1.9E-14 Ci/m^3	1.9E-15 Ci/m^3
cesium-137	1.9E-14 Ci/m^3	1.9E-15 Ci/m^3

DOE Order 5400.5 lists the concentrations that would result in **100 mrem/year** as follows. For ease of comparison, the right-hand column lists the concentrations that correspond to **1 mrem/year**.

	for **100 mrem/y**	for **1 mrem/y**
transuranics	2E-14 Ci/m^3	2E-16 Ci/m^3
uranium	1E-13 Ci/m^3	1E-15 Ci/m^3
tritium	1E-7 Ci/m^3	1E-9 Ci/m^3
strontium-90	9E-12 Ci/m^3	9E-14 Ci/m^3
cesium-137	4E-10 Ci/m^3	4E-12 Ci/m^3

According to Table 5-1 of the "Manual of Protective Action Guides" (**PAG**) EPA 400R92001**,** the dose conversion factors from **Ci/m³** to **rem/h** or **pCi/m³** to **mrem/h** are as follows.

Am-241	5.3E8 rem · h^{-1}· Ci^{-1} · m^3	= 0.53 mrem · h^{-1}· pCi^{-1} · m^3
Pu-239	5.2E8 rem · h^{-1}· Ci^{-1} · m^3	= 0.52 mrem · h^{-1}· pCi^{-1} · m^3
U-234	1.6E8 rem · h^{-1}· Ci^{-1} · m^3	= 0.16 mrem · h^{-1}· pCi^{-1} · m^3
U-238	1.4E8 rem · h^{-1}· Ci^{-1} · m^3	= 0.14 mrem · h^{-1}· pCi^{-1} · m^3
tritium	7.7E1 rem · h^{-1}· Ci^{-1} · m^3	

Sr-90	1.6E6 rem · h^{-1}· Ci^{-1} · m^3	= 1.6E-3 mrem·h^{-1}·pCi^{-1}·m^3
Cs-137	4.1E4 rem · h^{-1}· Ci^{-1} · m^3	= 4.1E-5 mrem·h^{-1}· pCi^{-1}·m^3

Note: the dose rates obtained from these three tables are similar (within a factor of 2) except for those from 40CFR61 for tritium, strontium-90, and cesium-137, which are much higher because they include ingestion of food grown near the release point.

ATTACHMENT 5

SOP-5242-5

Records Use only

Los Alamos NATIONAL LABORATORY EST. 1943

USE OF HOTSPOT FOR DOWNWIND CONCENTRATION AND DOSE

Use of Hotspot to calculate the downwind conditions. As an example, choose the following options.

In the Models tab, choose General Fire.

In the Source Term tab, choose

Radionuclide: Pu-239 Y

Material at Risk: 1.0000E+00 Ci

Deposition Velocity: 0.30 cm/sec, Airborne Fraction: 1E-2, and Respirable Fraction: 5E-2 are automatically set.

Enter Cloud Top is automatically selected.

Physical Height of Fire: 0 m is automatically selected.

Release Radius: 1.00E+02 m

Cloud Top: 10 m.

In the Meteorology tab, choose

10-meter Wind Speed: 3.0 m/s

Sun Low in the sky or cloudy (stability class C is automatically selected)

In the Output tab, click on TEDE Graph.

The graph shows the following.

Distance	Dose	Dose, dose rate, and concentration as a fraction of the value at 0.01 km
0.01 km	2E-3 rem	100%
1 km	3E-4 rem	3E-4/2E-3 = 15%
8 km	2E-5 rem	2E-5/2E-3 = 1%
50 km	2E-6 rem	2E-6/2E-3 = 0.1%

ATTACHMENT 6	
SOP-5242-6 **EXAMPLE**	Records Use only Los Alamos NATIONAL LABORATORY EST. 1943

Calculate the emissions of transuranics during a fire in Mortandad Canyon. As an example, assume the following.

Concentration of transuranics in soil:	50 pCi/g	See Attachment 1
Concentration ratio:	1.5E-2	See Attachment 2
Fuel consumed (grams wet):	67E6 g-wet/ha	See EPA AP42
Ratio of wet weight to ash weight:	50 g-wet/g-ash	See Attachment 2
Area of fire:	1 ha (1E4 m^2)	
Airborne mass loading of ash:	1E-3 g-ash/m^3	See Section 2.2
Vertical updraft velocity:	10 m/s	See Section 2.9
Duration of fire:	3600 s	

The concentration in the vegetation (wet weight) is

$$(50\ \text{pCi/g})(1.5\text{E-}2) = 0.75\ \text{pCi/g-wet}.$$

The total activity in 1 ha is

$$(0.75\ \text{pCi/g-wet})(\ 67\text{E}6\ \text{g-wet/ha})(1\ \text{ha}) = 5\text{E}7\ \text{pCi}.$$

The activity per gram of particulate is

$$(0.75\ \text{pCi/g-wet})(50\ \text{g-wet/g-ash}) \approx 40\ \text{pCi/g-ash}.$$

The air concentration at the scene of the fire is

$$(40\ \text{pCi/g-ash})(1\text{E-}3\ \text{g-ash/m}^3) = 4\text{E-}2\ \text{pCi/m}^3.$$

The ratio of the air concentration at the fire to the value in 40 CFR 61 Appendix E Table 2 (Attachment 4) is

$$(4\text{E-}2\ \text{pCi/m}^3)\ /\ (2\text{E-}3\ \text{pCi/m}^3) = 20.$$

Using EPA 400R92001 (Attachment 4) the dose rate to fire-fighters at the scene of the fire is

$$(4\text{E-}2\ \text{pCi/m}^3)(0.53\ \text{mrem}\cdot\text{h}^{-1}\cdot\text{pCi}^{-1}\cdot\text{m}^3) = 2\text{E-}2\ \text{mrem/h}.$$

The emission rate is

$$(4\text{E-}2\ \text{pCi/m}^3)(1\text{E}4\ \text{m}^2)(10\ \text{m/s}) = 4\text{E}3\ \text{pCi/s}.$$

The emission during 3600 s is

$$(4\text{E}3\ \text{pCi/s})(3600\ \text{s}) = 1.4\text{E}7\ \text{pCi}.$$