Australian Government
Australian Radiation Protection and Nuclear Safety Agency

arpansa

Missing Source Dose Assessment

Background

A Cs-137 ceramic source capsule ~20GBq is missing from an industrial gauge after transport of the gauge from s 22 - Irrelevant [redacted] in Western Australia to a depot in Perth. The source is a ceramic source ~ 6mm x 8mm. The source may be located along the route where it presents a danger to members of the public who may approach it. A search for the source will be conducted using vehicle mounted detector systems.

Version Changes

Version 1.2

- Added measurement integration calculations for mobile detector system

Simple gamma dose rate calculation:

Decay chain:

Cs-137 → Ba-137m → Ba137(stable)

Specific Gamma-ray dose constant (Γ) for Cs-137 = 2.393×10^{-10} $mSvh^{-1}$ MBq^{-1}[1]

Specific Gamma-ray dose constant (Γ) for Ba-137m = 8.216×10^{-5} $mSvh^{-1}$ MBq^{-1}

$$\text{Gamma dose rate} = \Gamma \times \frac{A}{d^2}$$

Assuming no gamma shielding provided by obstacles or source capsule:

$$\text{Gamma dose rate} = 8.216\text{x}10^{-5} \times \frac{20{,}000}{1^2} = 1.643$$

At 1m from the source: Dose rate = 1.643 $mSvh^{-1}$

At 10m from the source: Dose rate = 0.0164 $mSvh^{-1}$

[1] (2020) Peplow, D. Specific Gamma-Ray Dose Constants with Current Emission Data, Health Phys. 2020 Apr;118(4):402-416

For a drive by detection of the source at 15m assuming no shielding and obstacles:

At 15m from the source: Dose rate = 0.0073 $mSvh^{-1}$, 7.3μSvh^{-1}

This is within detection limits of vehicle mounted sodium iodide detection systems. For a source within 15m of the vehicle, assuming no obstacles, detection will depend on the detector system time-resolution. Testing should be conducted to determine an appropriate vehicle speed.

Small amounts of soil or roadway between the source and detection system may attenuate the dose rate significantly. From Rad Pro Calculator[2]:

At 15m with 30cm concrete (~soil density): 0.26μSvh^{-1}

At 15m with 50cm concrete (~soil density): 0.013μSvh^{-1}

Vehicles should travel on both sides of the road to avoid attenuation as much as possible. Mounting location of detectors should be considered. Low-mounted detectors may encounter more attenuation from a source behind small ground undulation.

Point source detection from a mobile detector system

The detector integration time can limit the speed at which a vehicle mounted system can travel and still detect a point source. The lowest integrated detector measurement occurs when the integration time begins or ends as the vehicle is horizontally adjacent to the source. This splits the highest source detection periods over two measurements. Distance d from the vehicle to the source varies as the vehicle passes the source (Figure 1):

$$d = \sqrt{(x^2 + y^2)}$$

Where:

d = distance from the detector in the vehicle to the point source

y = shortest distance from the point source to the detector line of travel

x = distance from the detector to the horizontally adjacent point

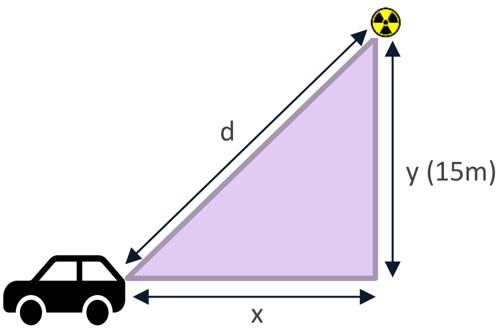


Figure 1 – vehicle mounted detector system measurement of a point source 15m from vehicle travel path

[2] Rad Pro Calculator does not have soil as a shielding option. Concrete was used as an approximate value and to account for potential road attenuation. Concrete is ~2.5 gcm^{-3} for concrete vs 1.6 gcm^{-3} for soil. Values are indicative of potential attenuation effects of terrain undulation.

For a vehicle travelling at a constant speed of 70kmh^{-1} (approximately 20ms^{-1}) with an integration time of 1s detecting a 20GBq source located 15m from the road, the measured dose rate is:

$$measured\ dose\ rate = \frac{1}{20}\int_0^{20} \frac{1.643mSvh^{-1}}{\sqrt{(225 + x^2)}^2} dx$$

Evaluating this gives a measured dose rate of 5µSvh^{-1}.

A three second integration time would give:

$$measured\ dose\ rate = \frac{1}{60}\int_0^{60} \frac{1.643mSvh^{-1}}{\sqrt{(225 + x^2)}^2} dx$$

Evaluating this gives a measured dose rate of 2.4µSvh^{-1}.

Travelling at 110kmh^{-1} would give ~30ms^{-1}. With a 1s integration time:

$$measured\ dose\ rate = \frac{1}{30}\int_0^{30} \frac{1.643mSvh^{-1}}{\sqrt{(225 + x^2)}^2} dx$$

Or 4µSvh^{-1}.

Table 1 – comparison of vehicle mounted detector measurements assuming an ideal detector

Speed	**Detector measurement (µSvh^{-1})**		
	Source 15m from road, 1s integration	Source 15m from road, 3s integration	Source 15m from road, ~30cm concrete attenuation
~35kmh^{-1}	6.3	4	1
~70kmh^{-1}	5	2.4	0.8
~110kmh^{-1}	4	1.7	0.6
Speed	**Detector measurement (µSvh^{-1})**		
	Source 30m from road, 1s integration	Source 30m from road, 3s integration	Source 30m from road, ~30cm concrete attenuation
~35kmh^{-1}	1.8	1.4	0.28
~70kmh^{-1}	1.6	1.0	0.25
~110kmh^{-1}	1.4	0.76	0.23
Speed	**Detector measurement (µSvh^{-1})**		
	Source 50 m from road, 1s integration	Source 50m from road, 3s integration	Source 50m from road, ~30cm concrete attenuation
~35kmh^{-1}	0.65	0.59	0.1
~70kmh^{-1}	0.63	0.48	0.1
~110kmh^{-1}	0.59	0.39	0.09

An unobstructed source of this type should be detectable by the vehicle mounted detector systems even at higher speeds. Faster measurement integration speeds significantly improve the speed the vehicle is able to travel while maintaining good detection probability. Other factors such as attenuation by terrain, a desire for more measurement locations or the potential of missing measurements may make a lower speed preferable.

The above calculated detector measurement values assume an ideal detector that is correctly calibrated and receives sufficient counts to return a valid measurement. Field testing of ARPANSA and ANSTO vehicle mounted detectors indicate that the detected counts are sufficient to detect sources of this strength at 15 and 30m for a vehicle travelling 70kmh^{-1}.

Varskin v1.1 assessment:

Scenario – source picked up and held for 60s by a member of the public:

Cylinder geometry 6mm x 8mm, averaged over 1cm^2 of skin, dose at depth of 70µm, exposure time 60s, no air gap. End wall is assumed to be stainless steel of 1mm thickness, 7500kgm^{-3} density.

A Photon dose of 870mSv to the most exposed 1cm^2 of skin is predicted for this scenario (Figure 2) This would be sufficient to cause prompt skin reactions and injuries including transient erythema, epilation, ulceration and other effects. Electron dose is attenuated by source encapsulation (represented by a cover).

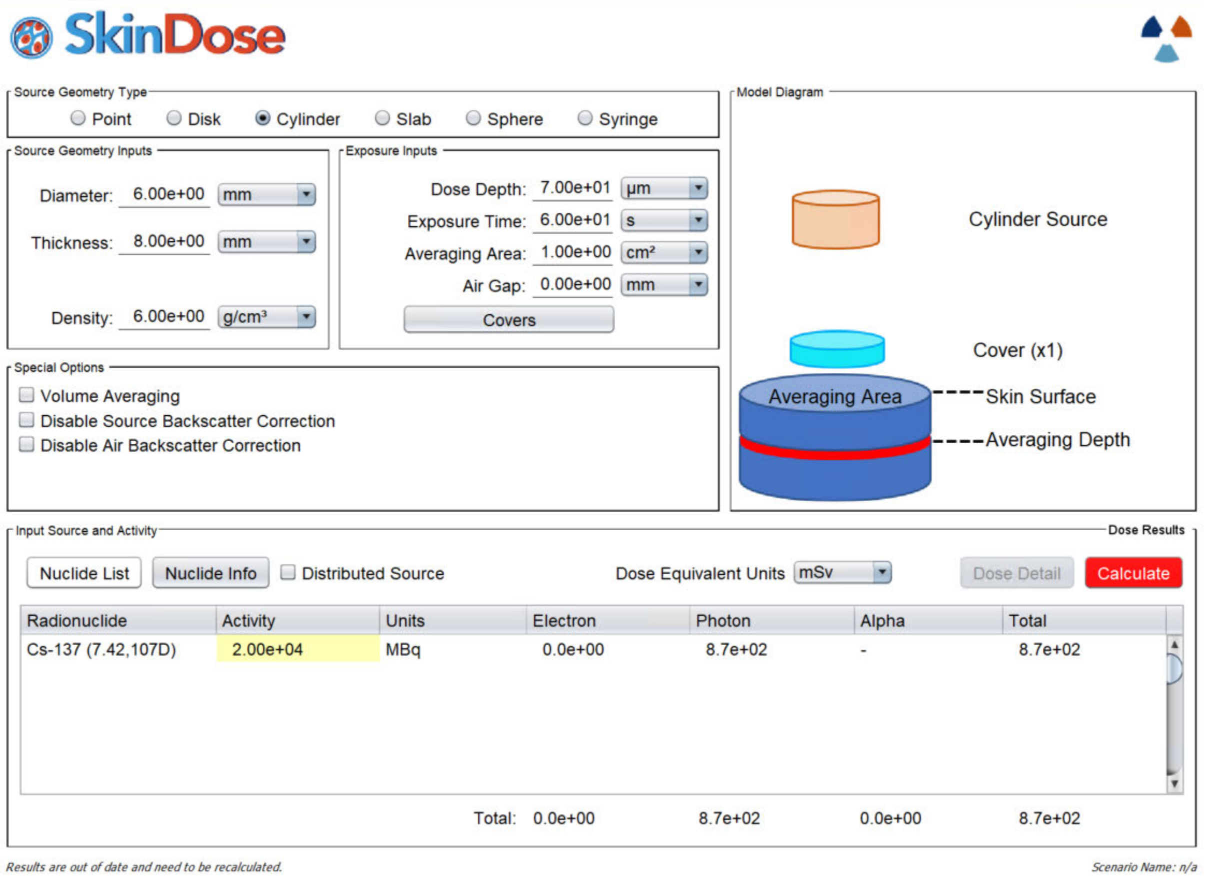


Figure 2 – Varskin Assessment Scenario 1

Scenario 2– source placed in a pocket and kept for 1h by a member of the public:

Cylinder geometry 6mm x 8mm, averaged over 1cm^2 of skin, dose at depth of 70µm, exposure time 3600s, no air gap. End wall is assumed to be stainless steel of 1mm thickness. An additional cover of 0.03mm representing cloth clothing (density assumed 20kgm^{-3}) is added.

A Photon dose of 5.140Sv to the most exposed 1cm^2 of skin is predicted for this scenario (Figure 3 and 4). This would be sufficient to cause prompt skin reactions and injuries including transient erythema, epilation, ulceration and other effects.

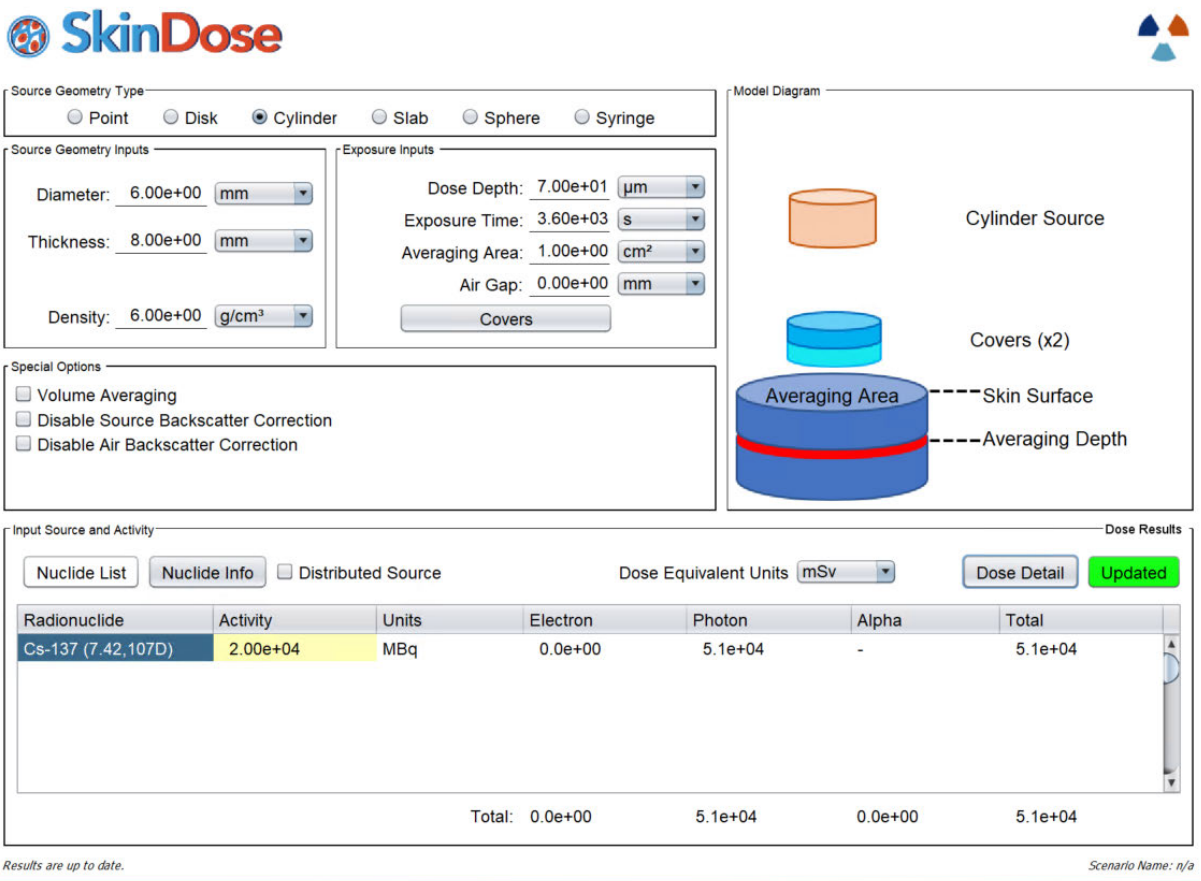
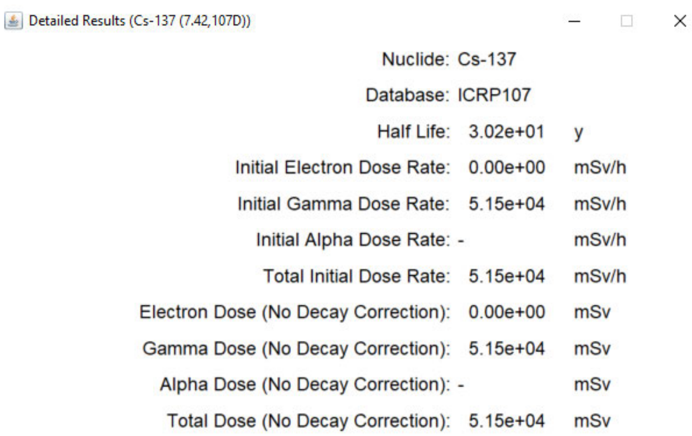


Figure 3 – Varskin Assessment Scenario 2


Detailed Results (Cs-137 (7.42,107D))

Nuclide:	Cs-137	
Database:	ICRP107	
Half Life:	3.02e+01	y
Initial Electron Dose Rate:	0.00e+00	mSv/h
Initial Gamma Dose Rate:	5.15e+04	mSv/h
Initial Alpha Dose Rate:	-	mSv/h
Total Initial Dose Rate:	5.15e+04	mSv/h
Electron Dose (No Decay Correction):	0.00e+00	mSv
Gamma Dose (No Decay Correction):	5.15e+04	mSv
Alpha Dose (No Decay Correction):	-	mSv
Total Dose (No Decay Correction):	5.15e+04	mSv

Figure 4 – Varskin Detailed Results Scenario 2

Varskin calculation of Hp(10) dose rate at 1m:

Cylinder source and covers remain in place. Air gap of 1000mm is used. Dose depth is calculated at 10mm. Varskin predicts 1.46 mSvh^{-1} for this scenario (Figure 5). Table 2 compares different calculation methods.

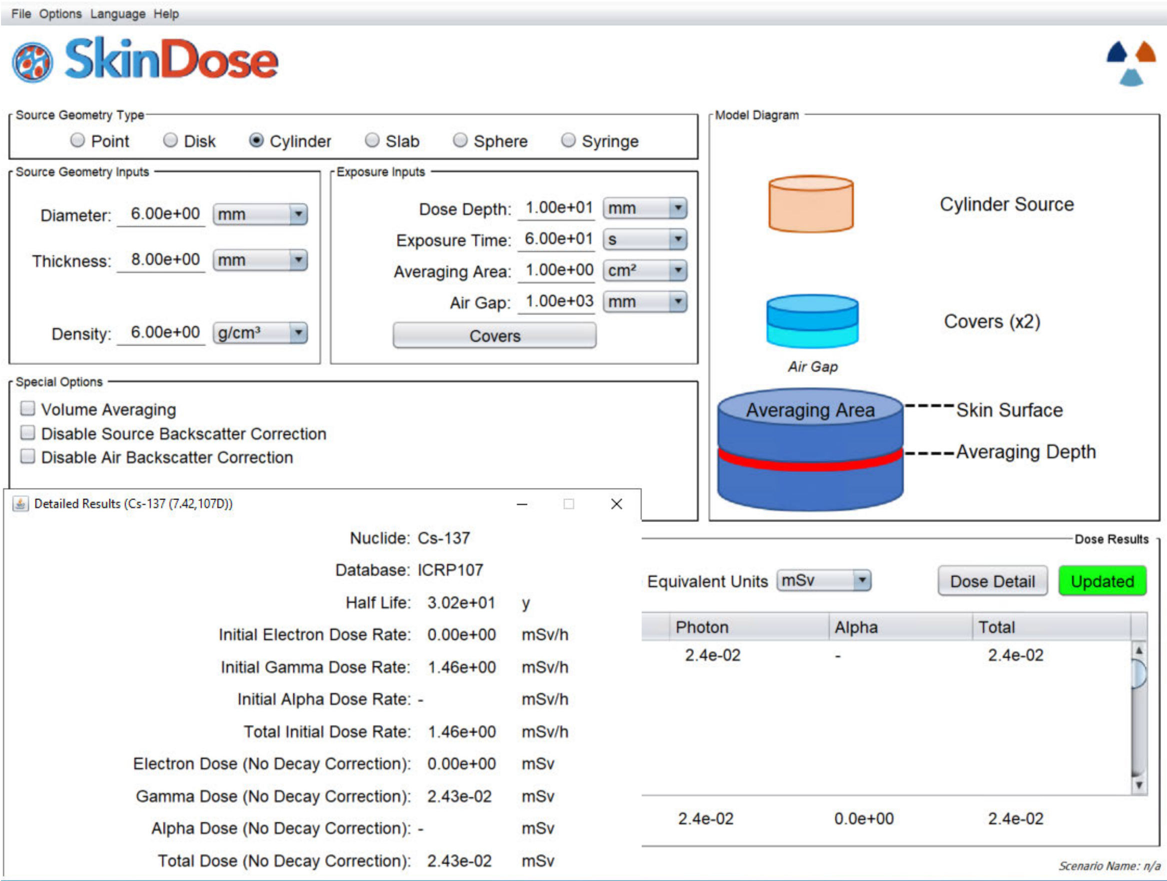


Figure 5 – Varskin Assessment 1m Hp(10)Dose Rate

Other calculation methods

The Radiation Protection Handbook gives a value of 1.07 x10^{-3} mSvh^{-1} MBq^{-1} at 30cm for Cs-137/Ba-137. For a 19GBq point source at 1m this gives a value of 1.926 mSvh^{-1}

Rad Pro Calculator gives 0.85 mSvh^{-1} MBq^{-1} at 30cm for Cs-137/Ba-137. For a 19GBq point source at 1m this gives 1.53 mSvh^{-1}.

Table 2 – comparison of dose rates at 1m

Method	Dose rate (mSvh^{-1})
Varskin 1.1	1.46
Radiation Protection Handbook	1.926
Rad Pro Calculator	1.53
Specific Gamma-ray dose constant	1.643