V&V REPORT

RadMap

Release v2.0.0



radmap.tech

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1 Introduction

This report records the verification and validation of one version of RadMap, named in the summary below. It is generated in the build that produces the version's installer, from the tests that build runs, and published with the version's documentation: every number in it was measured on the software it describes.

RadMap calculates dose rates from radioactive sources and the effect of shielding on them. Its intended use is stated in its licence agreement; what it does not calculate, or calculates only approximately, is listed in the user guide under *Known limitations*. A user qualifying RadMap for their own purpose can base that qualification on this report.

1.1 How the cases are built

Each **V&V case** is an automated test. Most build a project through RadMap's programming interface – sources, shields, materials and dose maps, as a user would – run the same simulation the application runs, and compare the results with expected values; a few check RadMap's own arithmetic, such as turning an activity concentration into a total, without a simulation. The case's text, its references and its checks below are taken from the test itself, so the report and the tests cannot differ.

Each case names the **requirements** it verifies. The requirements state what RadMap must get right for its dose rates to be correct; the traceability table shows which cases verify each, and lists any that no case verifies yet.

Each case states its **basis**, which says where its expected values come from, and names the published sources it uses; the last chapter lists them in full. The bases are:

- **Published reference.** Every expected value is derived from published data – decay data, attenuation coefficients, buildup factors, conversion coefficients – or, for geometry and arithmetic, worked out by hand. None comes from RadMap.
- **Partly RadMap's own result.** Part of an expected value, which the case's text names, is a result RadMap gave when the case was written. The rest is published data. Such a case shows that the part it takes from RadMap has not changed, not that it is right.
- **Condition.** The case checks a limit, a direction or that something holds – a shield covers the maps it should, a run completes, two runs agree – rather than a value.
- **Measurement.** Every expected value is a published measurement, and the tolerance comes from the experiment's stated uncertainties. Such a case validates RadMap rather than verifying it (*Verification and validation* below).

1.2 Checks and tolerances

Each check compares one result with its criterion: an expected value within a relative tolerance, a limit, or a condition. The tolerances allow for the statistical uncertainty of a Monte Carlo result and for the approximations a derivation makes; each case's text says what its tolerances cover.

A simulated result is shown as its value ± σ, its statistical uncertainty of one standard deviation as RadMap reports it, in the value's own unit (case U-Cs137-Spread checks that it matches the scatter of repeated runs). A check on such a result passes only if the run could tell a pass from a fail: three standard deviations must fit inside the tolerance, and a limit must hold by more than three standard deviations. Otherwise a wrong value could pass by chance. A ratio of two independent results carries both their uncertainties: results of separate runs, or maps in different directions from a source in vacuum, which no photon can reach both of. A ratio of two maps in the same place, such as AP to ROT, is shown without one: in vacuum the maps score

exactly the same photons, so the ratio's statistical noise is far below its tolerance, which the derivation alone sets.

The simulations run with a fixed seed, so a case's results vary between runs of the same build only in their last digits, from the order in which threads add their scores; the tolerances therefore guard against changes to RadMap, its data or Geant4, not against run-to-run noise.

1.3 Verification and validation

The cases **verify** RadMap: each shows that RadMap computes what its inputs imply – the decay data, the attenuation and conversion coefficients, the buildup factors – by comparing its results with values derived from published references. Most of those references are themselves calculated, not measured, so a passing case shows that RadMap reproduces accepted reference models, not that the models agree with a measurement.

Validation compares the results with measurements: the cases whose basis is *Measurement*, in ValidationTest. Of the quantities RadMap reports, air kerma is the one that can be measured. Effective dose is a protection quantity, defined on a reference phantom and not measurable; H∗(10) is estimated by instruments calibrated in air kerma. Both are the photon fluence times a published coefficient, a step the cases verify, so validating air kerma validates them too.

The validation cases are the gamma-ray experiments of Kansas State University with radionuclide sources: Cs-137 over a concrete floor, and Co-60 skyshine, which OECD/NEA's SINBAD database holds as an evaluated benchmark. Few photon shielding experiments are documented well enough, in geometry and in stated uncertainties, to compare a calculation with; MCNP's shielding validation suite has the same skyshine experiment and one other photon experiment. Geant4's published validation of the photon physics RadMap uses is open work; the skyshine case also compares RadMap with LLNL's COG on the same model.

2 Summary

Status
release 2.0.0

RadMap version
2.0.0

Source commit
`c10155d9d7d01d2ff5adf0ccd54d840e217fce26 (with uncommitted changes)`

Report generated
2026-11-04 19:08 UTC

V&V cases
52, 52 passed

Checks
168

Requirements
19, 19 verified by at least one case

- Published reference: 21 cases
- Partly RadMap's own result: 2 cases
- Condition: 27 cases
- Measurement: 2 cases

3 Requirements

3.1 R-1: Gamma emission

A source emits the gammas of its isotope's decay: those of every excited level of the daughter it reaches, long-lived ones included, with the yields of the decay data.

Verified by: A-Co60-ROT, A-Cs137-ROT, D-Co60-Cs137, B-Co60-Pb, B-Cs137-Pb, E-Cs137-Water, AK-Cs137, AK-Co60, AH-Cs137, AH-Co60, CK-Na22, X-Am241, C-Ru106-Chain, V-KSU-Cs137, V-KSU-Skyshine

3.2 R-2: X-ray emission

The vacancies that electron capture and internal conversion leave in the daughter's atomic shells refill with the X-rays of the atomic data.

Verified by: A-Cs137-ROT, AK-Cs137, AH-Cs137, X-Am241

3.3 R-3: Annihilation

Each positron from beta+ decay annihilates into two 511 keV photons.

Verified by: CK-Na22

3.4 R-4: Activity

A source's dose rates are proportional to its activity, given in any of RadMap's activity units.

Verified by: D-Co60-Cs137, AR-Absolute

3.5 R-5: Activity as a concentration

An activity given per volume or per mass resolves to a total: the concentration times the volume of the source's own material (its solid less the solids placed inside it), and for a mass concentration also times the material's density. An activity that cannot be resolved is refused, not taken as zero.

Verified by: AR-PerVolume, AR-VolumeUnit, AR-PerMass, AR-Children, AR-Refused, AR-NoVolume, AR-Zero

3.6 R-6: Source distribution

A source's decays are spread evenly through its solid's own material, excluding the solids placed inside it.

Verified by: S-Name-0x, S-World, R6-Sampling

3.7 R-7: Several sources

The dose rate from several sources is the sum of their contributions, each at its own activity.

Verified by: D-Co60-Cs137, C-Chain-PerSource, C-Chain-None

3.8 R-8: Decay chain

With *Full chain* on, the radioactive daughters of a source decay as well, each once for every decay of the source.

Verified by: C-Ru106-Chain, C-Chain-PerSource, C-Chain-None

3.9 R-9: Fluence in free air

A dose map scores the photon fluence averaged over its volume, in any orientation. In air the fluence from a point source falls with the inverse square of the distance, reduced only by the attenuation of the air.

Verified by: A-Co60-ROT, A-Cs137-ROT, D-Co60-Cs137, O-Co60-Orientation, AK-Cs137, AK-Co60, AH-Cs137, AH-Co60, CK-Na22, X-Am241, V-KSU-Cs137, V-KSU-Skyshine

3.10 R-10: Attenuation

A shield attenuates the photons crossing it according to the published attenuation coefficients of its material, over the thickness the geometry gives.

Verified by: B-Co60-Pb, B-Cs137-Pb, E-Cs137-Water, BK-Co60-Pb, BK-Cs137-Pb, EK-Cs137-Water, EK-Cs137-WaterInf, G-Box, G-Tube-Phi-0, G-Tube-Phi-180, G-Tube-Phi-Gap, G-Sphere-Phi-10, G-Sphere-Phi-190, G-Sphere-Theta-10, G-Sphere-Theta-0, V-KSU-Cs137, V-KSU-Skyshine

3.11 R-11: Scatter

Photons a shield scatters still reach the dose maps, so the dose behind a shield includes its buildup.

Verified by: B-Co60-Pb, B-Cs137-Pb, E-Cs137-Water, BK-Co60-Pb, BK-Cs137-Pb, EK-Cs137-Water, EK-Cs137-WaterInf, V-KSU-Cs137, V-KSU-Skyshine

3.12 R-12: Geometry

Solids and dose maps reach the simulation as entered: their dimensions, angular segments, positions and rotations, including those inherited from parent solids.

Verified by: O-Co60-Orientation, B-Co60-Pb, B-Cs137-Pb, E-Cs137-Water, S-Name-0x, R6-Sampling, G-Box, G-Tube-Phi-0, G-Tube-Phi-180, G-Tube-Phi-Gap, G-Sphere-Phi-10, G-Sphere-Phi-190, G-Sphere-Theta-10, G-Sphere-Theta-0, T-Translation, T-Rotation, T-Multiaxis, V-KSU-Skyshine

3.13 R-13: Materials

Materials reach the simulation with their composition and density, mixes of other materials included.

Verified by: B-Co60-Pb, B-Cs137-Pb, E-Cs137-Water, M-Mix-Composition, M-Mix-Nested-Composition, M-Name-0x, M-Density-Unit

3.14 R-14: Electrons and bremsstrahlung

With *Simulate electrons* on, electrons from decay are transported and their bremsstrahlung reaches the dose maps; with it off, they contribute nothing.

Verified by: F-Sr90-Toggle, F-P32-Plate

3.15 R-15: Effective dose

Effective dose is converted from fluence with the ICRP 116 coefficients, interpolated in photon energy, for the irradiation geometry chosen.

Verified by: A-Co60-ROT, A-Cs137-ROT, D-Co60-Cs137, B-Co60-Pb, B-Cs137-Pb, E-Cs137-Water, X-Am241, C-Ru106-Chain

3.16 R-16: Ambient dose equivalent

H∗(10) is converted from fluence with the ICRP 74 coefficients, interpolated in photon energy.

Verified by: AH-Cs137, AH-Co60

3.17 R-17: Air kerma

Air kerma is converted from fluence with the ICRP 74 coefficients, interpolated in photon energy.

Verified by: BK-Co60-Pb, BK-Cs137-Pb, AK-Cs137, AK-Co60, AH-Cs137, AH-Co60, EK-Cs137-Water, EK-Cs137-WaterInf, CK-Na22, X-Am241, C-Ru106-Chain, V-KSU-Cs137, V-KSU-Skyshine

3.18 R-18: Statistical uncertainty

Every dose rate is reported with a statistical uncertainty that matches the scatter of repeated runs.

Verified by: U-Cs137-Spread

3.19 R-19: Reproducibility

The same project and seed, run on one thread, give the same results; a different seed gives different ones. Runs on several threads are not reproducible to the bit, because the order in which threads add their scores varies.

Verified by: S-Seed

4 Traceability

Requirement	Cases	Refer-ence	Partly own	Condi-tion	Mea-sured
R-1: Gamma emission	15	12	1	0	2
R-2: X-ray emission	4	4	0	0	0
R-3: Annihilation	1	1	0	0	0
R-4: Activity	2	2	0	0	0
R-5: Activity as a concentration	7	4	0	3	0
R-6: Source distribution	3	0	0	3	0
R-7: Several sources	3	1	0	2	0
R-8: Decay chain	3	1	0	2	0
R-9: Fluence in free air	12	10	0	0	2
R-10: Attenuation	17	5	2	8	2
R-11: Scatter	9	5	2	0	2
R-12: Geometry	18	3	1	13	1
R-13: Materials	7	2	1	4	0
R-14: Electrons and bremsstrahlung	2	0	0	2	0
R-15: Effective dose	8	7	1	0	0
R-16: Ambient dose equivalent	2	2	0	0	0
R-17: Air kerma	13	10	1	0	2
R-18: Statistical uncertainty	1	0	0	1	0
R-19: Reproducibility	1	0	0	1	0

5 V&V cases

5.1 DoseTest

A-Co60-ROT: Co-60 point source in vacuum: effective dose, inverse square and geometry

Result
passed

Verifies
R-1, R-9, R-15

Basis
Published reference – *ICRP 116*, Table A.1; *DDEP Co-60*

Test
DoseTest

A 1 GBq Co-60 source in a 1 mm cube, in a 5 m cube of vacuum. Dose maps score effective dose in the ROT geometry at 0.5 m on the x axis, 1 m on the y axis and 2 m on the z axis, each facing the source and sized with its distance: 200 × 200 × 1 mm at 0.5 m, 400 × 400 × 2 mm at 1 m and 800 × 800 × 4 mm at 2 m. Maps in the same place as the one at 1 m score AP, PA, LLAT, RLAT and ISO.

The expected values sum every photon line of the decay data, each with the coefficient for its energy; none of them comes from RadMap. A coefficient is read from the published table on a natural cubic spline in energy, the interpolation RadMap uses, computed here independently. Below a table's lowest energy, 10 keV, a coefficient is zero, except air kerma's, which keeps its 10 keV value, as the user guide states under *Known limitations*. Lines adding less than 0.01 % are left out of the tables below, not of the sums. The fluence rate 1 m from 1 GBq is $10^9 / (4\pi \times 100^2)$ = 7 957.7 cm^{-2} s^{-1} per photon per decay.

The maps. A map reads the fluence averaged over its volume, so a plate facing a point source reads the mean fluence over its face. Each of these faces is a square 0.4 d on a side at a distance d, and the mean of d^2/r^2 over it, r being the distance to each point, is 0.9743: each map reads 0.9743 of the fluence at its centre. Scaled with its distance, every map subtends the same solid angle, reads the same fraction and counts about the same number of photons. In vacuum nothing scatters or attenuates, and the maps lie in different directions, so no photon reaches two of them: their errors are independent, and the ratio of two carries both their uncertainties. AK-Co60 and AH-Co60 score air kerma and H∗(10) in the same three places, in the same run: the three cases would otherwise simulate the same photons three times.

Dose rate at 1 m (ROT).

Line (keV)	Yield	h_E, ROT (pSv·cm²)
1173.228	0.9985	4.274
1332.492	0.999826	4.757

Per decay, Σ yield × h_E = 9.025 pSv·cm², so at a point 1 m away the dose rate is 7 957.7 × 9.025 × 10^{-12} × 3600 = 258.5 µSv/h, and the map reads 0.9743 of it: 251.9 µSv/h, within ±3 %.

Inverse square. Since the maps are scaled copies of each other, their readings scale exactly as $1/r^2$: the dose rate at 0.5 m is four times that at 1 m, and at 1 m four times that at 2 m, within ±3 %.

The case runs 1 500 000 decays, so that three standard deviations of each result fit inside its tolerance with room to spare.

Irradiation geometry. Maps in the same place score exactly the same photons, so their ratio to ROT varies only with the mix of the two lines among those photons, by well under 0.1 %, and is shown without an uncertainty. It checks that each geometry reads its own column of the table, within ±1 %, which allows for small differences between the decay data Geant4 uses and DDEP's:

Geometry	1173 keV	1332 keV	Ratio to ROT
ROT	4.274	4.757	
AP	5.090	5.608	1.1845
PA	4.411	4.908	1.0318
LLAT	3.725	4.187	0.8761
RLAT	3.522	3.977	0.8303
ISO	3.764	4.217	0.8837

Check	Result	Criterion	Verdict
d(0.5 m) / d(1 m)	4.036 ± 0.030	4 ± 3 %	pass
d(1 m) / d(2 m)	4.013 ± 0.030	4 ± 3 %	pass
d(1 m), ROT	(2.516 ± 0.013) × 10^{-4} Sv/h	2.519 × 10^{-4} Sv/h ± 3 %	pass
AP / ROT	1.185	1.185 ± 1 %	pass
PA / ROT	1.032	1.032 ± 1 %	pass
LLAT / ROT	0.8761	0.8761 ± 1 %	pass
RLAT / ROT	0.8303	0.8303 ± 1 %	pass
ISO / ROT	0.8837	0.8837 ± 1 %	pass

A-Cs137-ROT: Cs-137 point source in vacuum: effective dose, inverse square and geometry

Result
passed

Verifies
R-1, R-2, R-9, R-15

Basis
Published reference – *ICRP 116*, Table A.1; *DDEP Cs-137*

Test
DoseTest

The Co-60 case (A-Co60-ROT), with its maps and its way of deriving the expected values, with a 1 GBq Cs-137 source. It shares its run with AK-Cs137 and AH-Cs137.

Dose rate at 1 m (ROT). Cs-137 emits, through Ba-137m, one gamma line at 661.657 keV with a yield of 0.8499, where ICRP 116's spline gives h_E(ROT) = 2.539 pSv·cm² (2.54 at the table's 0.662 MeV); the line alone gives 61.8 µSv/h at a point 1 m away. It also emits Ba K X-rays, 31.8 to 37.4 keV, 0.0686 per decay, and Ba L X-rays, 4 to 6 keV, 0.0090 per decay. In vacuum both reach the map: the K X-rays add 0.0118 pSv·cm² per decay, 0.55 %, and the L X-rays nothing, being below the table. Per decay, Σ yield × h_E = 2.1695 pSv·cm², so at a point 1 m away the dose rate is 7 957.7 × 2.1695 × 10^{-12} × 3600 = 62.15 µSv/h, and the map reads 0.9743 of it: 60.55 µSv/h, within ±3 %.

Inverse square as in A-Co60-ROT, within ±3 %. With fewer than half the photons per decay of Co-60, the case runs 3 000 000 decays.

Irradiation geometry. As in A-Co60-ROT, within ±1 %. The ratios include the K X-rays, which add 0.4 to 0.8 % to each geometry's sum:

Geometry	h_E at 661.657 keV	Ratio to ROT
ROT	2.539	
AP	3.169	1.2516
PA	2.629	1.0335
LLAT	2.119	0.8338
RLAT	1.969	0.7744
ISO	2.169	0.8540

Check	Result	Criterion	Verdict
d(0.5 m) / d(1 m)	3.963 ± 0.031	4 ± 3 %	pass
d(1 m) / d(2 m)	4.035 ± 0.032	4 ± 3 %	pass
d(1 m), ROT	(6.077 ± 0.034) × 10^{-5} Sv/h	6.055 × 10^{-5} Sv/h ± 3 %	pass
AP / ROT	1.252	1.252 ± 1 %	pass
PA / ROT	1.033	1.034 ± 1 %	pass
LLAT / ROT	0.8338	0.8338 ± 1 %	pass
RLAT / ROT	0.7743	0.7744 ± 1 %	pass
ISO / ROT	0.854	0.854 ± 1 %	pass

D-Co60-Cs137: Two sources at one point: Co-60 1 GBq and Cs-137 3 GBq

Result
passed

Verifies
R-1, R-4, R-7, R-9, R-15

Basis
Published reference – *ICRP 116*, Table A.1; *DDEP Co-60*; *DDEP Cs-137*

Test
DoseTest

Both sources in the same 1 mm cube, with different activities, and the ROT maps of A-Co60-ROT at 0.5, 1 and 2 m. The dose rate at 1 m is the sum of the two cases above, each at its own activity: 251.9 µSv/h for Co-60 at 1 GBq (A-Co60-ROT) and 3 × 60.55 = 181.7 µSv/h for Cs-137 at 3 GBq (A-Cs137-ROT), 433.5 µSv/h in all, within ±3 %. Weighting both sources equally, or dropping one, would miss it by far more. The maps at 0.5 and 2 m check the inverse square law on the combined field, within ±3 %. The case runs 3 000 000 decays, as A-Cs137-ROT does.

Check	Result	Criterion	Verdict
d(0.5 m) / d(1 m)	3.994 ± 0.029	4 ± 3 %	pass
d(1 m) / d(2 m)	4.006 ± 0.029	4 ± 3 %	pass
d(1 m), ROT	(4.342 ± 0.022) × 10^{-4} Sv/h	4.335 × 10^{-4} Sv/h ± 3 %	pass

O-Co60-Orientation: Deep dose maps turned towards a point source read the mean over their volume

Result
passed

Verifies
R-9, R-12

Basis
Published reference – *ICRP 116*, Table A.1; *DDEP Co-60*

Test
DoseTest

The source of A-Co60-ROT, 1 GBq of Co-60 in a 1 mm cube in vacuum, and four deep dose maps 600 mm from it, each scoring effective dose (ROT):

Map	Size (mm)	Centre	Rotation	Facing the source
face	300 × 300 × 300	+x, 600 mm	none	a face
edge	300 × 300 × 300	+y, 600 mm	Z 45°	an edge
corner	300 × 300 × 300	+z, 600 mm	X 35.264°, Y 45°	a corner
box	120 × 240 × 480	−y, 600 mm	X 60°, Y 30°	none

A map reads the fluence averaged over its volume. Within each of these maps the fluence changes several-fold between its nearest and farthest points, so what it reads depends on the region it covers, and on nothing else: not on which of its faces the photons enter by. The thin plates of the other cases cannot tell the two apart: their photons all enter through one large face, and the fluence hardly changes across their thickness.

The expected values are the point dose rate at 600 mm times the mean of d^2/r^2 over each map's volume, with d = 600 mm the distance to its centre and r the distance to each point in it. The point dose rate is that of A-Co60-ROT at 1 m, 258.5 µSv/h, times $(1000/600)^2$: 718.1 µSv/h. The means come from a 64-point Gauss-Legendre rule along each edge of the map, in its own frame, turned as RadMap turns it: a vector turns about Z first, then Y, then X (T-Multiaxis).

Map	Mean of d^2/r^2	Dose rate (µSv/h)	Ratio to face
face	1.01851	731.3	
edge	1.02261	734.3	1.0040
corner	1.02444	735.6	1.0058
box	1.06672	766.0	1.0473

For a cube of side s, the mean is close to $1 + s^2/12d^2$ in any orientation, so the three cubes should read within 0.6 % of each other. The box is not a cube, and its mean depends on how it lies: with its long axis pointing at the source it would read 1.162, with its short axis 0.948. Turned with the rotations in the opposite order, or by its 60° about X only, it would read 1.114, 4.5 % higher than expected, so it checks that the map reaches the simulation turned as RadMap shows it. When the case was written it found a fault: maps were turned by the inverse of their rotation (D-0006), and the box read 1.114. Each dose rate is checked within ±3 %, as in A-Co60-ROT, and each ratio to the face-on cube within ±2 %; the ratios are free of the decay data and coefficients, which cancel.

A scorer that counted the photons entering each map, divided by its area seen from their direction – RadMap's until 2.0 (D-0005) – reads 1.262 face-on, 1.073 edge- on and 0.953 corner-on: the same cube 32 % higher face-on than corner-on, where it should read the same.

The maps lie in different directions from the source, and none can be reached by a photon that reaches another, so their errors are independent. The case runs 1 500 000 decays.

Check	Result	Criterion	Verdict
cube, face-on	(7.340 ± 0.027) × 10^{-4} Sv/h	7.313 × 10^{-4} Sv/h ± 3 %	pass
cube, edge-on	(7.331 ± 0.028) × 10^{-4} Sv/h	7.343 × 10^{-4} Sv/h ± 3 %	pass
cube, corner-on	(7.333 ± 0.028) × 10^{-4} Sv/h	7.356 × 10^{-4} Sv/h ± 3 %	pass
box, turned	(7.669 ± 0.034) × 10^{-4} Sv/h	7.660 × 10^{-4} Sv/h ± 3 %	pass
edge-on / face-on	0.9988 ± 0.0053	1.004 ± 2 %	pass
corner-on / face-on	0.9991 ± 0.0053	1.006 ± 2 %	pass
box / face-on	1.0449 ± 0.0060	1.047 ± 2 %	pass

B-Co60-Pb: Co-60 through 21.7 mm of lead: effective dose

Result
passed

Verifies
R-1, R-10, R-11, R-12, R-13, R-15

Basis
Published reference – *ANSI/ANS-6.4.3-1991*, Tables 1a and 3, as reproduced in NUREG/CR-5740; *NUREG/CR-5740*, Table 3; *ICRP 116*, Table A.1; *ICRP 74*, Table A.1; *DDEP Co-60*

Test
DoseTest

A lead slab, 300 × 300 mm and 21.7 mm thick, 100 mm from the Co-60 source of A-Co60-ROT, with the dose map at 1 m behind it. The attenuation coefficients and the buildup factors both come from the standard, so that depth and buildup are counted the same way: in mean free paths without coherent scattering. BK-Co60-Pb scores air kerma in the same place, in the same run; B-Cs137-Pb and BK-Cs137-Pb share one run likewise.

Narrow-beam attenuation. The standard's Table 1a gives μ/ρ for lead of 0.06844 cm^2/g at 1.0 MeV and 0.05102 cm^2/g at 1.5 MeV. Interpolated log-log, at 11.34 g/cm^3, μ = 0.691 cm^{-1} at 1.173 MeV and 0.630 cm^{-1} at 1.333 MeV, so the slab is 1.500 and 1.368 mean free paths thick. Weighting each line by its dose, 4.268 and 4.757 pSv·cm^2 per decay (A-Co60-ROT), it passes 0.240 of the unshielded 258.5 μSv/h at a point without scatter: 62.0 μSv/h.

Buildup. Photons the lead scatters still reach the map. The standard's Table 3 gives exposure buildup factors for lead of 1.38 at 1 mfp for both 1.0 and 1.5 MeV, and 1.68 and 1.73 at 2 mfp. Between 1 and 2 mfp lead's factor is close to linear in depth; between the energies it is taken linear in log energy. That gives 1.540 at 1.173 MeV and 1.503 at 1.333 MeV, and 1.519 weighted by the transmitted dose. The expectation is 62.0 × 1.519 = 94.2 μSv/h, within ±10 %.

The case differs from the standard's conditions in two ways, both smaller than the tolerance. The factors are for a point source in an unlimited medium, while this is a finite slab in air: for lead, the report's own comparison (Table 3 of its text, at 1 MeV) puts a slab's factor 1–2 % below the unlimited medium's. And the factors are for exposure, that is air kerma, while the case scores effective dose. Between 0.15 and 1.5 MeV, the energies at which scattered photons get through lead, ICRP 116's effective dose (ROT) per ICRP 74's air kerma stays between 0.80 and 0.88, against 0.84 at Co-60's lines. The scattered photons therefore count nearly alike in both quantities, and the effective-dose factor lies within about 2 % of the exposure factor.

Check	Result	Criterion	Verdict
d(1 m) behind lead, ROT	(9.04 ± 0.26) × 10^{-5} Sv/h	9.420 × 10^{-5} Sv/h ± 10 %	pass

B-Cs137-Pb: Cs-137 through 9.8 mm of lead: effective dose

Result
passed

Verifies
R-1, R-10, R-11, R-12, R-13, R-15

Basis
Published reference – *ANSI/ANS-6.4.3-1991*, Tables 1a and 3, as reproduced in NUREG/CR-5740; *NUREG/CR-5740*, Table 3; *ICRP 116*, Table A.1; *ICRP 74*, Table A.1; *DDEP Cs-137*

Test
DoseTest

The geometry of B-Co60-Pb with the Cs-137 source of A-Cs137-ROT and a 9.8 mm slab, derived as B-Co60-Pb is. The standard's Table 1a gives μ/ρ for lead of 0.1178 cm^2/g at 0.6 MeV and 0.08472 cm^2/g at 0.8 MeV. Log-log at 0.662 MeV, μ = 1.194 cm^{-1}, so the slab is 1.170 mean free paths thick and passes exp(−1.170) = 0.310 of the unshielded 61.8 μSv/h at a point (A-Cs137-ROT) without scatter: 19.2 μSv/h. Table 3 gives exposure buildup factors of 1.28 and 1.34 at 1 mfp, and 1.46 and 1.59 at 2 mfp, for 0.6 and 0.8 MeV; interpolated as in B-Co60-Pb, 1.335. The expectation is 19.2 × 1.335 = 25.6 μSv/h, within ±10 %. The slab and the effective dose differ from the standard's conditions as in B-Co60-Pb; effective dose (ROT) per air kerma is 0.81 at 0.662 MeV.

The case runs 2 000 000 decays. At 500 000 the statistical uncertainty was 4.2 %, too large for the run to tell a value inside ±10 % from one outside it.

Check	Result	Criterion	Verdict
d(1 m) behind lead, ROT	(2.457 ± 0.052) × 10^{-5} Sv/h	2.560 × 10^{-5} Sv/h ± 10 %	pass

E-Cs137-Water: Cs-137 through 230 mm of water, 300 mm wide: effective dose

Result
passed

Verifies
R-1, R-10, R-11, R-12, R-13, R-15

Basis
Partly RadMap's own result – *NIST XCOM*; *ICRP 116*, Table A.1; *DDEP Cs-137*

Test
DoseTest

A water slab, 300 × 300 mm and 230 mm thick, 100 mm from the Cs-137 source of A-Cs137-ROT, with the dose map at 1 m. Water scatters far more than it absorbs at 0.662 MeV, so most of the dose behind it is scattered photons. EK-Cs137-Water scores air kerma in the same place, in the same run.

NIST XCOM gives μ/ρ = 0.0857 cm^2/g, so the slab is 1.971 mean free paths thick and passes exp(−1.971) = 0.139 of the unshielded 61.8 μSv/h at a point (A-Cs137-ROT) without scatter: 8.6 μSv/h. The buildup factor for this finite slab in air, 2.1, is **RadMap's own result**: published factors are for a source inside an unlimited medium, which this geometry is far from – the slab lets scatter escape sideways, and no water lies beyond it to scatter photons back (EK-Cs137-WaterInf checks a published factor in its own geometry). The expectation is 8.6 × 2.1 = 18.1 μSv/h, within ±15 %; without the scattered photons the result would be 8.6 μSv/h and fail clearly. The case runs 1 000 000 decays: at 500 000 the statistical uncertainty was 4.7 %, and three times that barely fitted inside the tolerance.

Check	Result	Criterion	Verdict
d(1 m) behind water, ROT	(1.767 ± 0.060) × 10^{-5} Sv/h	1.810 × 10^{-5} Sv/h ± 15 %	pass

BK-Co60-Pb: Co-60 through 21.7 mm of lead: air kerma

Result
passed

Verifies
R-10, R-11, R-17

Basis
Published reference – *ANSI/ANS-6.4.3-1991*, Tables 1a and 3, as reproduced in NUREG/CR-5740; *NUREG/CR-5740*, Table 3; *ICRP 74*, Table A.1; *DDEP Co-60*

Test
DoseTest

The geometry of B-Co60-Pb, scored as air kerma, the quantity the standard's exposure buildup factors are for. With each line weighted by its kerma, 5.082 and 5.617 pGy·cm² per decay (AK-Co60), the slab passes 0.240 of the unshielded air kerma rate at a point 1 m away, 306.5 µGy/h, without scatter: 73.5 µGy/h. The buildup factor, weighted the same way, is 1.519, so the expectation is 73.5 × 1.519 = 111.6 µGy/h, within ±10 %. The slab differs from the standard's unlimited medium as in B-Co60-Pb.

Check	Result	Criterion	Verdict
air kerma at 1 m behind lead	(1.079 ± 0.031) × 10^{-4} Gy/h	1.116 × 10^{-4} Gy/h ± 10 %	pass

BK-Cs137-Pb: Cs-137 through 9.8 mm of lead: air kerma

Result
passed

Verifies
R-10, R-11, R-17

Basis
Published reference – *ANSI/ANS-6.4.3-1991*, Tables 1a and 3, as reproduced in NUREG/CR-5740; *NUREG/CR-5740*, Table 3; *ICRP 74*, Table A.1; *DDEP Cs-137*

Test
DoseTest

The geometry of B-Cs137-Pb, scored as air kerma, the quantity the standard's exposure buildup factors are for. Without scatter the slab passes 0.310 of the unshielded 75.7 µGy/h at a point 1 m away (AK-Cs137): 23.5 µGy/h. With the buildup factor of B-Cs137-Pb, 1.335, the expectation is 23.5 × 1.335 = 31.4 µGy/h, within ±10 %. It runs 2 000 000 decays, as B-Cs137-Pb does.

Check	Result	Criterion	Verdict
air kerma at 1 m behind lead	(3.017 ± 0.064) × 10^{-5} Gy/h	3.140 × 10^{-5} Gy/h ± 10 %	pass

AK-Cs137: Cs-137 point source in vacuum: air kerma and inverse square

Result
passed

Verifies
R-1, R-2, R-9, R-17

Basis
Published reference – *ICRP 74*, Table A.1; *DDEP Cs-137*

Test
DoseTest

The geometry and maps of A-Cs137-ROT, scored as air kerma, and derived as there. ICRP 74's air kerma table has no point at 0.662 MeV; between its points at 0.600 MeV (2.84 pGy·cm²) and 0.800 MeV (3.69 pGy·cm²) the spline gives 3.111 pGy·cm² at 661.657 keV, and the gamma line alone gives 75.7 µGy/h at a point 1 m away. Air kerma also counts the X-rays: the K X-rays add 0.041 pGy·cm² per decay, and the L X-rays, below the table and counted at its 10 keV value of 7.43 pGy·cm², add 0.067 pGy·cm² – together 3.9 % of the sum. In air the L X-rays would not get past a few centimetres. Per decay, Σ yield × h_K = 2.7514 pGy·cm², so at a point 1 m away the air kerma rate is 7 957.7 × 2.7514 × 10^{-12} × 3600 = 78.82 µGy/h, and the map reads 0.9743 of it: 76.79 µGy/h, within ±3 %. The inverse square law holds within ±3 %, at 3 000 000 decays as in A-Cs137-ROT.

Check	Result	Criterion	Verdict
k(0.5 m) / k(1 m)	3.975 ± 0.031	4 ± 3 %	pass
k(1 m) / k(2 m)	4.014 ± 0.032	4 ± 3 %	pass
air kerma at 1 m	(7.701 ± 0.043) × 10^{-5} Gy/h	7.679 × 10^{-5} Gy/h ± 3 %	pass

AK-Co60: Co-60 point source in vacuum: air kerma and inverse square

Result
passed

Verifies
R-1, R-9, R-17

Basis
Published reference – *ICRP 74*, Table A.1; *DDEP Co-60*

Test
DoseTest

The geometry and maps of A-Co60-ROT, scored as air kerma, and derived as there. Both lines fall between ICRP 74's points at 1.000 MeV (4.47 pGy·cm²) and 1.500 MeV (6.14 pGy·cm²); the spline gives 5.089 pGy·cm² at 1173.228 keV and 5.618 pGy·cm² at 1332.492 keV. Per decay, Σ yield × h_K = 10.700 pGy·cm², so at a point 1 m away the air kerma rate is 7 957.7 × 10.700 × 10^{-12} × 3600 = 306.5 µGy/h, and the map reads 0.9743 of it: 298.6 µGy/h, within ±3 %. The inverse square law holds within ±3 %, at 1 500 000 decays as in A-Co60-ROT.

Check	Result	Criterion	Verdict
k(0.5 m) / k(1 m)	4.036 ± 0.030	4 ± 3 %	pass
k(1 m) / k(2 m)	4.013 ± 0.030	4 ± 3 %	pass
air kerma at 1 m	(2.983 ± 0.015) × 10^{-4} Gy/h	2.986 × 10^{-4} Gy/h ± 3 %	pass

AH-Cs137: Cs-137 point source in vacuum: ambient dose equivalent H*(10)

Result
passed

Verifies
R-1, R-2, R-9, R-16, R-17

Basis
Published reference – *ICRP 74*; *DDEP Cs-137*

Test
DoseTest

The geometry and maps of A-Cs137-ROT, scored as H∗(10) and derived as there, with an air kerma map in the same place as the one at 1 m.

H*(10) at 1 m.** ICRP 74 brackets 661.657 keV between 0.600 MeV (3.44 pSv·cm²) and 0.800 MeV (4.38 pSv·cm²); the spline gives 3.741 pSv·cm². The K X-rays add 0.051 pSv·cm² per decay, 1.6 %, and the L X-rays nothing, being below the table. Per decay, Σ yield × h* = 3.2304 pSv·cm², so at a point 1 m away the dose rate is 7 957.7 × 3.2304 × 10^{-12} × 3600 = 92.54 µSv/h, and the map reads 0.9743 of it: 90.16 µSv/h, within ±3 %. The inverse square law holds within ±3 %, at 3 000 000 decays as in A-Cs137-ROT.

H*(10) against air kerma.** The air kerma map scores exactly the same photons, so the ratio of the two varies by well under 0.1 % and is shown without an uncertainty; it must equal the ratio of the two sums, 3.2304 / 2.7514 = 1.1741 Sv/Gy (AK-Cs137 for air kerma), within ±1 %. For photons the ratio of the coefficients stays between roughly 1 and 2, so a coefficient read from the wrong column of the table cannot satisfy it.

Check	Result	Criterion	Verdict
H∗(0.5 m) / H∗(1 m)	3.963 ± 0.031	4 ± 3 %	pass
H∗(1 m) / H∗(2 m)	4.034 ± 0.032	4 ± 3 %	pass
H∗(10) at 1 m	(9.051 ± 0.050) × 10^{-5} Sv/h	9.016 × 10^{-5} Sv/h ± 3 %	pass
H∗(10) / air kerma	1.175 Sv/Gy	1.174 Sv/Gy ± 1 %	pass

AH-Co60: Co-60 point source in vacuum: ambient dose equivalent H*(10), two lines

Result
passed

Verifies
R-1, R-9, R-16, R-17

Basis
Published reference – *ICRP 74*; *DDEP Co-60*

Test
DoseTest

The check AH-Cs137 cannot make: two lines per decay, both interpolated, neither at a point of the table. The geometry and maps are those of AH-Cs137, with Co-60, derived as in A-Co60-ROT.

H*(10) at 1 m.** ICRP 74 brackets both lines between 1.000 MeV (5.20 pSv·cm²) and 1.500 MeV (6.90 pSv·cm²); the spline gives 5.819 pSv·cm² at 1173.228 keV and 6.348 pSv·cm² at 1332.492 keV. Per decay, Σ yield × h* = 12.158 pSv·cm², so at a point 1 m away the dose rate is 7 957.7 × 12.158 × 10^{-12} × 3600 = 348.3 µSv/h, and the map reads 0.9743 of it: 339.3 µSv/h, within ±3 %; the inverse square law holds within ±3 %.

H*(10) against air kerma.** As in AH-Cs137, the ratio must equal that of the two sums: 12.158 / 10.700 = 1.1363 Sv/Gy (AK-Co60 for air kerma), within ±1 %.

Check	Result	Criterion	Verdict
H*(0.5 m) / H*(1 m)	4.036 ± 0.030	4 ± 3 %	pass
H*(1 m) / H*(2 m)	4.013 ± 0.029	4 ± 3 %	pass
H*(10) at 1 m	(3.390 ± 0.018) × 10^{-4} Sv/h	3.393 × 10^{-4} Sv/h ± 3 %	pass
H*(10) / air kerma	1.136 Sv/Gy	1.136 Sv/Gy ± 1 %	pass

EK-Cs137-Water: Cs-137 through 230 mm of water, 300 mm wide: air kerma

Result
passed

Verifies
R-10, R-11, R-17

Basis
Partly RadMap's own result – *NIST XCOM*; *ICRP 74*, Table A.1; *DDEP Cs-137*

Test
DoseTest

The geometry of E-Cs137-Water, scored as air kerma. Without scatter the slab passes 0.139 of the unshielded 75.7 µGy/h at a point (AK-Cs137): 10.5 µGy/h. In water at this energy scattering dominates, and air kerma and effective dose depend on photon energy alike, so the buildup factor is the same for both: 2.1 for this slab, which is **RadMap's own result** (E-Cs137-Water); no published factor applies to this geometry. The expectation is 10.5 × 2.1 = 22 µGy/h, within ±20 %.

Check	Result	Criterion	Verdict
air kerma at 1 m behind water	(2.166 ± 0.073) × 10^{-5} Gy/h	2.200 × 10^{-5} Gy/h ± 20 %	pass

EK-Cs137-WaterInf: Cs-137 inside water, 2 mean free paths from the maps: air kerma and buildup

Result
passed

Verifies
R-10, R-11, R-17

Basis
Published reference – *ANSI/ANS-6.4.3-1991*, Tables 1a and 3, as reproduced in NUREG/CR-5740; *NUREG/CR-5740*; *ICRP 74*, Table A.1; *DDEP Cs-137*

Test
DoseTest

The standard's buildup factors are for a point source in an unlimited medium, with the response at a point inside it, and the case builds that geometry. The Cs-137 source of A-Cs137-ROT, in a 1 mm cube of water, sits at the centre of a world of water 5 m wide, more than 20 mean free paths to every side: for the photons reaching the maps, the water is unlimited. Six air kerma maps lie 2 mean free paths from the source on ±x, ±y and ±z, and the case checks each.

The standard's Table 1a gives µ/ρ for water of 0.08943 cm^2/g at 0.6 MeV and 0.07856 cm^2/g at 0.8 MeV; log-log at 0.662 MeV, 0.08557 cm^2/g, so 2 mean free paths are 233.7 mm. Unattenuated, the source gives 6 763 photons cm^{-2} s^{-1} at 1 m (A-Cs137-ROT), so 1.238 × 10^5 cm^{-2} s^{-1} at 233.7 mm; with ICRP 74's 3.11 pGy·cm^2 (AK-Cs137) that is 1 386 µGy/h, of which e^{-2} = 0.1353 arrives without interacting: 188 µGy/h. Table 3 gives exposure buildup factors at 2 mfp of 4.49 at 0.6 MeV and 3.96 at 0.8 MeV; linear in log energy, 4.31 at 0.662 MeV. The expectation is 188 × 4.31 = 810 µGy/h, within ±10 %.

The maps are plates, 40 × 40 mm and 1 mm thick, facing the source. A map reads the fluence averaged over its volume, and across a plate's 40 mm that mean lies about 0.5 % below the value at its centre.

Measured when the case was written, the same six maps at 1, 2 and 3 mean free paths, each depth in a run of its own with 2 000 000 decays, gave buildup factors of 2.22 to 2.27 (σ 0.019 for each map), 4.20 to 4.39 (σ 0.08) and 6.70 to 7.36 (σ 0.23 to 0.30), against the standard's 2.28, 4.31 and 7.04.

Check	Result	Criterion	Verdict
air kerma at 2 mfp, +x	(7.90 ± 0.15) × 10^{-4} Gy/h	8.100 × 10^{-4} Gy/h ± 10 %	pass
air kerma at 2 mfp, -x	(8.24 ± 0.16) × 10^{-4} Gy/h	8.100 × 10^{-4} Gy/h ± 10 %	pass
air kerma at 2 mfp, +y	(7.94 ± 0.16) × 10^{-4} Gy/h	8.100 × 10^{-4} Gy/h ± 10 %	pass
air kerma at 2 mfp, -y	(7.88 ± 0.15) × 10^{-4} Gy/h	8.100 × 10^{-4} Gy/h ± 10 %	pass
air kerma at 2 mfp, +z	(8.02 ± 0.16) × 10^{-4} Gy/h	8.100 × 10^{-4} Gy/h ± 10 %	pass
air kerma at 2 mfp, -z	(8.01 ± 0.16) × 10^{-4} Gy/h	8.100 × 10^{-4} Gy/h ± 10 %	pass

CK-Na22: Na-22 in an aluminium capsule: air kerma, annihilation photons included

Result
passed

Verifies
R-1, R-3, R-9, R-17

Basis
Published reference – *ICRP 74*, Table A.1; *DDEP Na-22*; *NIST SRD 126*

Test
DoseTest

A 1 GBq Na-22 source in a 0.4 mm aluminium cube at the centre of a 2 mm aluminium cube, its capsule, in vacuum, scored as air kerma at 0.5, 1 and 2 m by the maps of A-Co60-ROT, on the capsule's axes, and derived as there. Aluminium stops the positrons within 0.6 mm, and every decay is at least 0.8 mm from the capsule's face, so both annihilation photons start at the source; without the capsule the positrons would range out over tens of centimetres of air, and in vacuum would not stop at all.

Na-22 decays by beta+ (90.36 %) or electron capture (9.64 %), all but 0.06 % of decays to the 1.2745 MeV level of Ne-22, so each decay gives a 1.2745 MeV gamma (yield 0.9994) and 1.807 annihilation photons at 0.511 MeV. Its Ne K X-rays, at 0.85 keV, do not leave the capsule. The spline gives ICRP 74's air kerma coefficients as 5.4297 and 2.4321 pGy·cm². The air kerma rate at a point 1 m away is (0.9994 × 5.4297 + 1.807 × 2.4321) × 10^{-12} × 7 957.7 × 3600 = 281.4 µGy/h, and the map reads 0.9743 of it: 274.2 µGy/h. Without the annihilation photons it would be 151.6 µGy/h.

The capsule's 1 mm of aluminium, at 2.70 g/cm³, takes 2.3 % of the 511 keV photons and 1.5 % of the 1.27 MeV photons crossing it, with mass attenuation coefficients of 0.0837 and 0.0544 cm²/g (NIST SRD 126, interpolated log-log): 1.8 % of the air kerma, less the photons it scatters forward. The tolerance, ±4 %, covers that loss and three standard deviations at 1 500 000 decays. The inverse square law holds within ±3 %.

Check	Result	Criterion	Verdict
k(0.5 m) / k(1 m)	3.969 ± 0.026	4 ± 3 %	pass
k(1 m) / k(2 m)	4.001 ± 0.027	4 ± 3 %	pass
air kerma at 1 m	(2.748 ± 0.013) × 10^{-4} Gy/h	2.742 × 10^{-4} Gy/h ± 4 %	pass

X-Am241: Am-241 point source in air: X-rays, air kerma and effective dose

Result
passed

Verifies
R-1, R-2, R-9, R-15, R-17

Basis
Published reference – *DDEP Am-241*; *NIST XCOM*; *ICRP 74*, Table A.1; *ICRP 116*, Table A.1

Test
DoseTest

A 1 GBq Am-241 source in a 1 mm cube of air, scored as air kerma and as effective dose (ROT) at 1 m. Am-241's alpha decay leaves Np-237 excited, and the internal conversion of its low-energy transitions empties L shells, which refill with Np L X-rays. This is the only case scored mainly on X-rays.

Photons per decay, from DDEP:

Photons	Energy (keV)	Per decay
gamma	59.54	0.3592
gamma	26.34	0.0231
gamma	33.20	0.0012
L X-rays, Ll	11.89	0.0084
L X-rays, Lα	13.9	0.1302
L X-rays, Lη	15.88	0.0038
L X-rays, Lβ	about 17.5	0.1858
L X-rays, Lγ	about 21.1	0.0483

Group energies are the intensity-weighted means of their lines. One metre of air (0.1205 g/cm²) passes 0.79 of the Lα, 0.86 of the Lβ and 0.98 of the 59.5 keV photons (NIST XCOM). Summing over the lines with the ICRP 74 and ICRP 116 coefficients and the point-source fluence gives 27.8 µGy/h of air kerma, 87 % of it from the X-rays, and 3.28 µSv/h of effective dose, 21 % from the X-rays. Without X-rays the air kerma would fall about eightfold.

Tolerances. Measured when the case was written: +9.4 % on the air kerma and +2.4 % on the effective dose, with statistical uncertainties of 1.3 % and 1.1 %. The air kerma's excess has two known parts. Geant4's L X-ray yields total 0.372 against DDEP's 0.377 but put more in Lα and less in Lβ and Lγ, worth +3.5 % with a coefficient this steep. The rest is air scatter, which the derivation removes in full although much of it still reaches the map. Hence ±15 % on the air kerma and ±10 % on the effective dose. The case runs 5 000 000 decays, because the map scores few X-rays and 500 000 left it about 5 % noisy.

Nothing below 10 keV, where the coefficient tables stop, reaches 1 m: the Np M X-rays (3.2 to 3.7 keV) travel about 6 cm in air.

Check	Result	Criterion	Verdict
air kerma at 1 m	(3.039 ± 0.041) × 10^{-5} Gy/h	2.780 × 10^{-5} Gy/h ± 15 %	pass
effective dose at 1 m	(3.360 ± 0.036) × 10^{-6} Sv/h	3.280 × 10^{-6} Sv/h ± 10 %	pass

C-Ru106-Chain: Ru-106 with Full chain on and off: its daughter Rh-106 decays only when on

Result
passed

Verifies
R-1, R-8, R-15, R-17

Basis
Published reference – *DDEP Ru-106*; *DDEP Rh-106*; *ICRP 116*, Table A.1; *ICRP 74*, Table A.1

Test
DoseTest

A 1 GBq Ru-106 source in vacuum, scored at 1 m as effective dose (ROT) and as air kerma, run once with *Full chain* on and once with it off. Vacuum (hydrogen at 10^{-25} g/cm³, as Geant4 models it) leaves nothing between source and map but the inverse square law, so the comparison is of the emission, the chain and the conversion alone.

Ru-106 (half-life 372 d) decays by beta− with an endpoint of 39.4 keV straight to the ground state of Rh-106 and emits no photons. Its daughter Rh-106 (30 s) decays by beta− to excited levels of Pd-106 and gives off 0.342 gammas per decay, over some ninety lines. So the photons come entirely from the daughter: with *Full chain* off RadMap must stop at Rh-106 and score nothing, and with it on Rh-106 must decay once for each decay of Ru-106. The daughter's ground state is what makes this a test of the chain: excited and metastable daughters decay either way.

Chain on. Summing every Rh-106 line DDEP lists, each with its ICRP 116 (ROT) and ICRP 74 coefficients as RadMap interpolates them, over the point-source fluence at 1 m, gives 22.3 µSv/h of effective dose and 27.4 µGy/h of air kerma. Three lines carry most of it:

Line (keV)	Per decay	Share of the effective dose
511.85	0.2052	52 %
621.90	0.0987	30 %
1050.39	0.0149	7 %

Measured when the case was written, with 10 000 000 decays: +0.6 % on the effective dose and +0.9 % on the air kerma, each with a statistical uncertainty of 1.0 %. Geant4's Rh-106 yields run 1 to 6 % above DDEP's, about +1.5 % weighted by dose. At 2 000 000 decays, with an uncertainty of about 2.2 %, one run read +4.5 %, which is why the case runs five times as many. The tolerance, ±5 %, covers both; a daughter decaying twice, or not at all, misses it by far.

Chain off. The dose rate must be below 1 % of that with the chain on; only stray photons from the betas could give any.

Check	Result	Criterion	Verdict
effective dose at 1 m, chain on	(2.251 ± 0.022) × 10^{-5} Sv/h	2.230 × 10^{-5} Sv/h ± 5 %	pass
air kerma at 1 m, chain on	(2.764 ± 0.027) × 10^{-5} Gy/h	2.740 × 10^{-5} Gy/h ± 5 %	pass
effective dose, chain off / on	0 ± 0	below 0.01	pass

C-Chain-PerSource: Full chain applies only to the isotope it is set on

Result
passed

Verifies
R-7, R-8

Basis
Condition

Test
DoseTest

Each simulation thread decays a project's sources one after another, so one source's *Full chain* setting must not carry over to the next decay (D-0013).

1 GBq each of Te-132, with *Full chain* off, and Ru-106, with it on, share one 1 mm cube of air, with an effective dose map (ROT) at 0.5 m. Were Ru-106's setting to leak, Te-132's daughter I-132, which emits far more photons than Te-132, would decay too. The two together must read the sum of each run alone, within ±5 %; with the fault put back they read 5.9 times the sum.

Check	Result	Criterion	Verdict
together / sum of the two alone	0.9953	1 ± 5 %	pass

C-Chain-None: Full chain changes nothing for an isotope with no chain

Result
passed

Verifies
R-7, R-8

Basis
Condition

Test
DoseTest

For an isotope whose daughters do not decay further, RadMap keeps *Full chain* off, since it could change nothing. Cs-137 is one: its daughter Ba-137m is followed in any case, as an excited state, and the ground state it falls to is stable. So the setting, on or off, must not move the dose rate.

1 GBq of Cs-137 in a 1 mm cube of air, with an effective dose map (ROT) at 0.5 m, run with the setting off and on. The API refuses to turn it on for such an isotope, so the case sets it on the model's source directly. The two must agree within ±5 %.

Check	Result	Criterion	Verdict
on / off	1	1 ± 5 %	pass

S-Name-0x: A source stays in its solid whatever the solid is called

Result
passed

Verifies
R-6, R-12

Basis
Condition

Test
DoseTest

A name may hold "0x", as `Block100x100` does, where Geant4's reader of geometry files cuts names by default. The source's confinement then found no volume, and decays spread through the box around the solid, children included (D-0014).

A 200 mm cube of air holds a 190 mm cube of lead, with 1 GBq of Cs-137 in the air, so its decays lie in a 5 mm shell outside the lead. With an effective dose map (ROT) at 0.5 m, the same project and seed must read the same under both names, within ±5 %. Before the fix `Block100x100` read 3.9 times lower, with most decays inside the lead.

Check	Result	Criterion	Verdict
Block100x100 / Block	1	1 ± 5 %	pass

S-World: A source in the world volume stays out of the world's children

Result
passed

Verifies
R-6

Basis
Condition

Test
DoseTest

The world volume is placed by Geant4, not by a line of the geometry file, so a source's confinement once found no volume by the name RadMap asks for, and decays spread through the whole world, children included (D-0019).

A 1200 mm cube of air holds a 1000 mm cube of lead, with 1 GBq of Cs-137 in the air, so its decays lie in a 100 mm shell outside the lead. The cube of air is the world in one run, and a solid in a larger world in the other, and an effective dose map (ROT) sits at the same place in the shell. The two must agree within ±5 %. They share a seed, so their errors are correlated and the ratio gets no σ. With the fault put back it read 0.47.

Check	Result	Criterion	Verdict
in the world / in a solid	0.9996	1 ± 5 %	pass

U-Cs137-Spread: The reported uncertainty matches the spread of repeated runs

Result
passed

Verifies
R-18

Basis
Condition

Test
DoseTest

RadMap reports each dose rate with a statistical uncertainty: the standard error of the mean of the doses the individual decays deposit, one standard deviation. The case checks that number against what it claims to predict, the scatter of the dose rate between independent runs.

A 1 GBq Cs-137 source in a 1 mm cube of air, with effective dose maps (ROT) at 0.5, 1 and 2 m, is run 20 times with 100 000 decays each, every run with its own seed. For each map, the standard deviation s of the 20 dose rates is compared with the mean uncertainty σ RadMap reported for them. If σ is right, $(s/\sigma)^2$ follows a χ^2 distribution with 19 degrees of freedom divided by 19, which puts s/σ between 0.55 and 1.5 with a probability of 99.8 %. An uncertainty reported twice too large or too small fails. The three maps catch about 1 100, 270 and 70 photons a run, so the check holds from well-sampled maps to sparse ones.

Scaling. The same project with 400 000 decays, four times as many, must report a relative uncertainty half as large: the mean of the 20 relative uncertainties at 100 000 decays over the one at 400 000 is 2, within ±10 %, which covers the scatter of the uncertainty estimates themselves.

Every map must report an uncertainty above zero in every run.

Measured when the case was written: s/σ of 0.88, 1.10 and 0.86 at 0.5, 1 and 2 m, and uncertainty ratios of 2.02, 2.01 and 2.07. The 21 runs take about 40 s.

Check	Result	Criterion	Verdict
every map reports an uncertainty above zero	holds	holds	pass
s / sigma at 0.5 m	0.8869	above 0.55	pass
s / sigma at 0.5 m	0.8869	below 1.5	pass
rel. sigma, 100k / 400k decays, 0.5 m	2.016	2 ± 10 %	pass
s / sigma at 1 m	1.107	above 0.55	pass
s / sigma at 1 m	1.107	below 1.5	pass
rel. sigma, 100k / 400k decays, 1 m	2.015	2 ± 10 %	pass
s / sigma at 2 m	0.8518	above 0.55	pass
s / sigma at 2 m	0.8518	below 1.5	pass
rel. sigma, 100k / 400k decays, 2 m	2.071	2 ± 10 %	pass

F-Sr90-Toggle: Sr-90 in a lead container: bremsstrahlung only with electron transport

Result
passed

Verifies
R-14

Basis
Condition – *DDEP Sr-90*

Test
DoseTest

Sr-90 decays by beta− (endpoint 0.546 MeV) straight to the ground state of Y-90: no gamma lines, and *Full chain* is off, so Y-90 does not decay. A 3.7 GBq source in a 1 mm cube of air sits inside a 3 mm lead cube with 1 mm walls; the betas stop within 0.1 mm of lead. The dose map, 200 × 200 × 1 mm, is at 0.5 m.

With *Simulate electrons* on, the betas' bremsstrahlung in the lead reaches the map; with it off, nothing does. The check is that the dose rate with electrons off is below 1 % of that with them on.

Check	Result	Criterion	Verdict
dose, electrons off / on	0 ± 0	below 0.01	pass

F-P32-Plate: P-32 behind a thin plate: more bremsstrahlung from lead than from PMMA

Result
passed

Verifies
R-14

Basis
Condition – *DDEP P-32*

Test
DoseTest

The situation radiation-protection guidance warns about: a beta source held behind a thin, dense absorber. P-32 decays by beta− (endpoint 1.711 MeV) with no gamma lines, so every photon reaching the map is bremsstrahlung. A 1 GBq source in a 1 mm cube of air sits 5 mm in front of a 100 × 100 mm plate: once 1 mm of lead, once 10 mm of PMMA, the plastic shield recommended for P-32. An effective dose map (ROT, photons), 200 × 200 × 1 mm, is at 30 mm, close behind the plate. Electron transport is on.

Bremsstrahlung grows with the atomic number of the absorber, so the lead plate gives the higher photon dose rate. Lead also absorbs much of its own soft bremsstrahlung, so the dose ratio is far smaller than the ratio of the yields: at 200 000 decays per run the case reads 2.09 ± 0.13, at 187 ± 8 µSv/h behind the lead. Four seeds at 1 000 000 decays per run gave 2.02 ± 0.05, 1.99 ± 0.06, 1.92 ± 0.10 and 1.97 ± 0.07. No published ratio for this geometry is known, so the check is a direction: lead gives more than PMMA, held by about 8σ.

Check	Result	Criterion	Verdict
dose, lead / PMMA plate	2.09 ± 0.11	above 1	pass

5.2 SourceDistributionTest

R6-Sampling: Decays fill the source's volume evenly, whatever its shape and placement

Result
passed

Verifies
R-6, R-12

Basis
Condition

Test
SourceDistributionTest

A source's volume is its solid less the solids placed inside it. Where its decays happen is decided in Geant4's source sampler: RadMap gives it a box enclosing the source solid, in world coordinates, and the sampler samples positions evenly in that box and keeps those that Geant4's navigator places in the source's volume – a position inside a child solid is placed in the child and rejected. So decays are even in the source's volume by construction, provided the box RadMap computes really encloses the solid. That box depends on the solid's shape, its rotation and every parent's position and rotation, and getting it wrong leaves part of the source without decays, or all of it, which a dose at a distance would barely show. This case looks at the decays themselves.

Three Sr-90 sources of 1 GBq each, in vacuum, chosen to make that box hard to get right:

Source	Shape	Placement
A	box 200 × 120 × 80 mm, containing a half sphere, a tube segment and a small box	inside a parent box moved to (300, 200, −100) mm and rotated (20°, 0°, 35°), itself moved and rotated (0°, 25°, 0°) in it
B	tube segment, radii 20 and 80 mm, 120 mm long, from 30° over 220°	rotated (30°, 45°, 0°), moved to (−300, 0, 100) mm
C	sphere segment, radii 10 and 70 mm, φ from 0° to 90°, θ from 0° to 60°	rotated (0°, 30°, 60°), inside a parent moved to (0, −450, 0) mm and rotated (40°, 0°, 50°)

The segments' bounding boxes are off-centre – source C's by about 60 mm – and the solids rotated, so the sampling box must turn its offset with them, and source C's with its parent's rotation too, composed in the right order; source A's box must follow two levels of transform. The case runs DoseAlgorithm on exactly the geometry and macro RadMap generates for the project, with 30 000 decays, and reads every decay's starting point from Geant4's own trace (/tracking/verbose 1).

Each point is taken back into the frame of the source it belongs to, with the positions and rotations as entered and RadMap's rotation order (an offset turns about Z, then Y, then X), and tested against the shape as defined – written out here, not taken from RadMap. The trace gives positions to three significant figures, ±0.5 mm at a few hundred millimetres, so a point counts as inside a solid within 1 mm of it, and inside a child only when more than 1 mm into it. The checks:

- each source's sampling box, as the macro gives it to Geant4, encloses the whole source: points spread densely over the shape as defined, placed in the world by the test's own transforms, lie no further outside the box than the macro's rounding allows (5 µm). This finds a box short by far less than the trace or the statistics below can show – a box fitted to the drawing mesh, which stops short of a curved surface between vertices, failed it by 30 µm;
- every decay lies inside one of the three sources;
- no decay lies inside a child of source A;
- each source receives a third of the decays, as their activities are equal;
- within each source, the decays fall into the cells of a 4 × 4 × 4 grid over the shape's extent in its own frame in proportion to each cell's share of the source's volume, which the test finds by sampling the shape evenly itself. The comparison is a χ^2 test against its 99.9 % point for the number of cells used, leaving out cells holding almost none of the volume, as χ^2 requires. A sampling box that misses a few centimetres of a source empties the cells there and fails it.

The case was checked against three wrong ways of placing the sampling box: with its offset not rotated, rotated the wrong way, and rotated by the source's own rotation without its parent's. Each fails it.

Check	Result	Criterion	Verdict
sampling box overreach, source A	4.263×10^{-14} mm	below 0.005 mm	pass
sampling box overreach, source B	5.684×10^{-14} mm	below 0.005 mm	pass
sampling box overreach, source C	5.684×10^{-14} mm	below 0.005 mm	pass
every decay inside one of the sources	holds	holds	pass
no decay inside a child of source A	holds	holds	pass
share of decays, source A	0.34	0.3333 ± 4.08 %	pass
grid chi2, source A	55.78	below 103.5	pass
share of decays, source B	0.3275	0.3333 ± 4.08 %	pass
grid chi2, source B	60.98	below 82.8	pass
share of decays, source C	0.3325	0.3333 ± 4.08 %	pass
grid chi2, source C	45.15	below 74.83	pass

5.3 GeometryShieldingTest

G-Box: Lead box: its width casts the expected shadow

Result
passed

Verifies
R-10, R-12

Basis
Condition

Test
GeometryShieldingTest

A Co-60 source and a lead shield in air, with effective dose maps (ROT) some of which the shield should cover. The expectation is geometry alone: a map the shield covers scores less than one it does not, which holds only if the shield's dimensions and angles reach Geant4 as RadMap describes them.

The source sits 100 mm in front of a 100 × 100 × 20 mm lead slab; three 30 mm maps lie 50 mm behind it, at x = 0, 40 and 90 mm. From the source, the slab's edge casts its shadow out to x ≈ 68 mm at the maps, so the maps at 0 and 40 mm are covered and the one at 90 mm is not. A slab of half the width would leave the map at 40 mm uncovered, and one of twice the width would cover the map at 90 mm, so the case also catches a halved or doubled dimension.

Check	Result	Criterion	Verdict
covered at x = 0 / uncovered	0.4379	below 1	pass
covered at x = 40 / uncovered	0.3923	below 1	pass

G-Tube-Phi-0: Lead tube sector from 0° to 180°: covers +Y only

Result
passed

Verifies
R-10, R-12

Basis
Condition

Test
GeometryShieldingTest

A Co-60 source and a lead shield in air, as in G-Box: a map the shield covers must score less than one it does not.

A half tube (radii 25 and 100 mm, 500 mm long) spans φ = 0° to 180°, the +Y side. Of two maps 300 mm from the source, the one at +Y is covered and the one at −Y is not.

Check	Result	Criterion	Verdict
+Y / -Y	0	below 1	pass

G-Tube-Phi-180: Lead tube sector from 180° to 360°: covers −Y only

Result
passed

Verifies
R-10, R-12

Basis
Condition

Test
GeometryShieldingTest

A Co-60 source and a lead shield in air, as in G-Box: a map the shield covers must score less than one it does not.

G-Tube-Phi-0 with the sector starting at φ = 180°: now the map at −Y is covered and the one at +Y is not, so the start angle is read as well as the span.

Check	Result	Criterion	Verdict
-Y / +Y	0	below 1	pass

G-Tube-Phi-Gap: Lead tube with a 20° gap: maps either side of its edge

Result
passed

Verifies
R-10, R-12

Basis
Condition

Test
GeometryShieldingTest

A Co-60 source and a lead shield in air, as in G-Box: a map the shield covers must score less than one it does not.

The tube spans φ = 10° to 350°, leaving a 20° gap around +X. A map at φ = 0° sees the source through the gap; maps at φ = ±25°, 15° inside the tube's ends, are covered.

Check	Result	Criterion	Verdict
phi = -25 deg / gap	0.08595	below 1	pass
phi = +25 deg / gap	0.001242	below 1	pass

G-Sphere-Phi-10: Lead sphere shell with a 20° azimuthal gap at +X

Result
passed

Verifies
R-10, R-12

Basis
Condition

Test
GeometryShieldingTest

A Co-60 source and a lead shield in air, as in G-Box: a map the shield covers must score less than one it does not.

A shell of radii 1 and 10 mm spans φ = 10° to 350° and all of θ, leaving a 20° gap around +X; the source sits in its hollow. Six small maps lie 11 mm from the centre in the XY plane, at φ = 0°, ±15°, 180° and 180° ± 15°. Only the one at φ = 0° is in the gap; the ones at ±15°, 5° past its edges, are covered.

Check	Result	Criterion	Verdict
phi = +15 deg / gap	0.6385	below 1	pass
phi = -15 deg / gap	0.5721	below 1	pass
phi = 180 deg / gap	0.6609	below 1	pass
phi = 165 deg / gap	0.6343	below 1	pass
phi = 195 deg / gap	0.6356	below 1	pass

G-Sphere-Phi-190: Lead sphere shell with a 20° azimuthal gap at −X

Result
passed

Verifies
R-10, R-12

Basis
Condition

Test
GeometryShieldingTest

A Co-60 source and a lead shield in air, as in G-Box: a map the shield covers must score less than one it does not.

G-Sphere-Phi-10 with the shell starting at φ = 190°, which moves the gap to −X: now only the map at φ = 180° is uncovered.

Check	Result	Criterion	Verdict
phi = 0 deg / gap	0.6015	below 1	pass
phi = +15 deg / gap	0.6122	below 1	pass
phi = -15 deg / gap	0.5744	below 1	pass
phi = 165 deg / gap	0.5892	below 1	pass
phi = 195 deg / gap	0.5921	below 1	pass

G-Sphere-Theta-10: Lead sphere shell with a 10° polar gap at +Z

Result
passed

Verifies
R-10, R-12

Basis
Condition

Test
GeometryShieldingTest

A Co-60 source and a lead shield in air, as in G-Box: a map the shield covers must score less than one it does not.

A shell of radii 1 and 10 mm spans θ = 10° to 180° and all of φ, leaving a 10° cap open around +Z; the source sits in its hollow. Six small maps lie 11 mm from the centre, at θ = 0°, 15° (twice), 180° and 165° (twice). Only the one at θ = 0° is in the gap; the ones at 15°, 5° past its edge, are covered.

Check	Result	Criterion	Verdict
theta = 15 deg, +X / gap	0.4671	below 1	pass
theta = 15 deg, -X / gap	0.6322	below 1	pass
theta = 180 deg / gap	0.5725	below 1	pass
theta = 165 deg, +X / gap	0.6212	below 1	pass
theta = 165 deg, -X / gap	0.6264	below 1	pass

G-Sphere-Theta-0: Lead sphere shell with a 10° polar gap at −Z

Result
passed

Verifies
R-10, R-12

Basis
Condition

Test
GeometryShieldingTest

A Co-60 source and a lead shield in air, as in G-Box: a map the shield covers must score less than one it does not.

G-Sphere-Theta-10 with the shell spanning θ = 0° to 170°, which moves the gap to −Z: now only the map at θ = 180° is uncovered.

Check	Result	Criterion	Verdict
theta = 0 deg / gap	0.6688	below 1	pass
theta = 15 deg, +X / gap	0.5289	below 1	pass
theta = 15 deg, -X / gap	0.7033	below 1	pass
theta = 165 deg, +X / gap	0.6568	below 1	pass
theta = 165 deg, -X / gap	0.6787	below 1	pass

5.4 GeometryTransformTest

T-Translation: Dose maps attached to a solid follow its position

Result
passed

Verifies
R-12

Basis
Condition

Test
GeometryTransformTest

Dose maps attached to a solid must land where the solid's transform puts them, and the check is exact. Each pair is two dose maps that should end up in the same place: one placed directly in the world at a position and rotation worked out by hand, the other attached to a source solid and placed relative to it, so that RadMap has to compose the solid's transform with the map's own. With a fixed seed on one thread (R-19), two maps in the same place score the same photons and must report identical results to the last digit; a map composed even slightly wrong does not.

Each map sits at its solid's origin, so it must land where the solid is: four solids at different positions, one unrotated and three rotated about X, Y and Z.

Check	Result	Criterion	Verdict
pair 1 — pure translation: source=(100,50,30) no rotation	holds	holds	pass
pair 2 — translation + RX(30°): source=(-100,-50,-30)	holds	holds	pass
pair 3 — translation + RY(45°): source=(0,60,0)	holds	holds	pass
pair 4 — translation + RZ(45°): source=(0,0,60)	holds	holds	pass

T-Rotation: A solid's rotation turns the offsets of its dose maps

Result
passed

Verifies
R-12

Basis
Condition

Test
GeometryTransformTest

Pairs of dose maps, one placed by hand and one through a solid, as in T-Translation: the two must report identical results to the last digit.

Each map is offset from its solid, and the solid's rotation must turn that offset into the world: no rotation, then 90° about X, Y and Z in turn. A fifth pair composes a solid's rotation of 30° about X with the map's own 30° about X, which must give 60°.

Check	Result	Criterion	Verdict
pair 1 — DM local X offset, no solid rotation: dm_local=(30,0,0) → world (110,0,0)	holds	holds	pass
pair 2 — RX(90°) rotates dm_local=(0,50,0) → (0,0,50): world (0,60,50)	holds	holds	pass
pair 3 — RY(90°) rotates dm_local=(50,0,0) → (0,0,-50): world (0,-60,-50)	holds	holds	pass
pair 4 — RZ(90°) rotates dm_local=(50,0,0) → (0,50,0): world (0,50,60)	holds	holds	pass
pair 5 — solid RX(30°) composed with DM local RX(30°) → world rot RX(60°)	holds	holds	pass

T-Multiaxis: Rotations about two axes compose in RadMap's order

Result
passed

Verifies
R-12

Basis
Condition

Test
GeometryTransformTest

Pairs of dose maps, one placed by hand and one through a solid, as in T-Translation: the two must report identical results to the last digit.

Each solid is rotated about two axes, X and Z, Y and Z, X and Y, and offsets its map. Rotations about different axes do not commute, so the hand-worked positions follow RadMap's order – an offset turns about Z first, then Y, then X – and the opposite order would put the maps elsewhere.

Check	Result	Criterion	Verdict
pair 1 — RX(90°)+RZ(90°): dm_local=(50,0,0) →RZ→(0,50,0) →RX→(0,0,50): world (0,0,50)	holds	holds	pass
pair 2 — RY(90°)+RZ(90°): dm_local=(50,0,0) →RZ→(0,50,0) →RY→(0,50,0): world (0,110,0)	holds	holds	pass
pair 3 — RX(90°)+RY(90°): dm_local=(0,0,50) →RY→(50,0,0) →RX→(50,0,0): world (50,-60,0)	holds	holds	pass

5.5 MaterialMixTest

M-Mix-Composition: A mix of two materials shields like its elements written out

Result
passed

Verifies
R-13

Basis
Condition

Test
MaterialMixTest

A mix reaches the simulation as a material made of other materials, which Geant4 builds into one homogeneous material from their compositions. The case runs the same geometry twice, changing only the shield's material: once the mix, and once a material written element by element with the composition the mix should have, at the same density. The shield is one box of one material, with nothing inside it. If the mix reaches Geant4 with its composition and density, the two shields are the same material and the dose rates behind them agree within their statistical uncertainty.

The mix is 30 % water and 70 % lead by mass, at 2.2 g/cm³. Each element's mass fraction is the sum over the mix's materials of the material's fraction times the element's fraction in it: hydrogen 0.3 × 0.1119 = 0.03357, oxygen 0.3 × 0.8881 = 0.26643, lead 0.7.

An Am-241 source in air sits 100 mm in front of a shield, 400 × 400 × 2 mm, and an effective dose map (ROT), 200 × 200 mm, lies 100 mm behind it; 10^6 decays per run. The shield lets about a sixth of the dose through. At Am-241's 59.5 keV gamma ray, lead attenuates about 25 times more per gram than water, so the dose rate shows the composition as well as the density; at Co-60's energies the two differ by less than a tenth and the case could not tell them apart. The

two runs use different seeds, so their results are independent; they must differ by less than 4 standard deviations of the difference.

Measured when the case was written, with the mix written wrongly: with its fractions swapped the dose rate is 2.4 times higher, and with its density 10 % higher it is 14 % lower, 7 standard deviations away. Either fails the case.

Check	Result	Criterion	Verdict
|mix - elements| / sigma	1.66	below 4	pass

M-Mix-Nested-Composition: A mix containing a mix shields like its elements written out

Result
passed

Verifies
R-13

Basis
Condition

Test
MaterialMixTest

As M-Mix-Composition, for a mix one of whose materials is itself a mix: half air and half the mix of M-Mix-Composition, by mass, at 1.1 g/cm³. Its elements, by the same sum taken twice: hydrogen 0.016785, carbon 0.000062, nitrogen 0.377634, oxygen 0.249106, argon 0.0064135, lead 0.35. The source, geometry and check are those of M-Mix-Composition, except that the shield is 8 mm thick in both runs. Holding a quarter of the lead per volume, it then attenuates as much as the 2 mm shield of M-Mix-Composition; at 2 mm a density 10 % off would change the dose rate by only 4 %, too little to tell from the statistics. No result is compared between the two cases.

Measured when the case was written, with the mix written wrongly: with its density 10 % higher the dose rate is 16 % lower, 8 standard deviations away, and with the air left out (the inner mix alone at 1.1 g/cm³) it is 4.6 times lower. Either fails the case.

Check	Result	Criterion	Verdict
|mix - elements| / sigma	2.281	below 4	pass

M-Name-Ox: Two materials named alike up to “Ox” stay two materials

Result
passed

Verifies
R-13

Basis
Condition

Test
MaterialMixTest

A name may hold “Ox”, as `Mix50x50` does, where Geant4 cuts the names of materials, elements and isotopes when it reads a geometry file, in their definitions and where they are used. Two names alike up to it became one, and every solid of either got the first definition, with no

message (D-0015). RadMap now writes such a name so that Geant4 sees no “0x”, and restores it on loading.

The source, geometry and check are those of M-Mix-Composition. `WALL0xB` is the mix’s composition at the mix’s density, written element by element, and is the shield’s material. `WALL0xA` is water, and a solid of it stands out of the beam, written to the file first so that its definition comes first: the one Geant4 kept for both names before the fix. The shield must read as `MIX_ELEMENTS` does, which is the same material under a name with no “0x”.

Measured when the case was written, without the fix: the shield took water’s definition, and the dose rate was 6.1 times higher, 138 standard deviations away.

Check	Result	Criterion	Verdict
|WALL0xB - MIX_ELEMENTS| / sigma	1.66	below 4	pass

M-Density-Unit: A density reaches the simulation the same in every unit

Result
passed

Verifies
R-13

Basis
Condition

Test
MaterialMixTest

RadMap hands Geant4 every density in g/cm³, converted from the unit the user chose. Until 2.0 it passed the unit’s name through, and Geant4 refused one it did not know: a material in kg/cm³ stopped the run (D-0009). The case runs the geometry of M-Mix-Composition twice, with a lead shield 0.2 mm thick: once of lead at 11.34 g/cm³, once of the same lead given as 11340 mg/cm³. Both runs must finish, and since the shields are the same material, the dose rates behind them must agree within their statistical uncertainty: less than 4 standard deviations of the difference, the runs having different seeds. A density reaching Geant4 a thousand times off would let almost everything or almost nothing through.

Check	Result	Criterion	Verdict
|g/cm3 - mg/cm3| / sigma	0.3826	below 4	pass

5.6 ValidationTest

V-KSU-Cs137: Cs-137 over a concrete floor: air kerma measured at 2 to 18 m

Result
passed

Verifies
R-1, R-9, R-10, R-11, R-17

Basis
Measurement – *Roseberry (1980)*; *LLNL-TR-838615*; *ICRU 90*; *SINBAD NEA-1517/91*

Test
ValidationTest

A validation case: the expected values are measurements, made at Kansas State University in 1979-80 with Cs-137 sources above a concrete floor (Roseberry), as LLNL documented them in 2022 to benchmark its own code (LLNL-TR-838615). A source 5.08 cm above a 22.86 cm concrete floor on ground, and an ion chamber 91.44 cm above the floor at 2 to 18 m from it: the dose rate comes from the photons that reach the chamber directly, attenuated by the air, and those the floor and the air scatter towards it – what RadMap computes in everyday use. The same programme's Co-60 skyshine measurements are the one gamma benchmark with a radionuclide source in SINBAD, the OECD/NEA archive of evaluated shielding experiments.

The model. The experiment did not record the materials, so the case takes LLNL's assumptions: ordinary concrete (NIST composition) at 2.17 g/cm³, ground of hydrogen, oxygen, silicon and aluminium (16, 57, 19 and 8 atoms in 100) at 1.7 g/cm³ under it, 76.2 cm deep, and dry air at the measured 1.142 mg/cm³. The floor and the air are 400 m square, where LLNL's model is 1 km; at 662 keV a photon's mean free path in this air is 113 m, so what lies beyond 200 m adds far less than the experiment's uncertainty at 18 m. The source is a bare 1 GBq of Cs-137: the experiment does not describe its capsule, which would have absorbed the Ba K X-rays, about 1.5 % of the air kerma a bare source gives. Each chamber is an air kerma map 91.44 cm above the floor on the x axis, a box 0.2 × the distance wide, and 0.2 × the distance, at most 0.8 m, deep and high: averaging the direct photons over it shifts its reading by under 0.5 %.

The measurements are exposure rates per mCi. With 1 R = 2.58 × 10^{-4} C/kg and W/e = 33.97 J/C for air (ICRU 90), 1 R is 8.764 mGy of air kerma, so 1 µR/h per mCi is 0.2369 µGy/h per GBq:

Distance (m)	Exposure rate (µR/h per mCi)	Air kerma rate (µGy/h per GBq)	Tolerance
2	79.77 ± 0.26	18.90	±10.0 %
4	22.53 ± 0.05	5.337	±10.0 %
5	14.68 ± 0.06	3.477	±10.1 %
7	7.44 ± 0.06	1.762	±10.2 %
8	5.62 ± 0.04	1.331	±10.1 %
10	3.78 ± 0.06	0.8954	±10.7 %
12	2.48 ± 0.04	0.5874	±10.7 %
14	1.81 ± 0.04	0.4287	±11.3 %
18	0.99 ± 0.04	0.2345	±13.7 %

Tolerances, set before the case was first run: twice the experiment's combined standard uncertainty – 3.5 % on the source strength and each reading's own – plus 3 % for what the experiment did not record: the concrete's composition and density and the source's capsule. LLNL's own model of the experiment emits one photon per decay where Cs-137 gives 0.85, which accounts for most of its 6 to 19 % excess; the case takes the measurements, not that model.

Check	Result	Criterion	Verdict
air kerma at 2 m	(1.879 ± 0.010) × 10^{-5} Gy/h	1.890 × 10^{-5} Gy/h ± 10 %	pass
air kerma at 4 m	(5.243 ± 0.028) × 10^{-6} Gy/h	5.337 × 10^{-6} Gy/h ± 10 %	pass
air kerma at 5 m	(3.350 ± 0.020) × 10^{-6} Gy/h	3.477 × 10^{-6} Gy/h ± 10 %	pass
air kerma at 7 m	(1.685 ± 0.012) × 10^{-6} Gy/h	1.762 × 10^{-6} Gy/h ± 10.2 %	pass
air kerma at 8 m	(1.285 ± 0.010) × 10^{-6} Gy/h	1.331 × 10^{-6} Gy/h ± 10.1 %	pass
air kerma at 10 m	(8.164 ± 0.072) × 10^{-7} Gy/h	8.954 × 10^{-7} Gy/h ± 10.7 %	pass
air kerma at 12 m	(5.621 ± 0.055) × 10^{-7} Gy/h	5.874 × 10^{-7} Gy/h ± 10.7 %	pass
air kerma at 14 m	(4.085 ± 0.043) × 10^{-7} Gy/h	4.287 × 10^{-7} Gy/h ± 11.3 %	pass
air kerma at 18 m	(2.407 ± 0.029) × 10^{-7} Gy/h	2.345 × 10^{-7} Gy/h ± 13.7 %	pass

V-KSU-Skyshine: Co-60 in an open silo: skyshine air kerma measured at 50 to 400 m

Result
passed

Verifies
R-1, R-9, R-10, R-11, R-12, R-17

Basis
Measurement – *SINBAD NEA-1517/91*; *LLNL-TR-838835*; *ICRU 90*

Test
ValidationTest

A validation case for skyshine: radiation that leaves a shield upwards and reaches the ground far away only because the air scatters it back down. Kansas State University measured it in 1977 with Co-60 in a concrete silo, open to the sky through a collimator, with an ion chamber 1 m above the ground at 50 to 700 m; the walls stop every photon headed for the chamber directly. SINBAD, the OECD/NEA archive of shielding benchmarks, evaluates the experiment, and LLNL documents its geometry (LLNL-TR-838835). This case takes the points at 50, 100 and 200 m, measured with a 10.33 Ci source, and at 300 and 400 m, measured with a 229.1 Ci source. SINBAD judges the reading at 300 m an anomaly of the measurement; the case keeps it, as LLNL does.

The model. As LLNL models it, with RadMap's shapes:

- the silo, 228.6 cm high on a 22.86 cm concrete pad: twelve-sided, 91.44 cm walls, here a tube of the same cross-section, 125.9 and 218.4 cm in radius;
- the collimator: 48 concrete wedges at 1.93 g/cm³ on the silo's rim, from 124.46 to 185.42 cm out, their tops rising from 231.14 to 248.60 cm, which shape a cone 150.5° wide; here 24 concentric rings stepped to that slope, each as high as the slope at its outer edge, and without the narrow gaps between the wedges;
- the sources as bare points, their casks not being described: the 10.33 Ci source 5.08 cm above the collimator's apex, 203.2 cm above the pad, as LLNL reads Roseberry's "2 in from the apex", and the 229.1 Ci source at the apex, 198.12 cm, where Roseberry puts the midpoints of the larger sources;
- the steel plate in the pad's top; the thinner pads around the silo, 10 cm of concrete lying on the ground, are left out;
- ground at 1.7 g/cm³ and dry air at the measured 1.096 mg/cm³, 2 km across and 1 km above the ground, the extent LLNL uses.

Each source is a run of its own, of 5 000 000 decays. Each chamber is four air kerma maps, 90° apart round the silo, 0.2 × the distance wide and 1.2 m high, centred 1 m above the ground, and deep along the radius: 4 m at 50 to 200 m, 8 m at 300 and 400 m, where the readings are fainter. The case averages the four. No photon is likely to reach two of them, so the average carries their combined uncertainty. A run scores at most 15 maps, so the fainter points get deeper maps, not more of them. Depth costs no accuracy: along it the reading changes almost linearly, which the average cancels, and what is left, about $d^2(\dot{X}'/\dot{X})^2/24$ of the reading, is under 0.1 %. It buys only part of the precision its volume suggests: photons entering a map through its top and sides grow in number with its depth, while those entering through the face towards the silo cross it once however deep it is. A wider box would cost accuracy: its ends lie further from the silo than its middle.

The measurements are exposure rates per Ci; with 1 R = 8.764 mGy of air kerma (ICRU 90), 1 µR/h per Ci is 2.369×10^{-4} µGy/h per GBq:

Distance (m)	Source (Ci)	Exposure rate (µR/h per Ci)	Air kerma rate (nGy/h per GBq)
50	10.33	27.49 ± 0.04	6.511
100	10.33	10.97 ± 0.07	2.598
200	10.33	2.72 ± 0.04	0.6443
300	229.1	0.842 ± 0.004	0.1994
400	229.1	0.340 ± 0.002	0.08054

Tolerance, set before the case was first run: ±21 %, twice SINBAD's combined standard uncertainty of about 8 % – 5 % on the source's activity, about 4 % on the source's correction factors, and the atmosphere – plus 5 % for the simplified geometry: the collimator's rings, the missing pads and casks. The 300 and 400 m points have the same tolerance, also set before they were first run.

Measured when the case was written: RadMap reads 0.85, 0.83, 0.93, 0.95 and 0.97 of the measurements at 50, 100, 200, 300 and 400 m, with statistical uncertainties of 1.9, 2.2, 3.0, 3.6 and 5.2 %: 3 to 17 % low, inside the tolerance.

Why it reads low. The difference lies in the model of the experiment, not in the transport, as a comparison with LLNL's code shows. It was made, like the sensitivities below, with the 10.33 Ci source's points alone, in single runs of 10 000 000 decays with chambers 2 m deep, in which RadMap read 0.86, 0.84 and 0.93 of the measurements, ±1.4 to 2.1 %. COG reads 0.92, 0.88 and 0.97, but LLNL's model places the chambers 2.21 m above the ground, 198.12 cm above the pad, where this case follows SINBAD's 1 m. With LLNL's chambers – rings of 30.48 cm radius at that height, here boxes 61 cm on a side – RadMap reads 0.91, 0.87 and 1.03 of the measurements, ±2.2, 2.6 and 3.4 %: the two codes agree within RadMap's uncertainty at 50 and 100 m, and within 2σ at 200 m. Both therefore leave about 10 % at 50 and 100 m to what the experiment's description leaves open, and SINBAD's MCNP evaluation agrees within its 8 %. How much the description leaves open: placing the source 5.1 cm lower, at the collimator's apex, where SINBAD's description puts the sources, lowers every reading by 7 to 9 %; 12 rings instead of 24 lower them by up to 2 %. The geometry as documented thus leaves an uncertainty about as large as the difference, and larger than the 5 % the tolerance allowed for it. At 300 and 400 m, with the 229.1 Ci source at the apex in both codes, COG reads 1.02 and 1.01; RadMap with LLNL's chambers, in one run of 5 000 000 decays, reads 1.02 and 0.92, ±4.1 and 5.3 %: the same at 300 m, and within 2σ at 400 m.

Check	Result	Criterion	Verdict
air kerma at 50 m	$(5.51 \pm 0.10) \times 10^{-9}$ Gy/h	6.512×10^{-9} Gy/h ± 21 %	pass
air kerma at 100 m	$(2.167 \pm 0.048) \times 10^{-9}$ Gy/h	2.598×10^{-9} Gy/h ± 21 %	pass
air kerma at 200 m	$(5.98 \pm 0.18) \times 10^{-10}$ Gy/h	6.443×10^{-10} Gy/h ± 21 %	pass
air kerma at 300 m	$(1.893 \pm 0.069) \times 10^{-10}$ Gy/h	1.994×10^{-10} Gy/h ± 21 %	pass
air kerma at 400 m	$(7.84 \pm 0.40) \times 10^{-11}$ Gy/h	8.054×10^{-11} Gy/h ± 21 %	pass

5.7 DoseAlgorithmSeedTest

S-Seed: The same seed on one thread reproduces a run; another seed does not

Result
passed

Verifies
R-19

Basis
Condition

Test
DoseAlgorithmSeedTest

One project, a fixture with a source and dose maps, is run five times: twice with seed 42 on one thread, once with seed 42 on four threads, and with seed 99 on one and on four threads. The two single-thread runs with seed 42 must give identical results files, byte for byte; changing the seed must change the results, on one thread and on four.

Runs on several threads with the same seed are not compared: Geant4 adds the threads' scores in whatever order the threads finish, so their sums differ in the last digits from run to run.

Check	Result	Criterion	Verdict
seed 42, one thread, twice: identical results	holds	holds	pass
seed 42 and seed 99, one thread: different results	holds	holds	pass
seed 42 and seed 99, four threads: different results	holds	holds	pass

5.8 ActivityResolverTest

AR-Absolute: A total activity is taken as entered, in its unit

Result
passed

Verifies
R-4

Basis
Published reference – none needed: geometry or arithmetic alone

Test
ActivityResolverTest

5 MBq entered as a total activity resolves to 5 MBq, whatever the source's solid or material, because a total depends on neither.

Check	Result	Criterion	Verdict
5 MBq / 5 x the MBq factor	1	1 ± 0.001 %	pass

AR-PerVolume: A volume concentration times the solid's volume

Result
passed

Verifies
R-5

Basis
Published reference – none needed: geometry or arithmetic alone

Test
ActivityResolverTest

RadMap's own arithmetic, checked against hand calculation. Each expected value is the same activity entered as a total and resolved by RadMap, not a number in RadMap's internal unit, so the check holds whatever scale RadMap keeps activities on. The cube is 10 cm on a side, 1000 cm^3, and filled with water at exactly 1 g/cm^3, so it holds 1000 g.

5 MBq/cm^3 in 1000 cm^3 is 5000 MBq.

Check	Result	Criterion	Verdict
5 MBq/cm3 in 1000 cm3 / 5000 MBq	1	1 ± 0.001 %	pass

AR-VolumeUnit: The volume unit of a concentration scales the total

Result
passed

Verifies
R-5

Basis
Published reference – none needed: geometry or arithmetic alone

Test
ActivityResolverTest

RadMap's own arithmetic, checked against hand calculation. Each expected value is the same activity entered as a total and resolved by RadMap, not a number in RadMap's internal unit, so the check holds whatever scale RadMap keeps activities on. The cube is 10 cm on a side, 1000 cm^3, and filled with water at exactly 1 g/cm^3, so it holds 1000 g.

1 MBq/m^3 in the cube is a millionth of 1 MBq/cm^3 in it, since 1 m^3 is 10^6 cm^3.

Check	Result	Criterion	Verdict
per m3 / per cm3	1.000×10^{-6}	1.000×10^{-6} ± 0.001 %	pass

AR-PerMass: A mass concentration times the volume and the material's density

Result
passed

Verifies
R-5

Basis
Published reference – none needed: geometry or arithmetic alone

Test
ActivityResolverTest

RadMap's own arithmetic, checked against hand calculation. Each expected value is the same activity entered as a total and resolved by RadMap, not a number in RadMap's internal unit, so the check holds whatever scale RadMap keeps activities on. The cube is 10 cm on a side, 1000 cm^3, and filled with water at exactly 1 g/cm^3, so it holds 1000 g.

5 MBq/g in 1000 g of water is 5000 MBq; 5 MBq/kg is a thousandth of that.

Check	Result	Criterion	Verdict
5 MBq/g in 1000 g / 5000 MBq	1	1 ± 0.001 %	pass
per kg / per g	0.001	0.001 ± 0.001 %	pass

AR-Children: Solids placed inside the source are left out of its volume

Result
passed

Verifies
R-5

Basis
Published reference – none needed: geometry or arithmetic alone

Test
ActivityResolverTest

RadMap's own arithmetic, checked against hand calculation. Each expected value is the same activity entered as a total and resolved by RadMap, not a number in RadMap's internal unit, so the check holds whatever scale RadMap keeps activities on. The cube is 10 cm on a side, 1000 cm^3, and filled with water at exactly 1 g/cm^3, so it holds 1000 g.

A 5 cm cube inside the source takes 125 cm^3 of it, leaving 875 cm^3: 1 MBq/cm^3 and 1 MBq/g both resolve to 875 MBq. Their agreeing also shows that the volume and the mass paths subtract the same.

Check	Result	Criterion	Verdict
1 MBq/cm3 / 875 MBq	1	1 ± 0.001 %	pass
1 MBq/g / 875 MBq	1	1 ± 0.001 %	pass

AR-Refused: A concentration that cannot be resolved is refused, not taken as zero

Result
passed

Verifies
R-5

Basis
Condition

Test
ActivityResolverTest

A concentration needs a solid to measure, and a mass concentration a material of known density. Without them RadMap must report that it has no total, so that the simulation refuses the source, rather than run it at zero. Each section takes one thing away: the solid's material, the material's entry in the library, the solid itself, the unit of the denominator. A total activity needs none of these and is never refused.

Check	Result	Criterion	Verdict
no material: per mass refused	holds	holds	pass
material not in library: per mass refused	holds	holds	pass
no solid: per mass refused	holds	holds	pass
no solid: per volume refused	holds	holds	pass
unset mass unit: refused	holds	holds	pass
unset volume unit: refused	holds	holds	pass
total activity: never refused	holds	holds	pass

AR-NoVolume: A solid that describes no volume leaves the concentration unresolved

Result
passed

Verifies
R-5

Basis
Condition

Test
ActivityResolverTest

A solid part-way through being set up can describe no volume: a flattened box has none, and a tube whose inner radius exceeds its outer one would have a negative one. A concentration in it, or around a child that has no volume, or around a child larger than the source, must stay unresolved rather than give a total that looks right. A total activity depends on no geometry and still resolves.

Check	Result	Criterion	Verdict
flat source: per mass unresolved	holds	holds	pass
flat source: per volume unresolved	holds	holds	pass
flat child: per mass unresolved	holds	holds	pass
flat child: per volume unresolved	holds	holds	pass
total activity: resolved	holds	holds	pass
child larger than source: per mass unresolved	holds	holds	pass
child larger than source: per volume unresolved	holds	holds	pass

AR-Zero: A zero concentration resolves to zero, not to nothing

Result
passed

Verifies
R-5

Basis
Condition

Test
ActivityResolverTest

A concentration the user set to zero is a total of zero, which the simulation then refuses as a zero activity; it is not the same as a concentration that cannot be resolved at all.

Check	Result	Criterion	Verdict
0 MBq/g resolves to exactly zero	holds	holds	pass

6 Checks by hand

The user interface and the PDF report are not covered by automated cases. Every change states whether it alters what a user sees; one that does is checked by hand when it is made, for what it touches, and its commit message records the check. The libraries behind them, wxWidgets and wxPdfDocument, are evaluated in the software development plan's component register. The installation verification is each user's own check of the whole chain, from the computed dose rate to the screen and the report.

This is the first release since the rule, so it was also checked by hand as a whole:

Item	Check (TESTING.md, Checks by hand)	Result
A1	Installs over the previous version; `Samples\Verification` read-only	passed
A2	About: version and third-party notices; License: full licence shown	passed
B3	Box, tube and sphere: 3D view matches dimensions, position, rotation	passed
B4	Material mixing two others, created and given to a solid	passed
B5	Source: isotope info; activity per mass gives the matching total	passed
B6	Dose maps ROT, H*(10), air kerma: dose settings show the data sources	passed
B7	Invalid name marked red and kept; save refused with a message	passed
B8	Save project; Save Volume with its source, Load Volume in a new project	passed
B9	Simulation: stages listed, results in panel and list, project locked	passed
B10	PDF report: run ID, primary particles, dose rates equal to the panel's	passed
B11	Delete results unlocks; Load project restores the results	passed
C12	Verification projects, full check: panel and report within the limits	passed
D13	Preferences: half-life range filters the isotope list, kept on restart	passed
D14	Material library: export, import, reset	passed
D15	No dose map, wrong extension, write-protected folder: messages, no crash	passed
D16	Panels resized at 150 %; window moved to a second screen at 100 %	passed

Checked on the installer built from commit 2e95023, Windows 11 25H2, display scaling 150 % (second screen 100 %), full licence, by Klas Marcks von Würtemberg, 2026-10-26.

Changes since the rule's introduction (2e95023): 46. 27 changed what a user sees.

Commit	Date	Change	Checked by hand
28cee3f	2026-10-27	Geometry in double precision; touching solids no longer reported as overlapping	decimals in position, rotation and box/tube/sphere
ec080b3	2026-10-27	Refuse isotopes Geant4 cannot decay; sweep test over all decay data (D-0004)	Barium no longer offers 132 (half-life range 1 s to no
117c0e9	2026-10-27	Isotope info: decay branches as Geant4 builds them; no 0 keV lines	Isotope info shows 4.46 annihilation photons per 100
a0cd6e3	2026-10-27	Refuse atomic numbers above 98 in material libraries	Apply refuses Z = 99 and accepts Z = 98 on the material, element and isotope tabs
afc8fe6	2026-10-27	Refuse material mixes by atom count	Fraction heading fixed for a material mix, switches to Composite for an element mix
2b7b67b	2026-10-28	Draw solids from the model's placement, not a copy of it	rotated solids in the 3D view, nothing odd seen (no
9138cbc	2026-10-28	Close full turns entered in radians; remove dead solid code; mesh tests	tubes and spheres drawn correctly; full turns in
26409b0	2026-10-29	Keep activities exactly as typed	source activity entry (absolute and per mass),
8258549	2026-10-29	Hand Geant4 densities in g/cm3; drop kg/cm3; tighten material gate	density units offered (mg/cm3, g/cm3); a run with
e1162e4	2026-10-29	Restore C4244/C4127 in the UI; fix the narrowings they find	PDF report tables
52fdd61	2026-10-29	UI review: case-sensitive solid material; exact material fractions	solid keeps ETHANE beside Ethane after a colour change; material editor shows, edits and saves
d6bd44b	2026-10-29	Dose maps are one cell: remove cell-line drawing, refuse more on save	dose map draws and highlights, project saves
1cedb17	2026-10-29	Fix the 3D view's arrow keys acting as if Ctrl were still held (D-0011)	Ctrl+A then cancel, arrows move not tilt; forward, pan and tilt; Shift diagonal pan; arrow
e443b1b	2026-10-29	Save Volume: let its sources/dose maps question be cancelled	Cancel, Escape and close box save nothing; OK with both and with neither checked, reloaded with
a793007	2026-10-30	Notebook panels: remove dead code	box, tube, sphere, dose map and source pages switch and
9a40fb6	2026-10-30	Dialog review: free particle cap, honest run log, clearer save errors	progress bar at run end; cancel log; free licence
4c718d7	2026-10-31	Report review: table page breaks, long project names, name cap behind the API	activities in Sources table, table headings repeat and title moves across page breaks, long
9831fab	2026-10-31	Report: warn when a name has characters the report cannot print (D-0012)	warning lists Greek and Korean names, PDF opens after OK, name prints with question marks and é
fca0dac	2026-10-31	Report: tables shrink to fit the page, measured in the current font	table with 20-W names reaches the right margin and stays readable, ordinary report

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