NIST Technical Note 1788

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Neutron Test Results of Preliminary Measurements and Calculations Using a Handheld Instrument

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Abstract
Initial neutron measurements and calculations were performed to investigate the response of handheld radionuclide identifiers (RIDs) to neutron sources with different moderators/scattering conditions.

Key words: neutron detection, handheld radionuclide identifiers, RIDs, ^{252}Cf moderators/scattering conditions.

Introduction
The purpose of these preliminary measurements and calculations is to investigate the differences in response of handheld radionuclide identifiers (RIDs) to neutron sources with different moderators/scattering conditions. Additional neutron spectral measurements and calculations will be performed in order to better understand the differences in instrument response under different measurement conditions.

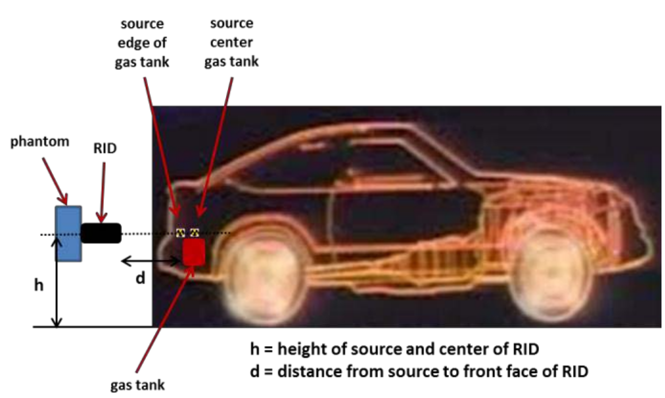
RIDs are handheld instruments designed to identify radionuclides by gamma-ray identification and detect neutrons. The RIDs tests are performed against two document standards, the American National Standard Institute/Institute of Electrical and Electronics Engineers (ANSI/IEEE) N42.34 standard and the Domestic Nuclear Detection Office (DNDO) Technical Capability Standard (TCS). The TCS does not include requirements for neutron detection since these are set in the ANSI/IEEE N42.34 standard. Currently, the standard requires testing with unmoderated (bare) ^{252}Cf with a neutron emission rate of 2×10^4 n/s without the presence of a phantom in a low-scatter environment.

Most field measurements are being carried out by users holding the instrument at an arm's length from their body in an environment that has substantially more neutron scattering than a low scatter laboratory environment. The field measurement settings change the neutron spectrum, substantially increasing the probability of detection by a neutron detector such as a bare (or lightly moderated) ^{3}He-based detector.

Measurements are required to assess the suitability of the ANSI/IEEE requirements and test methods compared to field measurements.

Measurements setup

In order to assess the difference in response of the RIDs to field measurements and standard test conditions a ^{252}Cf source was placed in different moderators/scattering conditions. The ^{252}Cf source was initially placed inside a vehicle (1983 AMC SX4) parked on a wet asphalt surface while a RID (Flir IndetiFinder-GN)[1] was positioned outside the vehicle at a fixed distance from the source. The RID is equipped with the NaI(Tl) gamma-ray detector and a ^{3}He neutron detector. The ^{252}Cf source was placed on the floor of the trunk in 2 different locations. One was directly over the center (both side-to-side and front-to-back) of the gasoline tank and another was over the edge of the gasoline tank (approximately 1 cm from the edge of the gasoline tank on the driver's side towards the back end of the trunk). For this particular vehicle the gasoline tank was located underneath the trunk without additional parts except for the rug and vehicle metal wall (there was no spare tire). The gasoline tank dimensions were approximately 42 cm wide, 78 cm long and 20 cm high. The gasoline tank was filled to 75 % of its 82.5 l full capacity. The distances from the front of the RID (located outside and in the back of the vehicle) to the source varied between 30 cm and 34 cm. In this case, the RID was held by a person, whose body was located at an arm's distance from the RID, which varied between 27 cm and 30 cm from the front face of the RID. The distance between the floor of the trunk and the wet asphalt surface was 74 cm. Figure 1 shows a diagram of the measurements setup.



[1] Mention of commercial products does not imply recommendation nor endorsement by the National Institute of Standards and Technology, nor does it imply that the products identified are necessarily the best available for the purpose.

Figure 1: Diagram of measurements setup with phantom

In order to compare the RID response when held by a person with that obtained in the presence of a phantom, the RID was mounted on an aluminum stand outside the vehicle at a fixed distance from the source. Phantoms were placed behind the detector; the source remained inside the vehicle. Two phantoms were used for this part of the test. One phantom was made of polymethyl methacrylate (PMMA) (dimensions: 40 × 40 × 15 cm) while the other was a water phantom (dimensions: 30 × 30 × 15 cm). The ^{252}Cf source was unmoderated (bare) and moderated by a 4 cm thick high density polyethylene (HDPE) sphere.

The ^{252}Cf source used for these measurements was identified by NIST source number 3828 with a neutron emission rate of 2.16×10^4 n/s with a reference time of 7 September 2012 12:00 PM EST and a combined standard relative uncertainty (k = 1) of 1.2 %. The source emission rate at the time of the measurements was 2.11×10^4 n/s. During the outdoor measurements the ambient temperature was (13 ± 2) °C, the relative humidity was (77 ± 4) % and the atmospheric pressure was (1022 ± 5) hPa.

The following configurations were measured in the vehicle:

a. Unmoderated (bare) ^{252}Cf source placed inside vehicle with the RID placed at the same height as the source with a person holding the RID (the source was placed at the center of the gasoline tank and at the edge of the gasoline tank)
b. Unmoderated (bare) ^{252}Cf source placed inside the vehicle with the RID placed at the same height as the source without the phantom present (the RID was placed on the aluminum stand; the source was placed at the edge of the gasoline tank)
c. Unmoderated (bare) ^{252}Cf source placed inside the vehicle with the RID placed at the same height as the source with the PMMA phantom present (the phantom was placed at 30 cm from front face of the RID, the same distance as the person holding the RID; the source was placed at the edge of the gasoline tank)
d. Unmoderated (bare) ^{252}Cf source placed inside the vehicle with the RID placed at the same height as the source with the water phantom present (the phantom was placed at 30 cm from the front face of the RID, the same distance as a person holding the RID; the source was placed at the edge of the gasoline tank)
e. ^{252}Cf source moderated by 4 cm thick high density polyethylene (HDPE) sphere placed inside vehicle with the RID placed at the same height as the source without a phantom present (the source was placed at the edge of the gasoline tank)
f. ^{252}Cf source moderated by 4 cm thick HDPE sphere placed inside the vehicle with the RID placed at the same height as the source with the phantom present (the phantom

was placed at 30 cm from the front face of the RID; the source was placed at the edge of the gasoline tank). Measurements were performed with both the PMMA and the water phantoms.

To assess under which test conditions the measurements in a low scatter laboratory environment match those measured in a vehicle configuration, the ^{252}Cf source with different moderators/scattering conditions was measured inside the laboratory. During the indoor measurements the ambient temperature was (20 ± 2) °C, the relative humidity was (56 ± 4) % and the atmospheric pressure was (1022 ± 5) hPa.

The following configurations were measured in the low scatter laboratory environment:

g. Unmoderated (bare) ^{252}Cf source placed in a low scatter environment with the RID placed at the same height as the source; phantom is not present (the source was placed on the aluminum stand)
h. Unmoderated (bare) ^{252}Cf source placed in a low scatter environment with the RID placed at the same height as the source with phantom present (phantom placed at 30 cm from the front face of the RID). Measurements were performed with both the PMMA and the water phantoms.
i. ^{252}Cf source moderated by 2 cm and 4 cm thick HDPE sphere placed in a low scatter environment with the RID placed at the same height as the source; phantom is not present
j. ^{252}Cf source moderated by 2 cm and 4 cm thick HDPE sphere placed in a low scatter environment with the RID placed at the same height as the source with phantom present (phantom placed at 30 cm from the front face of the RID). Measurements were performed with both the PMMA and the water phantoms.

The ANSI/IEEE N42.34 standard requires testing at a distance of 25 cm, this distance was not attainable in the vehicle configuration so the laboratory measurements were performed at the same vehicle distance (30 cm) in order to obtain the RID relative response between the different tests configurations instead of using the distance specified in the ANSI/IEEE n42.34 standard.

Results of measurements

The RID used for the measurements displays the neutron response in counts per minute (cpm). A neutron survey meter (Thermo Eberline ASP 2e) was used to measure the neutron background at the test location; the measured value was 0.055 ± 0.008 counts per second (cps) (3.3 cpm).

Table 1 and Table 2 summarize the neutron readings obtained from the RID for the different test configurations listed in the measurement setup section. The mean and standard deviation of 10 readings are calculated at the bottom of the tables for each test configuration. The 10 readings were performed over a period of 2 – 3 minutes. The 10 RID background readings without a neutron source present were all 0 cpm. The RID alarmed when the neutron display was 10 cpm or higher. The source to detector distance was approximately the same for all the measurements.

The response of the RID to an unmoderated ^{252}Cf source with a neutron emission rate of 2×10^4 n/s in a low-scatter environment as required by the ANSI/IEEE N42.34 standard is low compared to the response of the same RID when the source is placed inside a vehicle when parked on a wet asphalt surface. The ratio of the RID response to the unmoderated ^{252}Cf source when placed inside the vehicle with a person holding the RID is 5 to 9 times higher than that from the same source placed in the low-scatter environment, as tabulated in Table 3.

Table 3 summarizes the effects of choosing different low scatter environment configurations on expected in-vehicle count rates. For example, if the detector is calibrated with a bare ^{252}Cf source, the weighted average ratio of the in-vehicle measurements to the ANSI/IEEE N42.34 measurement requirements (i.e., low scatter environment bare source no phantom present) is 7.67 ± 3.73. This is because the in-vehicle configurations have much more scattering than the calibration configuration, generating more thermal neutrons, which are easily detected by the ^{3}He based detector. The moderated sources better predict the response of this detector for the in-vehicle configurations. Ideally, one would find an average of 1.0. Note that the ratio of the standard deviation to the weighted average is similar for all configurations. This is because the various in-vehicle configurations differ among themselves and no single low scatter environment can match all the configurations measured. In Table 3 the weighted average, is the average of the different ratios for a given low-scatter environment test configuration weighted by their respective uncertainty.

For the RID used in these measurements, the response to the ^{252}Cf source when placed inside the trunk of the vehicle at the edge of the gasoline tank could be simulated in the low-scatter environment by moderating the source with a 2 cm thick HDPE sphere and placing a PMMA phantom at a distance of 30 cm from the front edge of the RID.

For the RID used in these measurements, the response to the ^{252}Cf source when placed inside the trunk of the vehicle at the center of the gasoline tank, within the uncertainty of the measurements, could be simulated in the low-scatter environment by moderating the source with a 4 cm thick HDPE sphere without a phantom placed behind the RID. Therefore, the use of moderated neutrons for testing RIDs better describes the conditions that could be encounter in an operation setting. Testing in a low scatter environment with a neutron bare source with no phantom present is an ideal configuration but it does not represent an operational scenario.

Calculation results

Several scenarios were investigated with the Monte Carlo N-Particle (MCNP) modeling code to examine the effects of scattered neutrons on the detection of fission based neutron sources. The main diagnostic used was to compare calculated ^{3}He capture rate vs. calculated neutron tissue dose. The comparison was done by calculating neutron spectra and then integrating the neutron spectra over the appropriate cross section. For ^{3}He, the (n,p) cross section was used. For dose, the MCNP-supplied ANSI/ANS-6.1.1-1977 (rem/h)/(n/s cm^{2}) conversion function was used.

Relative to each other, the ^{3}He capture rate is more sensitive to slow or scattered neutrons and the neutron dose is more sensitive to fast neutrons. For both ^{3}He and dose tallies, the absolute magnitude is irrelevant since no physical detector was modeled. The ^{3}He capture rate may be viewed as a proxy for ^{3}He-based neutron detectors. The neutron dose may be viewed as a proxy for a generic neutron Rem-meter. For these calculations, the ^{3}He-based neutron detector is taken to be a bare ^{3}He tube. Two sets of calculations were done. The first set investigated the effects on neutron spectrum of the various covers. The second set investigated the effects of various scattering materials (asphalt, soil, water, etc.) on the neutron spectrum.

Sources in Air

Several sources were investigated without ground scattering. These were:
dh0: ^{252}Cf source in dry air
dh1: ^{252}Cf source inside 4 cm thick HDPE sphere
dh2: ^{252}Cf source inside 8 cm thick HDPE sphere.
dh3: ^{252}Cf source inside 8 cm thick borated HDPE sphere.
dh4: ^{252}Cf source inside 122 cm thick pine wood sphere.

The numbers before the colon represent the MCNP modeling code run number. All these calculations included a sphere of dry air of radius 200 m, with the ^{252}Cf source at the center. Runs dh1-dh4 had additional material around the source. The diagnostic results are shown in Table 4. In Table 4, the “dist” column lists the distance between source and tally point.

The relative magnitudes of the ^{3}He and dose rates are not important, since the units are totally different. What is significant is that the ratios change from about 1×10^{4} for air-only to about

1×10^7 to 3×10^7 for the high density polyethylene sphere covers. Even the borated covers show an increase of about a factor of 100 over the air-only results.

No calculations were done for some of the radii of the pine sphere since the calculated point would be inside the pine.

Neutron spectra calculated for a source-detector (tally) distance of 200 cm are plotted in Figure 2. A distance of 200 cm was chosen because it was outside the pine. The spectra differ dramatically. The bare ^{252}Cf spectrum has the highest high-energy component, but is lacking in slow neutrons. Below 1×10^{-4} MeV, the statistics for the bare ^{252}Cf are poor because of the scarcity of neutrons in this region.

Both of the unborated HDPE spectra show a pronounced thermal neutron peak. The borated HDPE sphere has the thermal neutron attenuated by about a factor of 100 while having about the same fast fluence as the 8 cm unborated sphere.

The pine sphere is more massive than the other covers and shows a larger overall attenuation than the other covers, but with a spectrum similar to the HDPE.

Sources over a surface

Additional calculations were done for geometries where the ^{252}Cf source was over a plane surface. These were:
dh5: ^{252}Cf source inside 4 cm HDPE placed 50 cm over asphalt
dh6: ^{252}Cf source inside 4 cm HDPE placed 100 cm over asphalt
dh7: bare ^{252}Cf source placed 50 cm over asphalt
dh8: bare ^{252}Cf source placed 50 cm over soil
dh9: bare ^{252}Cf source placed 100 cm over extended soil (with gasoline)
dh10: bare ^{252}Cf source placed 50 cm over water
dh11: bare ^{252}Cf source placed 100 cm over extended soil (no gasoline)
dh12: bare ^{252}Cf source placed 50 cm over concrete

For these calculations, the ground was a cylinder 182.9 cm (6 foot) in radius and 2.5 cm thick 50 cm or 100 cm below the source. Tally locations were offset 100 cm horizontally from the source at 50 cm and 100 cm above the ground plane. Figure 3 illustrates the geometry. Results are given in Table 5. Statistical uncertainties in the MCNP results are all under 1.3 % (k = 1).

The asphalt composition was taken from “Concise International Chemical Assessment Document 59” Table 2, California asphalt with a density of 1.1 g/cm^3. The soil was dry soil from “Basic considerations for Monte Carlo calculations in soil”, Applied radiation and Isotopes 62 (2005) 97-107. Table 5, Soil C, density = 2.6 g/cm^3. The concrete was “ordinary concrete” from pnnl-15870 (2.21 % hydrogen by mass). Gasoline was also taken from pnnl-15870. The gasoline was a 20.8 cm radius sphere (10 gallons) centered at 75 cm above the ground (25 cm below the source), offset by 50 cm horizontally from the source at a right angle to the detector.

Sources inside the HDPE gave the highest relative ^{3}He tallies, roughly similar to the in-air tallies with the same covers. In this case, the thermal neutrons are due to the source cover. Spectra are plotted in Figure 4.

For bare sources, the presence of hydrogen moderator controlled the ^{3}He detection. The dry soil used did not provide many scattered neutrons for ^{3}He detection. Concrete gave a much larger thermal neutron component, and then asphalt and water gave increasingly superior ^{3}He neutron detectability because of the higher thermal neutron fluences. Gasoline was also quite effective in scattering neutrons.

The asphalt actually gave more ^{3}He sensitivity than the water. The hydrogen content was about 11 % in each. Actual asphalt might also contain rock, which would make it less effective.

Generally, the calculated ANSI dose was not affected by the surroundings. The ^{3}He tallies differed by orders of magnitude. A detector with an unshielded ^{3}He counter would show a greater variation with surroundings than one based on ANSI dose. If a bare ^{252}Cf source were used to calibrate an unshielded ^{3}He detector, and the detector were used in a field with substantial scattered neutrons, the response per neutron would be substantially higher than one might expect, unless the variation in spectrum were taken into account.

If unshielded ^{3}He detectors are to be used, one might optimize the environment by measuring over asphalt or moist soil as opposed to concrete or dry soil.

Conclusions

From the calculations it can be observed that there are substantial differences in the neutron spectra when a ^{252}Cf source is moderated by different types of materials and placed on top of different types of surfaces. The number of possible configurations in an operational environment is of course much larger than the simulated cases.

From these preliminary measurements it was observed that the use of an unmoderated (bare) ^{252}Cf source with a neutron emission rate of 2×10^{4} n/s in a low-scatter environment as required in the ANSI/IEEE N42.34 standard produces a low response compared to the case when the source is placed inside the trunk of a parked vehicle when on a wet asphalt surface. A more realistic test configuration for standard performance testing would be to moderate ^{252}Cf source with a 4 cm thick HDPE moderator and place a PMMA phantom behind the RID to simulate the presence of a person. Some RIDs have the neutron detector placed in the handle of the instrument. In these cases an additional hand-phantom may be needed to simulate the presence of a person.

The use of moderated neutrons for testing RIDs better describes the conditions that could be encounter in an operation setting. Testing in a low scatter environment with a neutron bare source with no phantom present is an ideal configuration but it does not represent an operational scenario. Additional measurements and calculations are required to better describe the test conditions to be used for the RIDs neutron tests required by the ANSI/IEEE N42.34 standard.

Acknowledgments

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Table 1: Results of vehicle measurements over wet pavement

Reading Number	Bare edge tank person holding RID (cpm) (a)	Bare center tank person holding RID (cpm) (a)	Bare edge tank no phantom (cpm) (b)	Bare edge tank PMMA phantom 30 cm behind RID (cpm) (c)	Bare edge tank water phantom 30 cm behind RID (cpm) (d)	Moderated 4 cm HDPE edge tank no phantom (cpm) (e)	Moderated 4 cm HDPE edge tank PMMA phantom 30 cm behind RID (cpm) (f)	Moderated 4 cm HDPE edge tank water phantom 30 cm behind RID (cpm) (f)
1	16	33	9	19	12	41	25	33
2	15	28	8	18	10	43	24	34
3	12	32	8	20	6	42	23	33
4	15	26	9	21	8	40	32	34
5	16	23	12	19	9	45	34	33
6	12	23	12	20	12	41	33	32
7	13	30	8	18	16	37	35	34
8	15	25	9	18	15	36	39	32
9	17	27	8	19	17	31	42	36
10	14	28	9	17	8	34	31	32
Average	14.5	27.5	9.2	18.9	11.3	39	31.8	33.3
Std dev	1.7	3.4	1.5	1.2	3.7	4.4	6.3	1.3

Table 2: Results of low scatter laboratory environment measurements

Reading Number	Bare no phantom (cpm) (g)	Bare PMMA phantom 30 cm behind RID (cpm) (h)	Bare water phantom 30 cm behind RID (cpm) (h)	Moderated 4 cm HDPE no phantom (cpm) (i)	Moderated 4 cm HDPE PMMA phantom 30 cm behind RID (cpm) (j)	Moderated 4 cm HDPE water phantom 30 cm behind RID (cpm) (j)	Moderated 2 cm HDPE no phantom (cpm) (i)	Moderated 2 cm HDPE PMMA phantom 30 cm behind RID (cpm) (j)
1	2	8	4	30	31	32	16	13
2	3	6	7	28	38	28	15	13
3	4	3	6	31	33	27	15	12
4	3	5	8	32	34	31	15	12
5	2	4	4	34	42	29	17	15
6	4	3	8	35	39	30	16	13
7	3	8	6	32	40	33	15	15
8	3	10	3	34	38	29	13	17
9	2	6	6	29	41	28	12	16
10	4	4	8	30	40	31	14	17
Average	3	5.7	6	31.5	37.6	29.8	14.8	14.3
Std dev	0.8	2.4	1.8	2.3	3.7	1.9	1.5	1.9

Table 3: Ratios of counts for in-vehicle configurations to the low scatter configurations

Low scatter environment		Ratio of In-Vehicle to equivalent low scatter configuration										
Test Configuration	RID (cpm)	Bare edge tank person holding RID	Bare center tank person holding RID	Bare edge tank no phantom	Bare edge tank PMMA phantom 30 cm behind RID	Bare edge tank water phantom 30 cm behind RID	Moderated 4 cm HDPE edge tank no phantom	Moderated 4 cm HDPE edge tank PMMA phantom 30 cm behind RID	Moderated 4 cm HDPE edge tank water phantom 30 cm behind RID	Weighted Average	Standard Deviation	St Dev/ Average
bare source no phantom	3.00	4.83	9.17	3.07	6.30	3.77	13.00	10.60	11.10	9.15	3.73	0.41
uncertainty (k = 1)	0.82	1.43	2.75	0.98	1.76	1.61	3.83	3.57	3.05			
bare source PMMA phantom	5.70	2.54	4.82	1.61	3.32	1.98	6.84	5.58	5.84	4.85	1.96	0.40
uncertainty (k = 1)	2.36	1.10	2.09	0.72	1.39	1.05	2.93	2.56	2.43			
bare source water phantom	6.00	2.42	4.58	1.53	3.15	1.88	6.50	5.30	5.55	4.59	1.86	0.41
uncertainty (k = 1)	1.83	0.79	1.51	0.53	0.98	0.85	2.11	1.92	1.70			
4 cm HDPE no phantom	31.50	0.46	0.87	0.29	0.60	0.36	1.24	1.01	1.06	0.84	0.36	0.42
uncertainty (k = 1)	2.32	0.06	0.13	0.05	0.06	0.12	0.17	0.21	0.09			
4 cm HDPE PMMA	37.60	0.39	0.73	0.24	0.50	0.30	1.04	0.85	0.89	0.71	0.30	0.42
uncertainty (k = 1)	3.69	0.06	0.12	0.05	0.06	0.10	0.15	0.19	0.09			
4 cm HDPE water	29.80	0.49	0.92	0.31	0.63	0.38	1.31	1.07	1.12	0.88	0.38	0.42
uncertainty (k = 1)	1.93	0.07	0.13	0.06	0.06	0.13	0.17	0.22	0.08			
2 cm HDPE No phantom	14.80	0.98	1.86	0.62	1.28	0.76	2.64	2.15	2.25	1.80	0.76	0.42
uncertainty (k = 1)	1.48	0.15	0.30	0.12	0.15	0.26	0.40	0.48	0.24			
2 cm HDPE PMMA phantom	14.30	1.01	1.92	0.64	1.32	0.79	2.73	2.22	2.33	1.88	0.78	0.42
uncertainty (k = 1)	1.95	0.18	0.36	0.14	0.20	0.28	0.48	0.53	0.33			

Table 4: Dose and ^{3}He diagnostics for no-ground simulations

Infinite dry air (dh0)			4cm HDPE (dh1)			8cm HDPE (dh2)			8cm borated HDPE (dh3)			122 cm pine sphere (dh4)		
dist (cm)	dose	3He	dist (cm)	dose	3He	dist (cm)	dose	3He	dist (cm)	dose	3He	dist (cm)	dose	3He
20	2.36E-08	1.65E-04	20	1.35E-08	1.39E-01	20	7.13E-09	2.45E-01	20	6.90E-09	6.77E-03	20		
50	3.79E-09	2.66E-05	50	2.15E-09	2.21E-02	50	1.12E-09	3.79E-02	50	1.08E-09	1.05E-03	50		
100	9.52E-10	6.73E-06	100	5.41E-10	5.66E-03	100	2.81E-10	9.67E-03	100	2.72E-10	2.69E-04	100		
200	2.41E-10	1.72E-06	200	1.37E-10	1.49E-03	200	7.11E-11	2.53E-03	200	6.87E-11	7.18E-05	200	2.40E-13	1.58E-05
2000	2.85E-12	3.98E-08	2000	1.64E-12	2.31E-05	2000	8.56E-13	3.81E-05	2000	8.20E-13	1.72E-06	2000	2.62E-15	2.12E-07

	3He/dose	Normalized		3He/dose	Normalized		3He/dose	Normalized		3He/dose	Normalized		3He/dose	Normalized
20	7.01E+03	1.000	20	1.03E+07	1.000	20	3.44E+07	1.000	20	9.82E+05	1.000	20		
50	7.02E+03	1.002	50	1.03E+07	0.997	50	3.38E+07	0.983	50	9.68E+05	0.986	50		
100	7.06E+03	1.008	100	1.05E+07	1.016	100	3.44E+07	0.999	100	9.90E+05	1.008	100		
200	7.15E+03	1.021	200	1.09E+07	1.055	200	3.56E+07	1.035	200	1.04E+06	1.064	200	6.57E+07	
2000	1.40E+04	1.994	2000	1.41E+07	1.370	2000	4.45E+07	1.293	2000	2.09E+06	2.134	2000	8.09E+07	

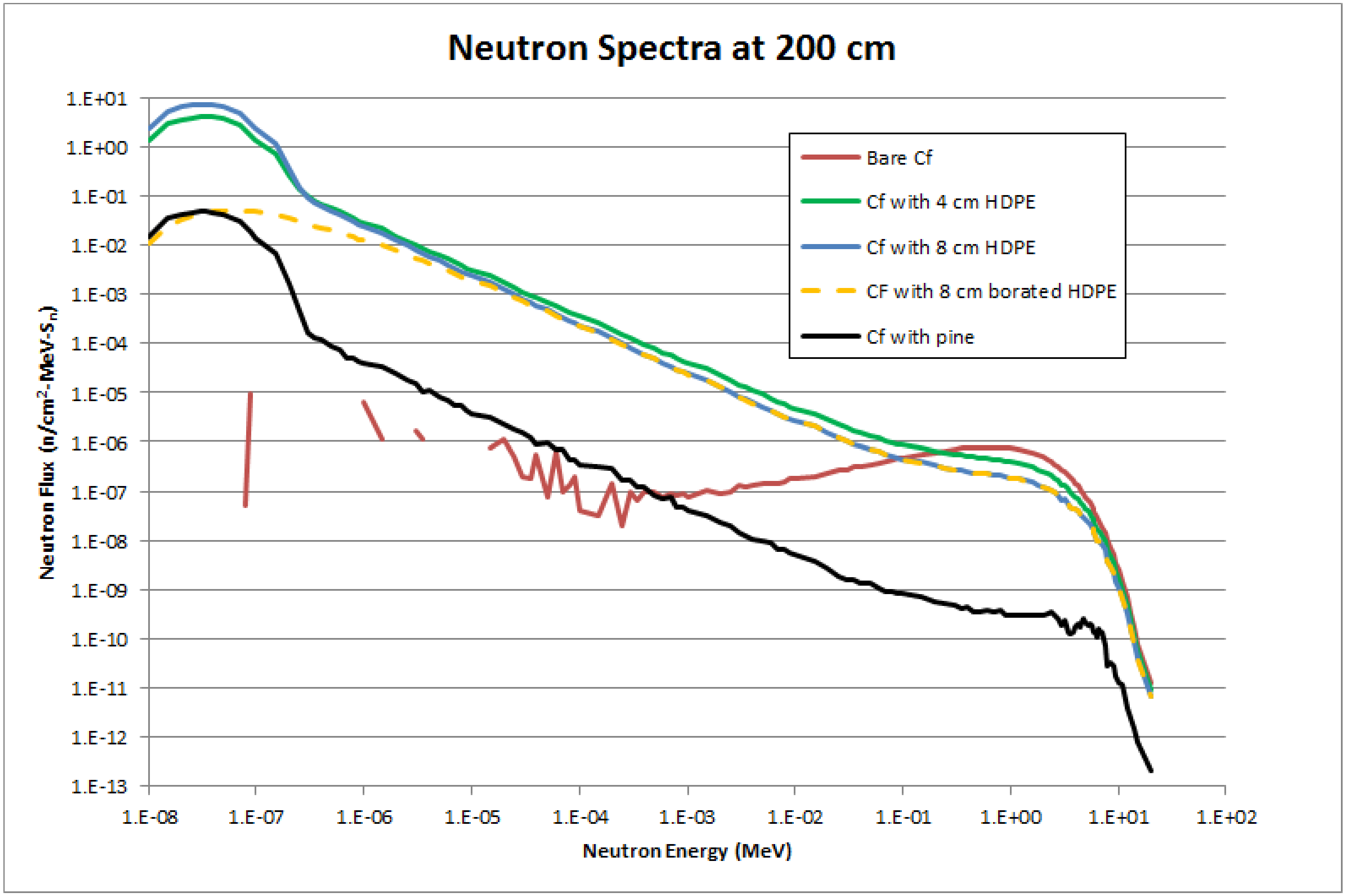

Figure 2: Calculated neutron spectra for no-ground geometries

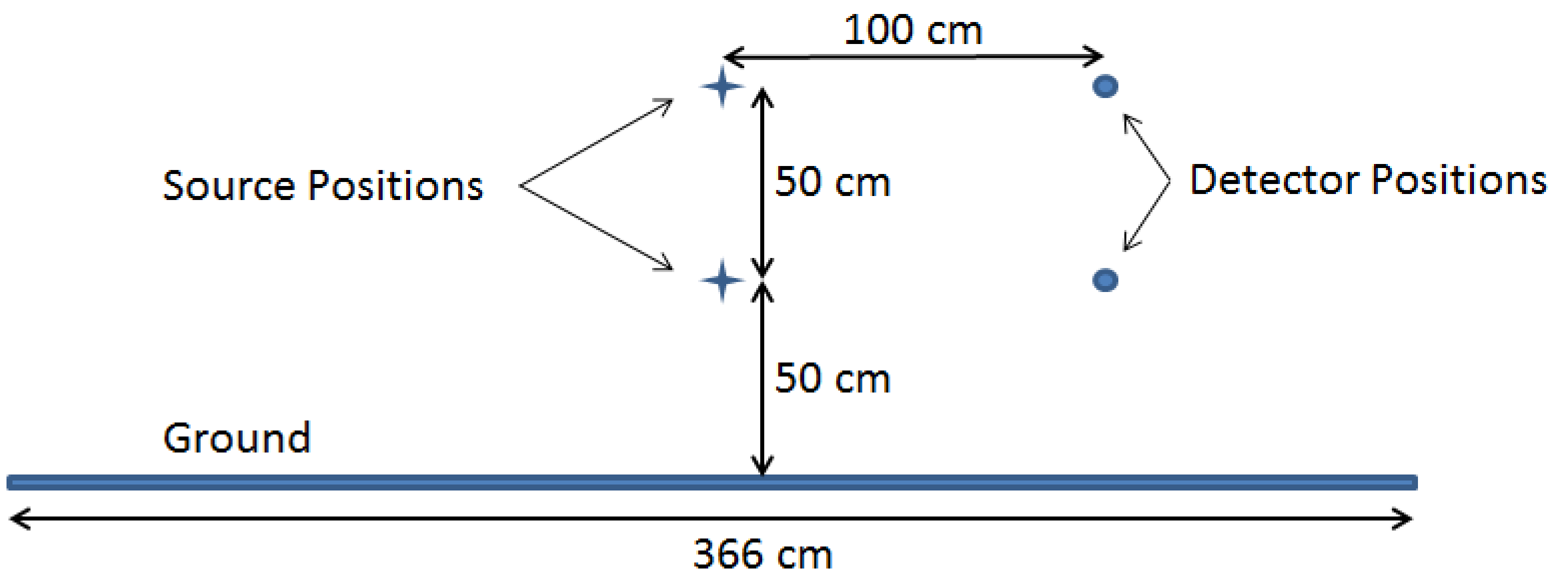

Figure 3: Schematic of geometry for calculations with ground

Table 5: Dose and 3He diagnostics for ground simulations

4 cm HDPE placed 50 cm over asphalt (dh5)

height (cm)	dose	3He
50	5.83E-10	9.86E-03
100	4.59E-10	7.47E-03

height (cm)	3He/dose
50	1.69E+07
100	1.63E+07

4 cm HDPE placed 100 cm over asphalt (dh6)

height (cm)	dose	3He
50	4.58E-10	7.40E-03
100	5.56E-10	7.52E-03

height (cm)	3He/dose
50	1.62E+07
100	1.35E+07

Bare Cf placed 50 cm over asphalt (dh7)

height (cm)	dose	3He
50	1.02E-09	6.67E-04
100	8.08E-10	5.02E-04

height (cm)	3He/dose
50	6.52E+05
100	6.21E+05

Bare Cf placed 50 cm over soil (dh8)

height (cm)	dose	3He
50	1.10E-09	8.15E-06
100	8.57E-10	6.30E-06

height (cm)	3He/dose
50	7.40E+03
100	7.35E+03

Bare Cf placed 100 cm over extended soil (no gasoline) (dh9)

height (cm)	dose	3He
50	8.57E-10	6.30E-06
100	1.01E-09	7.31E-06

height (cm)	3He/dose
50	7.35E+03
100	7.21E+03

Bare Cf placed 50 cm over water (dh10)

height (cm)	dose	3He
50	1.01E-09	5.20E-04
100	7.98E-10	3.83E-04

height (cm)	3He/dose
50	5.15E+05
100	4.79E+05

Bare Cf placed 100 cm over extended soil (with gasoline) (dh11)

height (cm)	dose	3He
50	8.60E-10	2.94E-04
100	1.02E-09	3.49E-04

height (cm)	3He/dose
50	3.42E+05
100	3.43E+05

Bare Cf 50 cm over concrete (dh12)

height (cm)	dose	3He
50	1.07E-09	6.89E-05
100	8.37E-10	5.00E-05

height (cm)	3He/dose
50	6.45E+04
100	5.97E+04

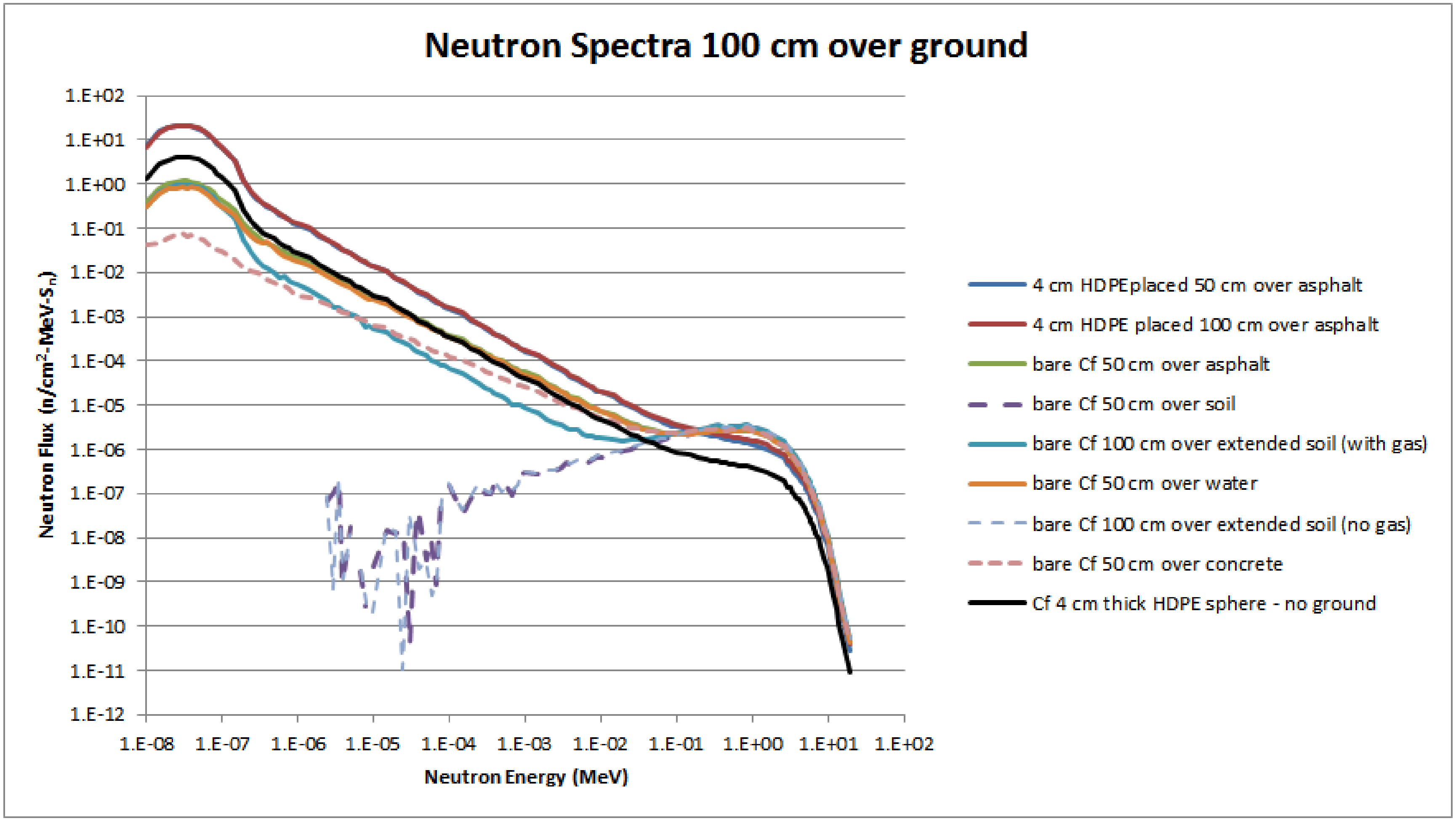

Figure 4: Calculated neutron spectra for ground geometries