Sourceless Calibration of Neutron Detectors – A Simple Solution for A Serious Problem

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Overview

8 years after the introduction of natural Lutetium testadapters for the convenient field testing and calibration of gamma detectors, Thermo Fisher Scientific now proposes a safe and pragmatic method for the reliable and precise response verification and calibration of neutron detectors. Leveraging the omnipresent natural cosmic neutron background radiation a simple and inexpensive reverse calibration kit enables the user to perform a complete neutron performance verification of his instrument(s) by himself. The method involves zero extra radiation exposure, no instrument down time or reccuring external cost. And, compared to performance checks using a conventional neutron check source, there is no administrative hassle related to the possession of radioactive material.

Is my gamma radiation detection instrument working correctly?

Sensitive gamma radiation detection instruments respond to the presence of naturally occurring radioactive material (NORM) that is always present in the environment. Users of those instruments are therefore accustomed to see a variable count rate due to variations in the background radiation during a mobile search exercise. As well, a qualitative response check can be easily performed using exempt low activity check sources, such as 1 µCi of Cs-137 or a smoke detector containing small amounts of Am-241. Alternatively popular "personal check sources" using natural radioactivity are:

- old watches with Radium dials (Ra-226)
- old Fiesta dinnerware (Uranium)
- a bag of KCl (K-40)
- a lantern mantle (Th-232 with progeny)
- a piece of rock (Ra-226 & Th-232 with progeny, K-40)

While these traditional "check sources" containing natural radioactive material are usually not very well characterized and therefor problematic for instrument response characterization, Thermo Fisher Scientific introduced the so called Lu-testadapters in 2008, which are made of natural and chemically pure high density Lu_2O_3 ceramics. These adapters allow perfectly reproducible and safe gamma and beta test and calibration [1].

TABLE 1. Characteristics of Lu-176 (in Lu_2O_3)

Half Life:	3.7 E10 years
Natural Abundance:	2.6 %
Annual limit of intake:	220 kg
Contact dose rate:	app. 200 nSv/h (36 g) app. 50 nSv/h (6 g)

Psychological (and regulatory) Advantages

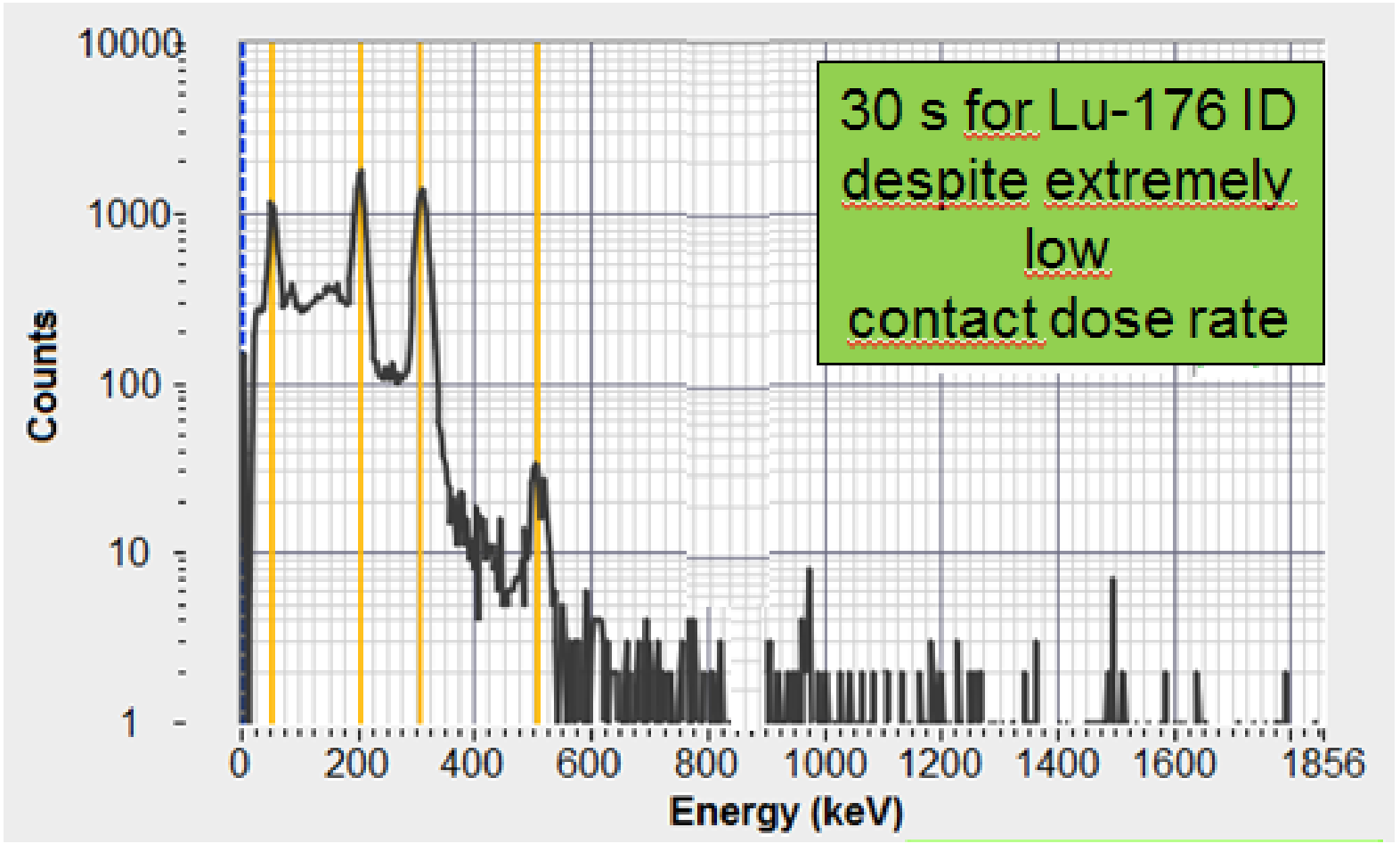
- Natural origin
- Stable: Half life exceeding the age of the Universe
- Touchable surface
- Low specific activity & low total activity

Practical (and scientific) Advantages

- No decay correction required, 1-time buy
- Inherently homogeneous activity distribution
- Inherently reproducible (check source clones)
- No risk of contamination

FIGURE 1.
Safe gamma calibration and spectroscopic test for a Personal Radiation Detector PRD

FIGURE 2.
Gamma Spectrum of Lu-176 in contact to the RadEye



Is my neutron radiation detection instrument working correctly?

Here users experience and expect to see a „zero" count rate during field measurements, since NORM does not emit any detectable amount of neutron radiation. Any useful neutron check sources however needs to contain significant amounts of radioactivity (and in particular tranuranium elements), so the usage of such material is very problematic, especially in the field.

- Relying on a cal sticker on the instrument is not the perfect solution, since unnoticed damage or degradation may have happened since the last calibration in a neutron lab many months ago…

  Very users limit their performance check to one of the following observations:

Expect a "zero" background reading – and see a "zero"

0,0 µSv/h
0,0 cps

Expect a count "once in a while" – and see a count "once in a while"

„CLICK"

Sourceless (reverse) calibration

In the context of the proposed method, sourceless or „reverse" calibration means the removal or at least reduction of the neutron field (i.e. the cosmic neutron background) – instead of the conventional „classic" addition of a neutron source.

FIGURE 3.
The principle of classic and "reverse" calibration

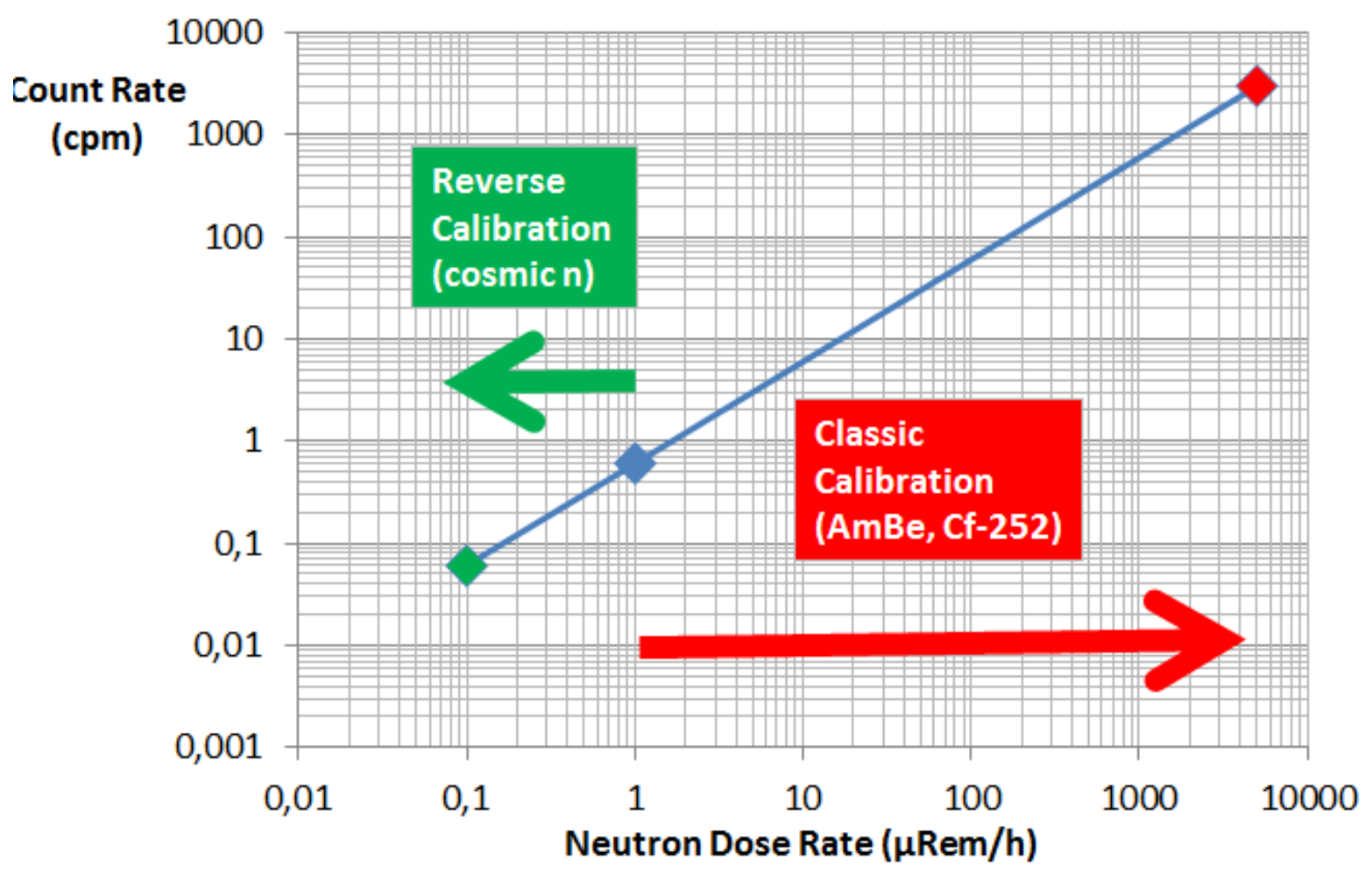
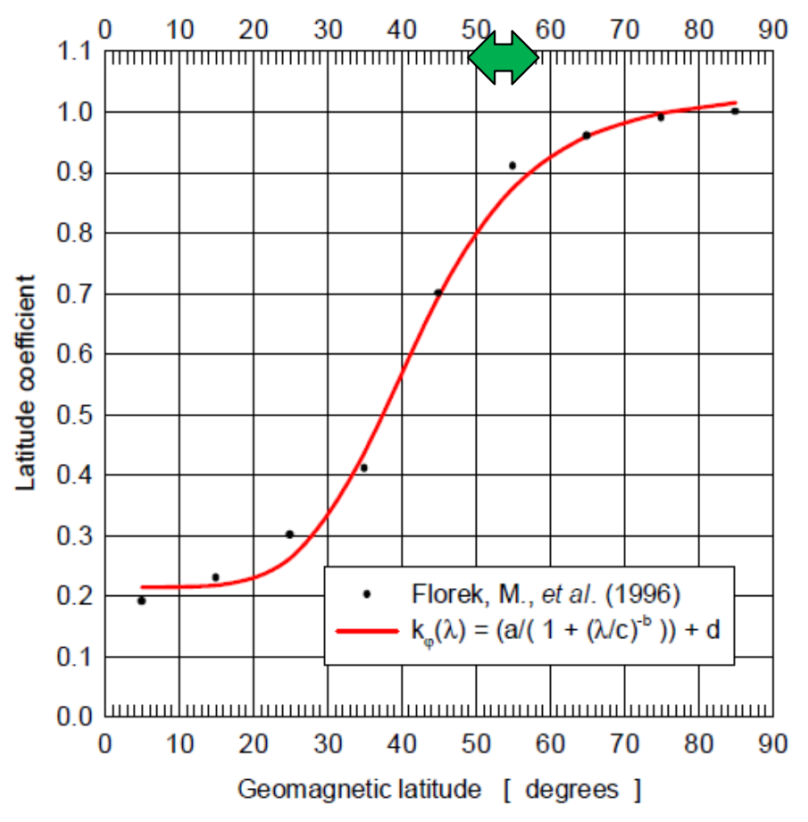


TABLE 2.
Comparison of classic and reverse neutron calibration

	Classic	Reverse
Source	AmBe, Cf-252	Neutron Component of Secondary Cosmic Radiation
Dose Rate	µ to mSv/h range	app.10 nSv/h
Background measurement #0	Absence of noise verification	**Measurement in „suitable" location**
Measurement #1	**Measurement in the direct neutron field**	Measurement with „neutron-shield"
Measurement #2	Shadow cone measurement	
Net count rate	R(#1) – R(#2)	R(#0) – R(#1)
Measurement time	app 1 h (1 d incl. #0)	app 1 d
Out of reach	days / weeks	NA
Cost	Significant	NA

Applicability to the UK-Territory

FIGURE 4.
Cosmic neutron magnetic latitude coefficient [2, 3]



The magnetic latitude for the UK ranges from ***53° N (Dover) to 60° N (Isle of Lewis)*** indicated as a green arrow in figure 4.

➔ Even on sea level (z = 0 m) a reasonable average neutron fluence rate of 0,016 n/(cm²s) can be expected:

$$\Phi(z, \lambda) = 0.0178\, k\phi\, (\lambda)\, Exp[0.00084\, z] \quad [3]$$

Note: Altitude correction for Ben Nevis would be 300 %

Pocket-sized high sensitivity personal neutron detector RadEye SPRD-GN

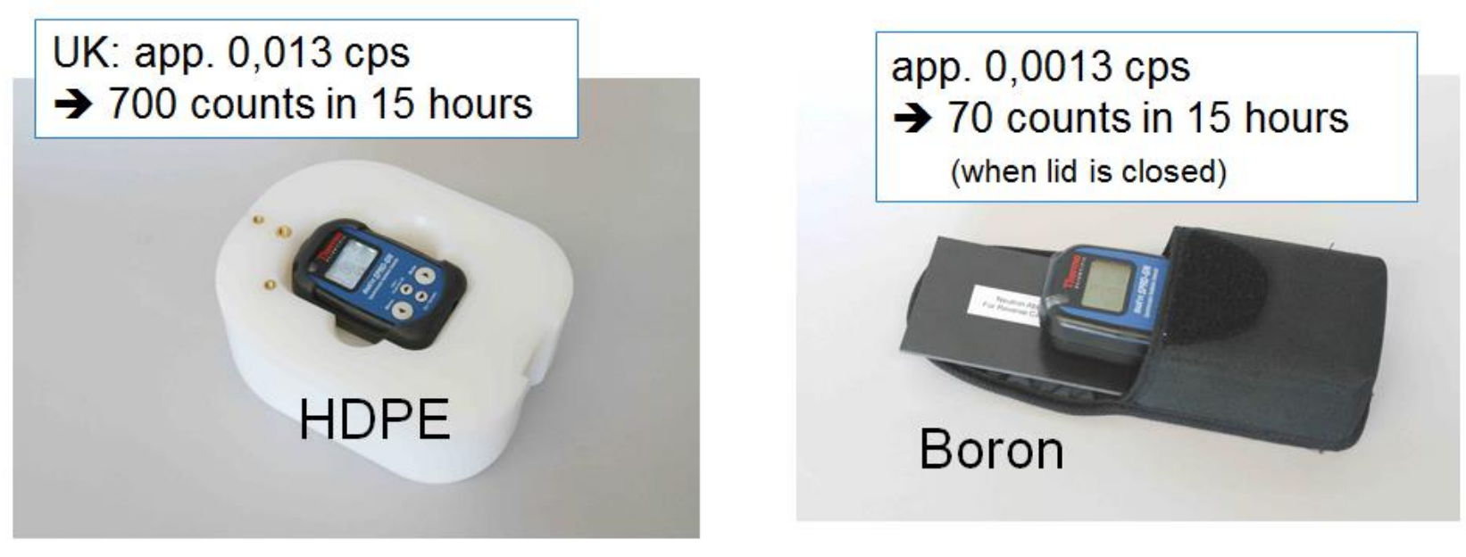
FIGURE 5.
Spectroscopic pager RadEye SPRD-GN with built-in pulse shape discrimination and multi channel analyzer

Due to the very high neutron sensitivity of the elpasolite scintillator Cs_2LiYCl_6:Ce (CLYC), the RadEye SPRD-GN is ideal for the concept of reverse 2-point calibration: Anywhere in the UK the neutron background count rate is completely sufficient gor good statistics in an over night measurement. The small size of the instrument and allows for easy attentuation of the low energy part of the cosmic neutron field.

FIGURE 6.
Display of RadEye SPRD-GN after exposure to neutron background

No computer required:
Direct display of peak and average neutron count rate after 17 h of exposure.

FIGURE 7.
Reverse neutron calibration set-up (example)



UK: app. 0,013 cps
➔ 700 counts in 15 hours

app. 0,0013 cps
➔ 70 counts in 15 hours
(when lid is closed)

Figure 4 shows a setup for maximal (left) and minimal (right) neutron background count rate. Figure 5 shows the commercial version of a calibration kit – convenient for field usage, domestic and international travel.

FIGURE 8
Compact reverse neutron calibration kit

Two RadEye SPRD-GN instruments can be simultaneously exposed to the local secondary galactic neutron field:

One instrument (#1) is surrounded by boron, the other (#0) is not. Both are operating in the same carrying case made (PE-shell). The expected count rate ratio #1/#0 is app. 1/8. Significant deviations from the expected net count rate indicate a problem with the neutron sensitivity. Significant deviations from the expected count rate ratio indicate electronic noise or spill over from radiation other than low energy neutrons (e.g. gammas or muons).

Estimated Count Times for RadEye SPRD-GN Source less Reverse Calibration

TABLE 2.
Impact of location for different cities in the northern hemisphere

RadEye SPRD-GN	geo latitude	geo longitude	magnetic latitude	latitude coeff.	altitude (m)	altitude coeff.	Expected Count Rate high point (cpm)	Expected Count Rate low point (cpm)	Expected net Count Rate (cpm)	Exposure time (h) ea. for net precision of 10 %
Santa Fe	36 N	106 W	44	0,68	2230	6,51	2,12	0,32	1,81	1,3
Denver	40 N	105 W	48	0,78	1600	3,83	1,44	0,22	1,22	1,8
Salt Lake City	41 N	112 W	48	0,78	1300	2,98	1,12	0,17	0,95	2,4
Mexico City	19 N	99 W	27	0,30	2250	6,62	0,95	0,14	0,81	2,8
Madrid	40 N	3 W	43	0,66	670	1,76	0,56	0,08	0,47	4,8
Las Vegas	36 N	115 W	43	0,66	610	1,67	0,53	0,08	0,45	5,0
Erlangen	49 N	11 E	49	0,79	280	1,27	0,48	0,07	0,41	5,5
Chicago	42 N	87 W	51	0,81	160	1,14	0,44	0,07	0,38	6,0
Glasgow	56 N	4 W	58	0,91	0	1,00	0,44	0,07	0,37	6,1
Riga	57 N	24 W	55	0,91	0	1,00	0,44	0,07	0,37	6,1
Berlin	52 N	31 E	52	0,82	35	1,03	0,41	0,06	0,34	6,5
Amsterdam	52 N	5 E	53	0,84	0	1,00	0,40	0,06	0,34	6,6
London	51 N	0°	53	0,83	0	1,00	0,40	0,06	0,34	6,7
Paris	49 N	2 E	50	0,80	35	1,03	0,40	0,06	0,34	6,7
Seattle	47 N	122 W	52	0,82	0	1,00	0,39	0,06	0,33	6,8
New York	41 N	74 W	50	0,80	0	1,00	0,38	0,06	0,33	6,9
San Francisco	38 N	122 W	44	0,68	0	1,00	0,33	0,05	0,28	8,2
Los Angeles	34 N	118 W	40	0,57	0	1,00	0,27	0,04	0,23	9,7
Miami	26 N	80 W	35	0,43	0	1,00	0,21	0,03	0,18	12,8
Singapore	1 N	103 E	9	0,22	0	1,00	0,11	0,02	0,09	25,0

It can be seen from table 2. that the sourceless reverse calibration is applicable nearly everywhere. The calculation of the magnetic latitude was done using the web tool of [4].

Application to Backpack Device

FIGURE 9.
Reverse neutron calibration of backpack PackEye FHT 1377
Left: Regular transport and measurement case
Right: Special reverse calibration case with inner boron lining

For a highly sensitive gamma/neutron detection backpack FHT 1377, the required exposure time for sourceless calibration is approximatel 25 times shorter than for the RadEye SPRD-GN.

Practical Recommendations

- Perform measurent "under the roof", not in the basement!
- Be sure that no neutron sources are anywhere near!
- Correct for atmospheric pressure / sunspot activity for enhanced precision
- Good practice: Run at least 2 devices in parallel

Conclusion

Reverse calibration is an excellent technique to verify the good function of neutron detectors across the UK-territory:

- no source license required
- no risk of loosing a neutron source (AmBe or Cf-252)
- no dose exposure of the user
- no risk of unnoticed instument malfunction

This technique appears to be ideal for homeland security, emergency response teams, environmental agencies, universities and anybody who does not have easy access to a conventional neutron source, such as AmBe or Cf-252.

References

[1] Iwatschenko-Borho, M. (2008), Test Adapters Based on Natural Lutetium – a Discussion of Benefits versus Conventional Check Sources, IRPA 12 Buenos Aires

[2] M. Florek, J. Masarik, I. Szarka, D. Nikodemova, A. Hrabovcova. (1996) Natural neutron fluence rate and the equivalent dose in localities with different elevation and latitude.
Radiat. Prot. Dosim. 67(3): 187-192.

[3] Vega C, H.R. (2003). Study of the environmental neutron spectrum at Zacatecas city. 6 International Conference 16 National Congress on Solid State Dosimetry, Mexico

[4] Data Analysis Center for Geomagnetism and Space Magnetism Graduate School of Science, Kyoto University, Kitashirakawa-Oiwake Cho, Sakyo-ku, Kyoto 606-8502, JAPAN