



Nordic nuclear safety research

NKS-504  
ISBN 978-87-7893-602-8

---

Determination of Am-241 conversion coefficients  
from air kerma to dose equivalent –  
A Nordic measurement campaign

Joonas Tikkanen<sup>1</sup>, Reetta Nylund<sup>1</sup>  
Peter Kaidin Frederiksen<sup>2</sup>, Anders Beierholm<sup>2</sup>  
Robert Billnert-Maróti<sup>3</sup>, Anastasios Anastasiadis<sup>3</sup>, Linda Persson<sup>3</sup>  
Per Otto Hetland<sup>4</sup>, Elisabeth Lindbo Hansen<sup>4</sup>

<sup>1</sup>Radiation and Nuclear Safety Authority (STUK), Finland  
<sup>2</sup>Danish Health Authority, Radiation Protection (SIS), Denmark  
<sup>3</sup>Swedish Radiation Safety Authority (SSM), Sweden  
<sup>4</sup>Norwegian Radiation and Nuclear Safety Authority (DSA), Norway

September 2025

## **Abstract**

In radiation protection instrument calibrations, conversion coefficients from air kerma to dose equivalent are needed to convert an ionization chamber measurement result to the desired calibration quantity. These coefficients can be tabulated in standards, or have to be determined separately for the radiation beam in question. Am-241 is the primary choice of nuclide for energies in the X-ray range. The coefficients for Am-241 sources, according to the 2019 updated standard ISO 4037, need to be determined with spectrometry. The spectrometry method for determining the conversion coefficients have been established at STUK, and the STUK spectrometer and scientist visited other Nordic laboratories to determine conversion coefficients in their beams for the Am-241 sources. The differences in the coefficients between labs were 0.8 % at most, and the differences to monoenergetic coefficients for the main emission of Am-241 of 59.5 keV less than 2 %.

## **Key words**

Instrument calibration, Am-241, conversion coefficients

# **Determination of Am-241 conversion coefficients from air kerma to dose equivalent – A Nordic measurement campaign**

**Final Report from the NKS-B Acronym activity AmSpecNORDOS  
(Contract: AFT/B(23)7)**

Joonas Tikkanen<sup>1</sup>, Reetta Nylund<sup>1</sup>  
Peter Kaidin Frederiksen<sup>2</sup>, Anders Beierholm<sup>2</sup>  
Robert Billnert-Maróti<sup>3</sup>, Anastasios Anastasiadis<sup>3</sup>, Linda Persson<sup>3</sup>  
Per Otto Hetland<sup>4</sup> and Elisabeth Lindbo Hansen<sup>4</sup>

<sup>1</sup>Radiation and Nuclear Safety Authority (STUK), Jokiniemenkuja 1, Vantaa, Finland

<sup>2</sup>Danish Health Authority, Radiation Protection (SIS), Knapholm 7, Herlev, Denmark

<sup>3</sup>Swedish Radiation Safety Authority (SSM), Solna Strandväg 96, Stockholm, Sweden

<sup>4</sup>Norwegian Radiation and Nuclear Safety Authority (DSA), Grini Næringspark 13, Østerås, Norway

## Table of contents

	Page
Abstract	3
1. Introduction	3
2. Fluence spectrum calculation and determination of conversion coefficients	4
3. Measurements	6
4. Results and Discussion	6
5. Conclusions	8
6. Acknowledgements and disclaimer	8
7. References	10

## **Abstract**

In radiation protection instrument calibrations, conversion coefficients from air kerma to dose equivalent are needed to convert an ionization chamber measurement result to the desired calibration quantity. These coefficients can be tabulated in standards, or have to be determined separately for the radiation beam in question. Am-241 is the primary choice of nuclide for energies in the X-ray range. The coefficients for Am-241 sources, according to the 2019 updated standard ISO 4037, need to be determined with spectrometry. The spectrometry method for determining the conversion coefficients has been established at STUK, and the STUK spectrometer and scientist visited other Nordic laboratories to determine conversion coefficients in their beams for the Am-241 sources. The differences in the coefficients between labs were 0.8 % at most, and the differences to monoenergetic coefficients for the main emission of Am-241 of 59.5 keV less than 2 %.

## **1. Introduction**

The determination of dose-equivalent quantities in a calibration laboratory is often achieved by measuring the air-kerma, or air-kerma rate with a reference instrument, and using a conversion coefficient from air-kerma to dose-equivalent. These conversion coefficients are given in the standard ISO 4037-3:2019 for gamma and X-ray fields used for radiation protection instrument calibrations (ISO, 2019b). However, the coefficients given for a radiation quality are valid only under certain conditions. For X-ray qualities, the coefficients from the standard can be used only if the matched field criteria are fulfilled. If this is not possible, the conversion coefficients must be determined via spectrometry (characterized field) (ISO, 2019a).

In the 2019 version of the ISO 4037 standard, the S-Am quality, meaning an irradiator with an Am-241 source, was moved into an annex (ISO, 2019b). This was done mostly because of lack of data while updating the standard. The standard also does not give generic conversion coefficients for the S-Am quality, only estimated values, and states that the coefficients should be determined via spectrometry.

Setting up the spectrometry method for determination of fluence of continuous spectra (such as X-ray irradiator spectra, or radionuclide source with scatter component in the spectrum) requires expensive equipment, characterization of the spectrometer for Monte Carlo modelling and scripting for the analysis of the results. The amount of work required for setting up the method can be several months. The method is detector, and not beam specific, and therefore, once the method has been established for one laboratory, the same spectrometer can be used for determination of fluence in another lab.

Four Nordic laboratories, STUK, SSM, SIS and DSA use Am-241 sources for radiation protection instrument calibrations. The spectrometry method has been previously established at STUK for determination of the conversion coefficients (Tikkanen, 2019). The method was not available for the other laboratories, and therefore the S-Am calibrations could not be given according to the new version of the ISO 4037 standard. Since the spectrometry method is detector specific, the four laboratories established a project supported by NKS (Nordic Nuclear Safety Research) called AMSPECNORDOS to transport the STUK spectrometer in the other laboratories to determine the conversion coefficients for the S-Am fields. This document presents the results from these measurements.

## 2. Fluence spectrum calculation and determination of conversion coefficients

If the photons interacted only via photoelectric interaction, all that would be needed to convert a measured spectrum into fluence spectrum would be the detection efficiency as a function of energy. However, the incident photons can impart only part of their energy in the active volume of the spectrometer, and a Compton scattered photon or an X-ray excited by an electron can escape the volume. This leads to a measured spectrum from a monoenergetic source having X-ray escape peaks and a continuum of counts in addition to the photopeak at the source energy.

If the spectrum that is measured is continuous, the full absorption counts (so called photopeak counts) and the X-ray escape and continuum counts (called here continuum counts for simplicity) are mixed in the measured spectrum. This means that the detection efficiency cannot be directly used for conversion to fluence, and the continuum counts need to be subtracted from the spectrum. The procedure to achieve this is called unfolding.

There are few different methods for the unfolding, and the one used in this work is called peeling method. Even though the spectrum in reality is continuous, it can be approximated to consist of monoenergetic photons with multiple energies, whose energies correspond to the spectrum bin centre energies. If the energy resolution of the detector is not considered, the counts in the bin corresponding to the highest source energy consist only of photopeak counts. This is due to the fact that the continuum counts are always at lower energies than the photon energy. If the shape of the spectrum caused by photons of this energy is known, the continuum counts caused by photons with the highest energy can be subtracted from the lower energy bins. Now the continuum counts in the second highest bin of the spectrum have been subtracted, since the continuum contribution came only from the highest bin, and those counts have already been subtracted. Therefore, the continuum counts caused by photons with energy of this bin can be subtracted from lower energies with the knowledge of the spectrum shape for incoming photons of the energy of the second highest bin, and the third highest bin consists now of only photopeak counts, and so on. This can be written as

$$s_2(i) = s_1(i) - \sum_{j=1}^n s_2(j)S(E_j, i)/S(E_j, j) \quad (1)$$

where  $n$  is the highest bin of the spectrum,  $s_1$  the measured spectrum,  $s_2$  the unfolded spectrum, and  $S(E_j, i)$  bin  $i$  of the measured spectrum created by monoenergetic photons with energy of bin  $j$ . Note that, as discussed,  $s_2(n) = s_1(n)$ , and the calculation is done in order from highest to lowest bin. The spectra  $S$  are calculated with Monte Carlo simulations, and this requires detailed modelling of the spectrometer. Usually, the spectra  $S$  are put into a single matrix, and this matrix is called a response matrix.

After unfolding the spectrum, the fluence is calculated with the knowledge of the detection efficiency, and the area of the beam entering the spectrometer through collimation

$$\phi(i) = \frac{s_2(i)}{\varepsilon(E_i)\pi r^2} \quad (2)$$

where  $\varepsilon(E_i)$  is the full energy peak efficiency at energy of bin  $i$ , meaning the probability with which a photon coming through the collimator hole (with radius  $r$ ) deposits all of its energy in the active volume of the spectrometer.

The air-kerma can be calculated for each bin of the spectrum, and the result is a so called air-kerma spectrum. The air-kerma for monoenergetic photons with energy of bin  $i$  is given by

$$K_{a,i} = \phi E_i \left( \frac{\mu_{en}}{\rho} \right)_{E_i} \quad (3)$$

Where  $(\mu_{en}/\rho)_{E_i}$  is the mass energy-absorption coefficient at energy  $E_i$ . The total air-kerma for a non-monoenergetic source is given as an integral over the spectrum, which can be approximated as a sum

$$K_a = \sum_{i=1}^n K_{a,i} = \sum_{i=1}^n \phi(i) E_i \left( \frac{\mu_{en}}{\rho} \right)_{E_i} \quad (4)$$

The dose equivalent for monoenergetic photons is calculated with monoenergetic conversion coefficients from air-kerma to dose equivalent  $h(E)$  with

$$H_i = K_{a,i} h(E_i) \quad (5)$$

and the dose-equivalent over a spectrum is given by

$$H = \sum_{i=1}^n K_{a,i} h(E_i) = \sum_{i=1}^n \phi(i) E_i \left( \frac{\mu_{en}}{\rho} \right)_{E_i} h(E_i) \quad (6)$$

The conversion coefficient for the spectrum is then obtained with

$$h = \frac{H}{K_a} \quad (7)$$

This coefficient can be thought of as a weighted average of  $h(E)$  over the spectrum. In this work, the  $(\mu_{en}/\rho)_{E_i}$  values were from NIST XCOM database (Berger *et al.*, 2011), and the monoenergetic  $h(E)$  coefficients from ISO 4037:2019. The  $(\mu_{en}/\rho)_{E_i}$  and  $h(E)$  coefficients were interpolated with a piecewise cubic hermite interpolating polynomial (PCHIP) in MATLAB.

The  $\varepsilon$  approaches zero at low energies, and the  $(\mu_{en}/\rho)_{E_i}$  grows exponentially. Therefore, if the unfolded spectrum  $s_2$  does not go to zero at low energies (either due to statistical fluctuation of the data or non-perfect unfolding), the fluence, and kerma would be amplified significantly, even though the value does not correspond to reality. Therefore, a lower energy threshold was applied to the air-kerma spectrum calculation. The threshold was set to 16 keV, the energy being slightly below  $L\beta$  X-ray energies of Np-237. Because the photon emissions of Am-241 above 60 keV have a negligible intensity, the bins above 62 keV were omitted from the calculations, although the effect was minimal. The conversion coefficient calculation and uncertainty estimation are described in more detail in STUK TR-30 report (Tikkanen, 2019).

### 3. Measurements

The Am-241 sources at SSM, SIS and DSA are installed inside a source carousel, whereas STUK has portable source that is put inside the (also portable) irradiator system. The irradiators and sources are listed in table 1.

**Table 1:** Irradiators and Am-241 sources used in the measurements, with nominal activity  $A$  of the sources.

	Irradiator	Source	$A$ (GBq)
SSM	DIR-101, Veenstra Instruments (Netherlands)	AMC30, AEA Technology QSA GmbH (Braunschweig, Germany)	111
SIS	OG-8, VF Nuclear (Černá Hora, Czech Republic)	Eckert & Ziegler (Berlin, Germany)	220
DSA	DIR-101, Veenstra Instruments (Netherlands)	AMC30, AEA Technology QSA GmbH (Braunschweig, Germany)	111
STUK	Custom built	FT-100, Industrial Dynamics (Torrance, USA)	11

The detector provided by STUK was an Ortec GEM S5020P4 (AMETEK, Oak Ridge, USA) HPGe spectrometer with a Canberra Inspector 2000 multi-channel analyser. A custom-made lead shield was put on the spectrometer, and the radiation beam intensity was reduced with collimator plates in front of the spectrometer. The radiation beam was collimated so that field size was smaller than the outer diameter of the collimator plates and the lead shielding: the beam would not go past the shielding, and scattered photons could not enter the detector from behind the shielding. The spectra were measured at one- and two-meter distances at SSM and SIS, and at one meter and approximately 1.6 m distances at DSA. At STUK, the measurement distance was 50 cm. The measurement setups for the visited laboratories are visualized in figures 1–3.

#### 4. Results and Discussion

The conversion coefficients for the S-Am radiation beams are given in tables 2–7. The results are measured at one-meter distance for SSM, SIS and DSA, and 50 cm distance for STUK. In addition, the monoenergetic conversion coefficients for the main photon emission of 59.5 keV (calculated from linear interpolation) is given for comparison. The expanded uncertainty estimation for the measured coefficients is 1.5 % ( $k = 2$ , normal distribution). The uncertainty estimated according to STUK TR-30 would be lower, but the estimation given here includes uncertainty due to the selection of the low energy threshold and the possibility of small amount of scattered radiation entering the detector behind the lead shielding.

The conversion coefficients at the 2 m and 1.6 m distances compared to 1 m were practically equal for DSA and SIS (differences less than 0.1 %). For SSM, the coefficients were lower at 2 m, which means that scattered radiation entered the detector from behind the lead shielding due to improper collimation. The  $h(E)$  coefficients increase with energy below 60 keV, air attenuates the lower energies of the spectrum more, and the spectrum is harder further away, and the



**Figure 1:** Measurement setup at SSM. The spectrometer lead shielding is visible on the right. The beam from the irradiator was collimated with a 1.4 cm hole diameter collimator from STUK. The purpose of the additional collimator was to reduce the beam size to smaller than the lead shielding around the spectrometer. The fluence entering the detector was reduced further with a 2 mm diameter collimator disk in front of the detector.

conversion coefficients should hence, if there is a difference, be larger. For these reasons, only the 1 m results are given in tables 2–7. The agreement between DSA 1 m and 1.6 m, and SIS 1 m and 2 m results indicate that the coefficients can be assumed to be valid also at distances larger than 2 m as long as the requirements on the measurement geometry given in ISO 4037 are fulfilled.

The results in tables 2 – 7 show, that the conversion coefficients from air-kerma to dose equivalent are similar between the S-Am beams, with maximum difference in the coefficients of 0.77 % for  $h_{pK}(10, 75^\circ)_{\text{slab}}$  between STUK and SIS. The differences to the 59.5 keV

monoenergetic coefficients were significantly larger, the maximum difference being 1.72 %, and the difference growing as a function of angle. At zero angle, the difference was 1.21 % at maximum (STUK  $h_{pK}(10, 0^\circ)_{\text{slab}}$ ). The difference to values given in ISO 4037-3 Annex B is slightly larger, since the 60 keV monoenergetic coefficients are given in the annex instead of 59.5 keV interpolated values. Exception to this is  $h_{pK}(0, 07, \phi)_{\text{slab}}$  in ISO 4037-3 table B.5, where the coefficients deviate from the monoenergetic 60 keV values given in the standard (table 33) significantly. This might indicate a mistake in the standard. Also, the set of angles in tables 33 and B.5, and hence in table 4 of this work, differ.



**Figure 2:** Measurement setup at SIS. The beam from the irradiator was collimated with two additional collimators, a lead KAP collimator and a lead collimator from STUK with 1.4 cm hole diameter, before the spectrometer. The fluence entering the detector was reduced further with a 2 mm diameter collimator disk in front of the detector.

## 5. Conclusions

The spectra for Am-241 irradiators in the Nordic SSDL laboratories were successfully measured with the HPGc spectrometer. The determined conversion coefficients from air-kerma to dose equivalent between the beams were consistent between the laboratories with maximum difference of 0.8 %. The differences to 59.5 keV monoenergetic factors were higher, the difference being almost 2 % at largest. Also, the estimated expanded uncertainty of 1.5 % is significantly lower than the expanded uncertainty of 4 % for matched X-ray, S-Cs and S-Co fields given in ISO 4037.

## 6. Acknowledgements and disclaimer

NKS conveys its gratitude to all organizations and persons who by means of financial support or contributions in kind have made the work presented in this report possible.

The views expressed in this document remain the responsibility of the authors and do not necessarily reflect those of NKS. In particular, neither NKS nor any other organisation or body supporting NKS activities can be held responsible for the material presented in this report.

**Table 2:** Conversion coefficients  $h_{pK}(10, \phi)_{\text{slab}}$  for the Am-241 sources and the ICRU slab phantom.

	0°	15°	30°	45°	60°	75°
SSM	1.864	1.844	1.804	1.693	1.475	1.038
SIS	1.872	1.852	1.811	1.700	1.482	1.043
DSA	1.869	1.849	1.809	1.698	1.480	1.041
STUK	1.861	1.841	1.801	1.690	1.472	1.035
59.5 keV	1.884	1.864	1.824	1.713	1.494	1.053

**Table 3:** Conversion coefficients  $h_{pK}(3, \phi)_{\text{scyl}}$  for the Am-241 sources and the cylinder phantom consisting of ICRU tissue

	0°	15°	30°	45°	60°	75°	90°
SSM	1.655	1.644	1.624	1.594	1.523	1.392	1.090
SIS	1.659	1.649	1.629	1.599	1.527	1.396	1.095
DSA	1.658	1.647	1.627	1.597	1.526	1.395	1.093
STUK	1.653	1.643	1.623	1.592	1.521	1.390	1.088
59.5 keV	1.667	1.657	1.637	1.607	1.537	1.406	1.105

**Table 4:** Conversion coefficients  $h_{pK}(0,07, \phi)_{\text{slab}}$  for the Am-241 sources and the ICRU slab phantom.

	0°	15°	30°	45°	60°	75°
SSM	1.696	1.665	1.625	1.547	1.418	1.309
SIS	1.700	1.669	1.629	1.550	1.421	1.311
DSA	1.698	1.668	1.628	1.549	1.420	1.310
STUK	1.694	1.664	1.624	1.546	1.417	1.308
59.5 keV	1.706	1.676	1.636	1.556	1.426	1.317

**Table 5:** Conversion coefficients  $h_{pK}(0,07)_{\text{rod}}$  for the Am-241 sources and rod phantom.

SSM	1.137
SIS	1.137
DSA	1.137
STUK	1.136
59.5 keV	1.139

**Table 6:** Conversion coefficients  $h_{pK}(0,07)_{\text{pill}}$  for the Am-241 sources and pillar phantom.

SSM	1.383
SIS	1.385
DSA	1.384
STUK	1.382
59.5 keV	1.388

**Table 7:** Conversion coefficients  $h_{pK}^*(10)$  for the Am-241 sources.

SSM	1.719
SIS	1.725
DSA	1.723
STUK	1.716
59.5 keV	1.737



**Figure 3:** Measurement setup at DSA. The beam from the irradiator was collimated with two additional collimators (tungsten KAP collimator and a lead block with 1 cm hole diameter) before the spectrometer. The fluence entering the detector was reduced further with a 2 mm diameter collimator disk in front of the detector.

## 7. References

M. Berger, J. Hubbell, S. Seltzer, J. Chang, J. Coursey, R. Sukumar, D. Zucker, and K. Olsen. XCOM: Photon Cross Sections Database, NIST Standard Reference Database 8 (XGAM), 2011.

ISO 4037-1:2019. X and gamma reference radiation for calibrating dosimeters and doserate meters and for determining their response as a function of photon energy – Radiation characteristics and production methods. Standard, International Organization for Standardization, Geneva, 2019.

ISO 4037-3:2019. X and gamma reference radiation for calibrating dosimeters and doserate meters and for determining their response as a function of photon energy – Part 3: Calibration of area and personal dosimeters and the measurement of their response as a function of energy and angle of incidence. Standard, International Organization for Standardization, Geneva, 2019.

J. Tikkanen. STUK-TR30: Muunnoskertoimien ilmakermasta annosekvivalenttiin laskeminen ISO N- ja ISO H -röntgensäteilylaaduille spektristä sekä Ortec'in GEM-S5020P -spektrometrin mallintaminen. Technical report, Radiation and Nuclear Safety Authority (STUK), 2019.

Title	Determination of Am-241 conversion coefficients from air kerma to dose equivalent – A Nordic measurement campaign
Author(s)	Joonas Tikkanen, Reetta Nylund, Peter Kaidin Frederiksen, Anders Beierholm, Robert Billnert-Maróti, Anastasios Anastasiadis, Linda Persson, Per Otto Hetland, and Elisabeth Lindbo Hansen
Affiliation(s)	Radiation and Nuclear Safety Authority (STUK), Finland. Danish Health Authority, Radiation Protection (SIS), Denmark. Swedish Radiation Safety Authority (SSM), Sweden. Norwegian Radiation and Nuclear Safety Authority (DSA), Norway.
ISBN	978-87-7893-602-8
Date	September 2025
Project	NKS-B / AmSpecNORDOS
No. of pages	10
No. of tables	7
No. of illustrations	3
No. of references	4
Abstract max. 2000 characters	In radiation protection instrument calibrations, conversion coefficients from air kerma to dose equivalent are needed to convert an ionization chamber measurement result to the desired calibration quantity. These coefficients can be tabulated in standards, or have to be determined separately for the radiation beam in question. Am-241 is the primary choice of nuclide for energies in the X-ray range. The coefficients for Am-241 sources, according to the 2019 updated standard ISO 4037, need to be determined with spectrometry. The spectrometry method for determining the conversion coefficients have been established at STUK, and the STUK spectrometer and scientist visited other Nordic laboratories to determine conversion coefficients in their beams for the Am-241 sources. The differences in the coefficients between labs were 0.8 % at most, and the differences to monoenergetic coefficients for the main emission of Am-241 of 59.5 keV less than 2 %.
Key words	Instrument calibration, Am-241, conversion coefficients