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Nordic *In Situ* gamma Intercomparison.  
Final Report from NKS-B NISI project  
(Contract: AFT/B(16)2)

T Gäfvert<sup>1</sup>, J Boson<sup>2</sup>, T Karhunen<sup>3</sup>, G Jónsson<sup>4</sup>, S Juul Krogh<sup>5</sup>  
J Drefvelin<sup>1</sup>, P O Hetland<sup>1</sup>, L Skuterud<sup>1</sup>, P Reppenhagen Grim<sup>5</sup>  
P Smolander<sup>3</sup>, K Guðnason<sup>4</sup>, P Frisk<sup>2</sup>, B Winther<sup>5</sup>, C Andreis<sup>5</sup>

<sup>1</sup>NRPA  
<sup>2</sup>SSM  
<sup>3</sup>STUK  
<sup>4</sup>IRSA  
<sup>5</sup>DEMA

## Abstract

Having the necessary skills and tools for radiological site characterization is very important in both early and late phases of an incident involving radioactive deposition over large areas. *In situ* gamma spectrometry is, compared to soil sampling, a rapid method to measure the deposition from fresh fallout after a nuclear accident. With an operative detector system, results can be generated in minutes after the measurements. The NKS Nordic *in situ* intercomparison (NISI) project provided a platform for comparing equipment, methods and results from *in situ* gamma spectrometric site characterizations. A one-day practical field exercise was carried out in the Jotunheimen area of Norway, which is an ideal location for this type of measurement as it contains large flat areas with significant levels of deposited Cs-137 from the Chernobyl accident in sites that are virtually undisturbed by industrial or agricultural influences. All teams were skilled and trained enough to be able to deliver the results in time, and all teams reported results that agreed well both between the countries and between the results from earlier soil sampling in 2011.

## Key words

*In situ* gamma spectrometry, intercomparison, emergency preparedness

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T Gäfvert<sup>1</sup>, J Boson<sup>2</sup>, T Karhunen<sup>3</sup>, G Jónsson<sup>4</sup>, S Juul Krogh<sup>5</sup>, J Drefvelin<sup>1</sup>, P O Hetland<sup>1</sup>, L Skuterud<sup>1</sup>, P Reppenhausen Grim<sup>5</sup>, P Smolander<sup>3</sup>, K Guðnason<sup>4</sup>, P Frisk<sup>2</sup>, B Winther<sup>5</sup>, C Andreis<sup>5</sup>

<sup>1</sup>NRPA

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## Contents

1. Introduction	4
2. Objectives	4
3. Materials and methods	5
3.1 Measurement sites	5
3.2 Exercise tasks	6
3.3 Denmark (DEMA)	8
3.4 Norway (NRPA)	10
3.5 Sweden (SSM)	12
3.6 Finland (STUK)	15
3.7 Iceland (Geislavarnir Ríkisins)	17
3.8 Soil sampling and analysis	19
4. Results	20
5. Discussion and Conclusions	25
6. References	27
7. Acknowledgement	27

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## 1. Introduction

Having the necessary skills and tools for radiological site characterization is very important in both early and late phases of an incident involving radioactive deposition over large areas. *In situ* gamma spectrometry is, compared to soil sampling, a rapid method to measure the deposition from fresh fallout after a nuclear accident. With an operative detector system and appropriate calibrations and methods, results can be generated in minutes after the measurements. To get correct results some knowledge about the depth distribution of the activity and soil characteristics have to be known. For fresh fallout a common approach is to assume a plane surface source, or, a more realistic, slightly superficial distribution. For aged fallout, a normal procedure is to collect and slice a number of soil cores, and subsequently analyse samples with respect to gamma emitters in the different layers at the laboratory. *In situ* gamma spectrometry also has the ability to average out heterogeneities over the field of view of the detector, while soil sampling can be largely affected by local heterogeneity in the deposition pattern.

The NKS Nordic *in situ* intercomparison (NISI) project provided a platform for comparing equipment, methods and results from *in situ* gamma spectrometric site characterizations. A one-day practical field exercise was carried out in the Jotunheimen area of Norway, which is an ideal location for this type of measurement as it contains large flat areas with significant levels of deposited Cs-137 from the Chernobyl accident in sites that are virtually undisturbed by industrial or agricultural influences.

In connection to the field intercomparison exercise, a one-day seminar focusing on *in situ* gamma spectrometric methods was also arranged. This provided participants with an opportunity to exchange results and information on methods, software, calibration routines, research and development, etc.

This project also gave the opportunity to discuss harmonization of methods in order to facilitate assistance between Nordic countries and to ensure that *in situ* measurement results are comparable in the case of an emergency scenario. As *in situ* gamma spectrometry is one of the first sources of information in an incident involving radiological contaminants, it is safe to assume that being able to successfully share information will be important in both early and late phases of a potential incident. The activity as a whole provides a platform for further developing a Nordic network working on *in situ* gamma spectrometry and radiological site characterizations. It was also recognized that the majority of the participants will, or already have registered an *in situ* gamma spectrometry capacity in the IAEA RANET emergency and response network. Furthermore, the project gave participants valuable experience in travelling with equipment across borders, testing field procedures, validation of calibrations and the ability to produce results in short time.

## 2. Objectives

The main objective of the NISI project is to compare results from *in situ* gamma spectrometry at two pre-selected, characterized, sites affected by fallout from the Chernobyl accident in 1986. The sites are located in the Jotunheimen, a mountain area in the central part of Norway. At one of the sites a new set of soil samples were collected and analysed for comparison. Hidden radioactive point sources were also used to test the teams' ability to identify unexpected peaks in the spectra.

### 3. Materials and methods

In total five teams from all Nordic countries participated in the NISI project. The equipment and methods used for calibration of the detectors are in some aspects quite different between the countries. Both mathematical calibration and calibration with reference point sources have been used. Participants have also used, for example, different references for calculating primary photon fluence in air per unit activity, for different depth distributions of activity. All teams had planned to use a high resolution HPGe-detector for the field measurements. Due to technical problems one of the teams had to use LaBr<sub>3</sub>(Ce)-detector as a back-up solution.

#### 3.1 Measurement sites

The measurements took place in Jotunheimen at two locations, Oskampen and Buhø. In 2011 extensive soil sampling were performed in order to characterize these sites with respect to Cs-137 deposition. The deposition, in Bq/m<sup>2</sup>, at each site is based on 30 soil cores collected within a circular area with a radius of 16 meters. At the center point the soil cores were sliced in 3 cm layers in order to find the depth distribution of Cs-137. All samples were later analyzed by gamma spectrometry in the laboratory at the NRPA. The activity concentration of natural radioactivity in the area is well below average for Norway. The geometric average and the depth distribution of the Cs-137 deposition at each site are shown in Tables 1-3. During previous fieldwork, the observed soil density varied between 1.0 g/cm<sup>3</sup> and 1.6 g/cm<sup>3</sup> depending on soil type, moisture content, etc. The analytical uncertainty of the relative Cs-137 layer concentrations are approximately 5-10 % at 1σ.

**Table 1.** GPS position and deposition of Cs-137 from the 2011 soil sampling (reference time September 2016) at the measurement sites.

Site name	GPS lat.	GPS long.	Cs-137 (kBq/m <sup>2</sup> )	1 σ (kBq/m <sup>2</sup> )
Buhø 1	61.3923	9.1448	63	16
Oskampen 1	61.4139	9.1367	63	14

**Table 2.** Cs-137 depth distribution for Buhø 1 in the 2011 soil samples.

Soil core layer	Relative Cs-137 content
0-3 cm	91.4 %
3-6 cm	7.2 %
6-8 cm	1.4 %

**Table 3.** Cs-137 depth distribution for Oskampen 1 in the 2011 soil samples

Soil core layer	Relative Cs-137 content
0-3 cm	96.7 %
3-6 cm	2.8 %
6-9 cm	0.3 %
9-11 cm	0.1 %

### 3.2 Exercise tasks

At each site five orange markers were distributed on the ground. One on the reference point (Buhø 1 and Oskampen 1) and the other four in the close vicinity. In three of the markers, weak calibration source (Cs-134, Co-57 and Am-241) were hidden (see spectra in Figure 2). At one spot (Oskampen 5), a new set of soil samples were collected for comparison with the results from *in situ* gamma spectrometry.

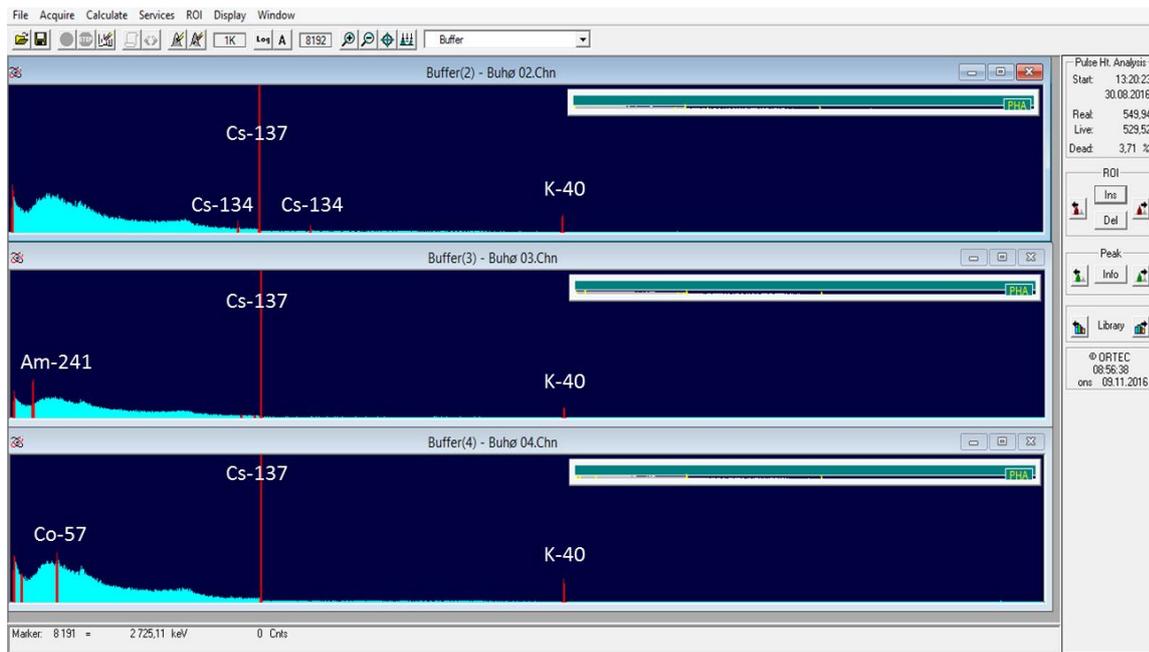
Each participant was instructed to acquire a gamma spectrum for at least 10 minutes 1 meter above each marker and report the following information early the next day:

- 1) Total deposition with the assumption of a 3 cm thick slab source of Cs-137 with a soil density of  $1.6 \text{ g/cm}^3$ .
- 2) Total deposition with the assumption of a plane surface source distribution of Cs-137 (surface equivalent deposition).
- 3) Any other observations in the spectra.

The reason for also reporting results for surface equivalent deposition is that this is not dependent on soil parameters and thus more suitable for comparing results that are only dependent on detector parameters.



**Figure 1.** *In situ* detectors set up over orange markes at one of the locations (Buhø). Photo: Per Grim.



**Figure 2.** Three HPGe-spectra (10 minutes acquisition time each) from measurement point 2, 3 and 4 at Buhø, with hidden point sources.

Below are descriptions by the different teams of their methods, equipment and calibration used for *in situ* gamma spectrometry.

### 3.3 Denmark (DEMA)



**Figure 3.** The Danish team setting up the detector at Oskampen. Photo: Per Grim.

#### **Equipment**

DEMA use the electrically cooled Canberra F5000 Falcon Ge-detector. It has a relative efficiency of 18 % and runs approximately for 6 hours on battery (hot swapping 3 batteries). The detector is operated via Wi-Fi by a ruggedized tablet using either a simple program or Canberra Genie 2000. Further specifications for individual measurement systems are listed in attached system description. Other equipment used is the handheld dose rate and nuclide identification instrument RS-220 with a NaI(Tl) detector and a camera.

#### **Measurement site selection**

If the measurement location is not pre-determined, care should be taken to locate a suitable area, i.e. an area that is representative for the survey area. This should be relatively flat, free of potentially interfering objects (such as trees or buildings), and it should display a homogeneous dose rate at one meter above ground. The exact position of the measurement point is recorded by the internal GPS of the Falcon detector.

#### **Detector setup**

The detector is strapped to a plate mounted on a tripod. The endcap is pointing downwards over the side of the plate at 1 m above ground, see figure 3.

#### **Spectrum acquisition**

Spectra are recorded for as long as needed to ensure adequate counting statistics in relevant full energy peaks (less than 1% uncertainty on relevant peaks). The standard acquisition time we used was 10 min, but this would be corrected if adequate statistic was not obtained. This was not the case in for these measurements.

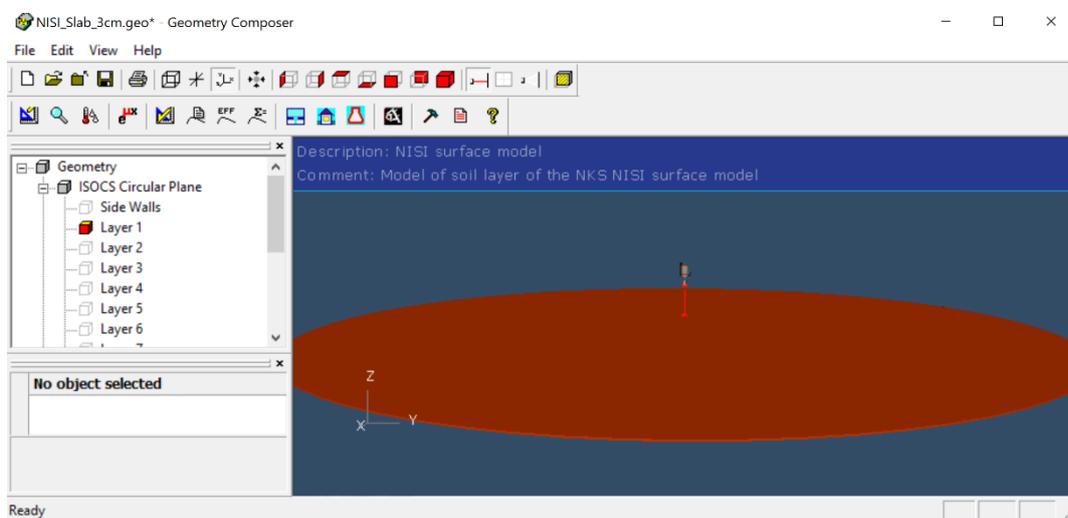
#### **Dose rate measurement**

A dose rate measurement is always performed in the same position as the *in situ* measurement.

#### **Calibration**

To calculate the efficiency curve for the detector, we use a method called source-less calibration. The detector was delivered with a characterization file for the sources-less calibration software ISOCS (*In Situ* Object Counting System). In Geometry Composer a

module for simulating *is situ* geometries is available, see figure 4. Here we can simulate a great range of deposition models, as long as we build them as layers with individual soil composition and relative concentration. There is no practical limit on the thickness of the layer or the complexity of the composition of the soil material the layer is comprised of.



**Figure 4.** Canberra ISOCS calibration software.

With this set up, efficiency curves for an unlimited amount of different surface, exponential, layer or slab models can be generated.

Energy calibration is done with a Europium-152 source, and then checked using Cobalt-60, Caesium-137 and Americium-241. The checks are done routinely to make sure the detector is always operational.

### **Spectrum analysis and results**

When the efficiency and energy calibrations are loaded into Genie 2000 the activity can either be read directly of each peak in the spectrum or Genie2000 can generate a report by executing a sequence of analysis tools where an interference corrected activity will be calculated.

### **Reporting**

The reported in-situ results may be:

- Activity (Bq, Bq/m<sup>2</sup>, Bq/kg or Bq/l for each relevant identified radionuclide for the chosen efficiency model).
- Associated dose-rate measurement at in-situ position.

### 3.4 Norway (NRPA)



**Figure 5.** The Norwegian team adjusting the detector at Buhø. Photo: T. Gäfvert

#### **Equipment**

Measurements are performed using the following equipment:

- P-type (coaxial) HPGe-detector (ORTEC) with a relative efficiency of about 30 %.
- Portable MCA (ORTEC DigiDART).
- Ruggedized laptop (used for spectrum analysis and calculation of results).
- Tripod (Canberra Insitpod).

Auxiliary equipment includes dose rate instrument, handheld GPS, tape measure and camera.

#### **Measurement site selection**

If the measurement location is not pre-determined, a flat and open area should be selected. The dose rate at one meter above ground should be as homogenous as possible. The exact position of the measurement point, obtained from a handheld GPS, is recorded and reported with the results.

#### **Detector setup**

The detector is mounted on a tripod so that the centre of the endcap is positioned one meter above ground, with the symmetry axis of the crystal orthogonal to the ground surface.

#### **Spectrum acquisition**

Spectra are recorded for as long as needed to ensure adequate counting statistics in relevant full energy peaks.

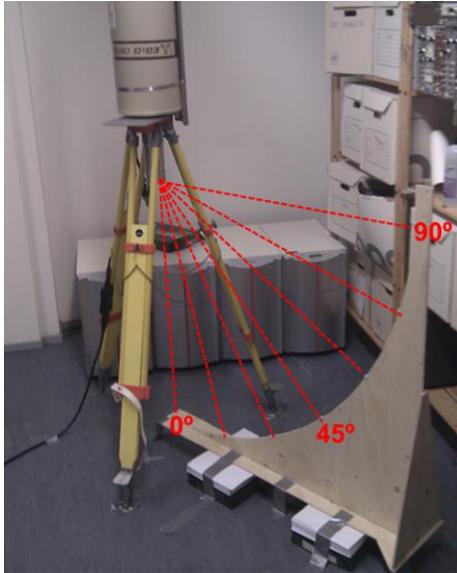
#### **Dose rate measurement**

A dose rate measurement should always be performed in the same position as the *in situ* measurement.

#### **Calibration**

Calibration has been performed following methods described in ISO 18589-7 and ICRU 53.

The detector intrinsic full energy peak efficiency has been determined at a number of different photon energies and 7 angles (0°, 15°, 30°, 45°, 60°, 75° and 90°) of incidence using reference point sources.



**Figure 6.** Calibration rig for *in situ* detector at the NRPA. Photo: A. Mairing.

The following radionuclides were used for the calibration: Am-241, Ba-133, Cs-137, Co-57 and Co-60. The calibration factor is calculated from following equation:

$$\frac{R}{A} = \frac{R_0}{\psi} \times \frac{R}{R_0} \times \frac{\psi}{A} \quad (\text{eq. 1})$$

Where:  $R/A$  = detector efficiency

$R_0/\Psi$  = full energy efficiency (normal incidence)

$R/R_0$  = angular correction factor

$\Psi/A$  = fluence rate per unit activity

Possible depth distributions are: surface, exponential, homogeneous and single slab.

### Spectrum analysis and results

The spectrum is acquired in ORTEC Maestro, where peaks are identified and net areas of relevant full energy peaks are calculated. Results are later calculated in an in-house software (InSiCal) where detector efficiency, deposition model and photon energy can be selected.

### Reporting

The report from InSiCal includes:

- Nuclide.
- Deposition in  $\text{Bq/m}^2$  for each relevant nuclide for the chosen efficiency model.
- $\text{Bq/kg}$  for natural radioactivity
- Associated dose-rate measurement at measurement position.
- Coordinates, and location name

### 3.5 Sweden (SSM)



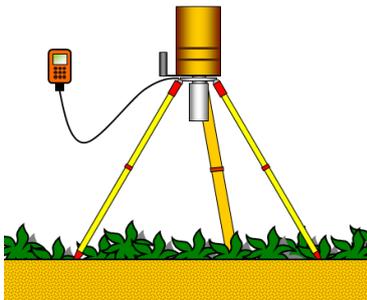
**Figure 7.** The Swedish team working at Oskampen. Photo: Per Grim.

#### **Equipment**

Measurements are performed using a coaxial, p-type HPGe detector. The detector is connected to a portable MCA (Ortec DigiDART). A ruggedized laptop is used for spectrum analysis and reporting. Further specifications for individual measurement systems are listed in corresponding system description. Auxiliary equipment includes dose rate instrument, handheld GPS, tape measure and camera.

#### **Measurement site selection**

If the measurement location is not pre-determined, care should be taken to locate a suitable area, i.e. an area that is representative for the survey area, relatively flat, free of potentially interfering objects (such as trees or buildings), and that displays a homogeneous dose rate at one meter above ground. The exact position of the measurement point, obtained from a handheld GPS, is recorded.



**Figure 8.** In Situ Measurement Setup. Illustration: Jonas Boson

### Detector setup

The detector is mounted on a tripod so that the centre of the crystal is positioned one (1) meter above ground, with the symmetry axis of the crystal orthogonal to the ground surface (Figure 8).

### Spectrum acquisition

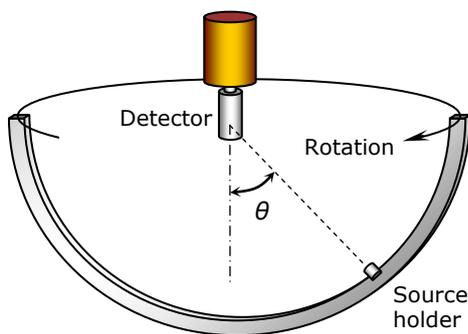
Spectra are recorded for as long as needed to ensure adequate counting statistics in relevant full energy peaks. If appropriate, at least one measurement with longer live time (~10 min) should be performed at each site to enable identification and quantification of less abundant radionuclides.

### Dose rate measurement

A dose rate measurement should always be performed in the same position as the *in situ* measurement.

### Calibration

The detector intrinsic full energy peak efficiency has been determined at a number of different photon energies and angles of incidence ( $\theta$ ). In order to counter any potential variations in detector efficiency at different azimuthal angles, the calibration source is rotated around the detector (Figure 9). Efficiency data is recorded in a matrix of energies and angles.



**Figure 9.** Calibration Setup at SSM.

Illustration: Jonas Boson

The following radionuclides were used for the calibration: Am-241, Ba-133, Cs-137, Co-57, Co-60, Hg-203, Mn-54, Na-22, and Y-88.

The total measurement efficiency is calculated by integrating the contribution to the detector response over the entire source matrix using various assumptions about the activity and density depth distributions, using the aforementioned efficiency data. Possible depth distributions are: surface, exponential, homogeneous, slab (single or multiple) or plane at a fixed depth. In the absence of depth distribution data, and for relatively fresh fallouts, an “emergency preparedness model” will be assumed: a single, homogenous slab with thickness 2 cm and density  $500 \text{ kg/m}^3$  containing all activity (Lidström et al. 1998). The calculations of total measurement efficiency are made in dedicated in-house software *EfficiencyCalc*. As an output from the software, .eft-files can be produced that can subsequently be imported in GammaVision in order to assess the ground deposition density directly from the spectrum.

### **Spectrum analysis and results**

By loading the relevant .eft-file the ground deposition density are obtained directly from GammaVision in Bq/m<sup>2</sup> in real time.

In order to verify that obtained results are reasonable, expected dose rate contributions can be calculated for all anthropogenic radionuclides. The total dose rate contribution can then be compared to the measured dose rate (subtracting the assumed natural background at the measurement point).

### **Reporting**

The reported in-situ results may be:

- Nuclide vector.
- Deposition (Bq/m<sup>2</sup> for each relevant nuclide in the vector for the chosen efficiency model).
- Associated dose-rate measurement at in-situ position.

### 3.6 Finland (STUK)



**Figure 10.** The detector system (LaBr<sub>3</sub>(Ce)) used by the Finnish team.  
Photo: Per Grim

#### **Equipment**

Measurements are performed using the Ortec Micro Detective - a portable, coaxial, p-type HPGe detector integrated with an MCA and electrical cooling system. As a secondary detector, a 1.5" LaBr<sub>3</sub>(Ce) detector unit can be used. A ruggedized laptop is used for data acquisition, spectrum analysis and reporting. Auxiliary equipment includes USB connectible GPS, tape measure and camera.

#### **Measurement site selection**

If the measurement location is not pre-determined, care should be taken to locate a suitable area, i.e. an area that is representative for the survey area, relatively flat, free of potentially interfering objects (such as trees or buildings), and that displays a homogeneous dose rate at one meter above ground. The exact position of the measurement point, obtained from a USB connectible GPS, is recorded.

#### **Detector setup**

The detector is mounted on a tripod so that the centre of the crystal is positioned one meter above ground, with the detector front cap facing the ground surface. If using the Micro Detective, the detector is fastened to the tripod with straps. When using the LaBr<sub>3</sub>(Ce) detector, no fastening is required.

#### **Spectrum acquisition**

Spectra are recorded for as long as needed to ensure adequate counting statistics in relevant full energy peaks. At least ten minutes acquisition should be performed at each site.

#### **Dose rate measurement**

Dose rate follows directly from the in situ measurement. The dose rate is calculated from the acquired spectrum by considering the count rates of pre-selected ROI areas and their corresponding calibration coefficients determined from reference dose rate measurements. The method is described in (Toivonen et al 2008).

#### **Calibration**

The detector peak efficiency has been determined at a number of different photon energies. The following radionuclides were used for the calibration: Am-241, Ba-133, Cs-137, Eu-152 and Co-60.

The total measurement efficiency is calculated by integrating the point source efficiency over a plane (representing the ground surface) to obtain the efficiency for a surface source. Correction factors are then calculated based on an assumption of the depth distribution of the activity. Possible depth distributions are: surface, exponential, uniform (homogeneous) and uniform slab. The calculation of the correction factors for the different activity distributions are based on (Finck 1992), The calculations of total measurement efficiency are made in an in-house developed software *Spectrum Tool* by applying its *In-situ tool* plugin onto the measured spectrum imported into the program.

### Spectrum analysis and results

A measured spectrum is imported into the *Spectrum Tool* program (Figure 11). The user may then use the *In-Situ tool* plugin to specify the different parameters of calculation to obtain surface activity in Bq/m<sup>2</sup>, activity concentration in Bq/kg (uniform distribution or uniform slab only) or deposition in Bq/m<sup>2</sup> (exponential or uniform slab)

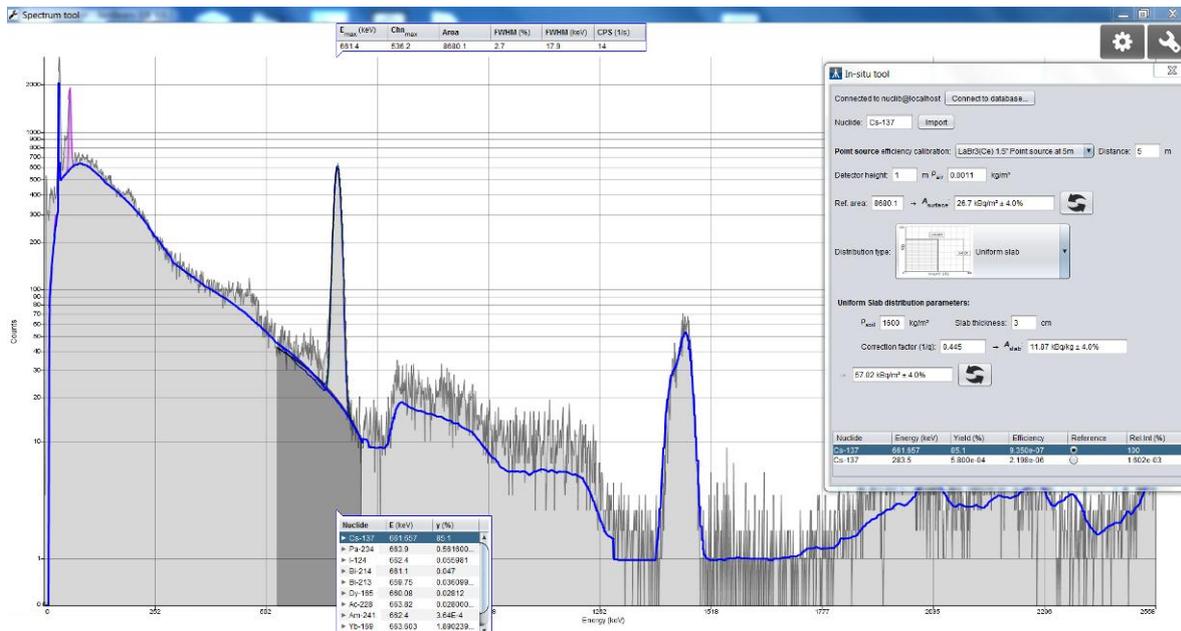


Figure 11. The *Spectrum Tool* software used with the *In-Situ tool* to determine activity concentration from a spectrum acquired with a LaBr<sub>3</sub>(Ce) detector.

### Reporting

The reported in-situ results may be:

- Deposition (Bq/m<sup>2</sup>) or activity concentration (Bq/kg) for nuclides of interest.
- Ambient dose rate.

### 3.7 Iceland (Geislavarnir Ríkisins)



**Figure 12.** The Icelandic team setting up their detector at Buhø. Photo: Per Grim

#### **Equipment**

Measurements are performed using a coaxial, p-type HPGe detector. The detector is connected to a portable MCA (Ortec DigiDART). A laptop is used for spectrum analysis and reporting. Further specifications for individual measurement systems are listed in corresponding system description. Auxiliary equipment includes dose rate instrument and tape measure.

#### **Measurement site selection**

If the measurement location is not pre-determined, care should be taken to locate a suitable area, i.e. an area that is representative for the survey area, relatively flat, free of potentially interfering objects (such as trees or buildings), and that displays a homogeneous dose rate at one meter above ground. The exact position of the measurement point, obtained from a handheld GPS, is recorded.

#### **Detector setup**

The detector is mounted on a tripod so that the centre of the crystal is positioned one meter above ground, with the symmetry axis of the crystal orthogonal to the ground surface.

#### **Spectrum acquisition**

Spectra are recorded for as long as needed to ensure adequate counting statistics in relevant full energy peaks.

**Dose rate measurement**

A dose rate measurement should always be performed in the same position as the *in situ* measurement.

**Calibration and analysis**

The detector intrinsic full energy peak efficiency has been determined at a number of different photon energies and angles of incidence ( $\theta$ ) from 0-90°. Efficiency data is recorded in a matrix of energies and angles.

The following radionuclides were used for the calibration: Eu-152, Cs-137, Co-60.

The total measurement efficiency is calculated by integrating the contribution to the detector response over the entire source matrix using various assumptions about the activity and density depth distributions, using the aforementioned efficiency data. The software InSical 0.9 (author: Alexander Mairing) is used to calculate the distribution. Possible activity depth distributions are: surface, exponential, homogeneous, slab (single).

**Reporting**

The reported in-situ results may be nuclide vector, deposition ( $\text{Bq/m}^2$ ) and dose rate measurements.

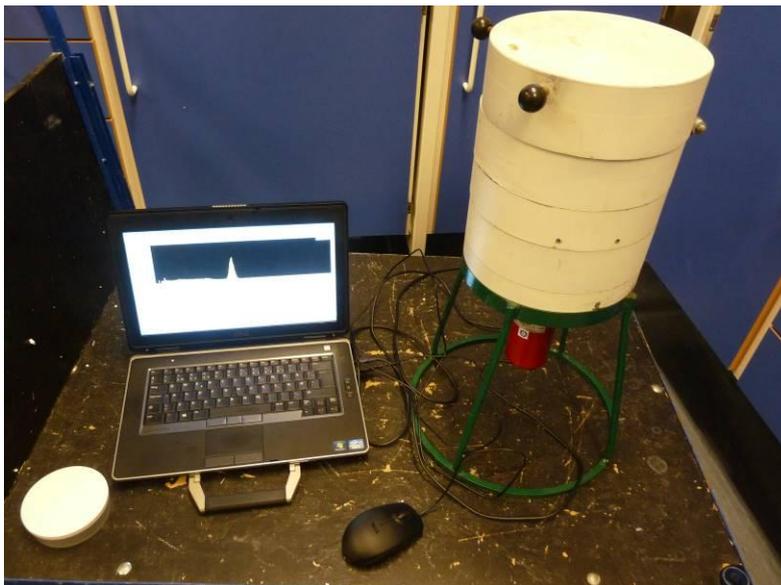
### 3.8 Soil sampling and analysis

At one location, Oskampen 5, new soil samples were collected for comparison with the *in situ* gamma spectrometry results. The samples were prepared in the field, and analysed by gamma spectrometry and reported later the same night. The samples were collected in a cross pattern (N to S and E to W) by a soil corer with a diameter of 10.6 cm. Soil cores were collected at the axis origin and at 1 m and 3 m from the origin in each direction. Each soil core was sliced in a 0-3 cm layer and a 3-6 cm layer, weighed under field conditions, and transferred to a 215 ml plastic container.



**Figure 13.** Preparation of soil samples in the field at Oskampen. Photo: Per Grim.

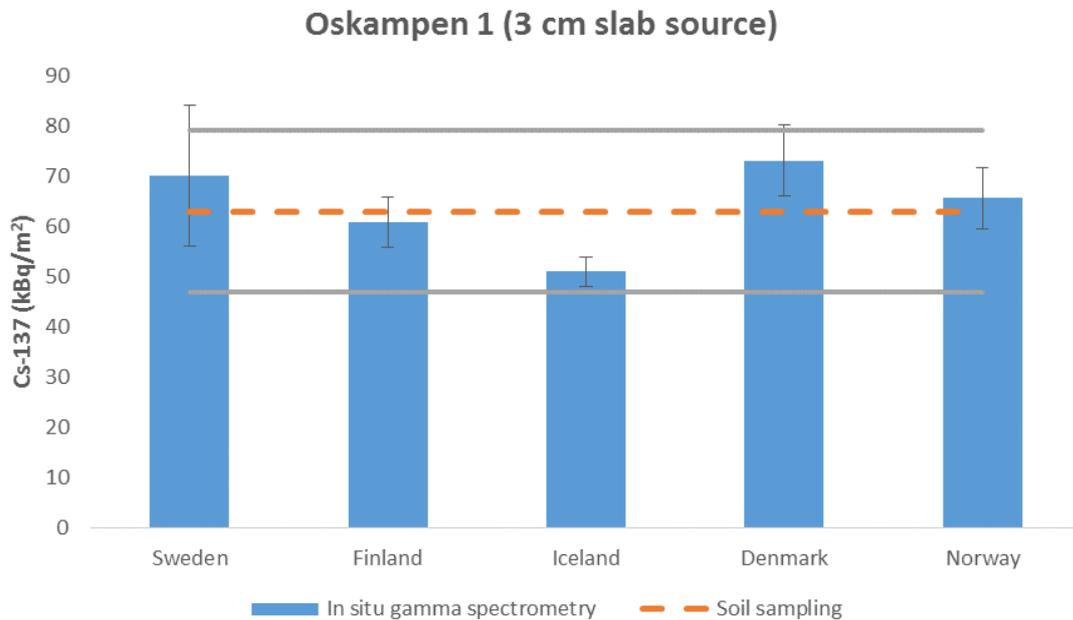
The samples were analysed by gamma spectrometry using a 3x3 NaI(Tl)-detector in a lead shield, connected with a Canberra Osprey MCA (Figure 14). Spectrum analysis was performed with Canberra Genie-2000. For calibration, a NIST traceable Cs-137 standard source was used.



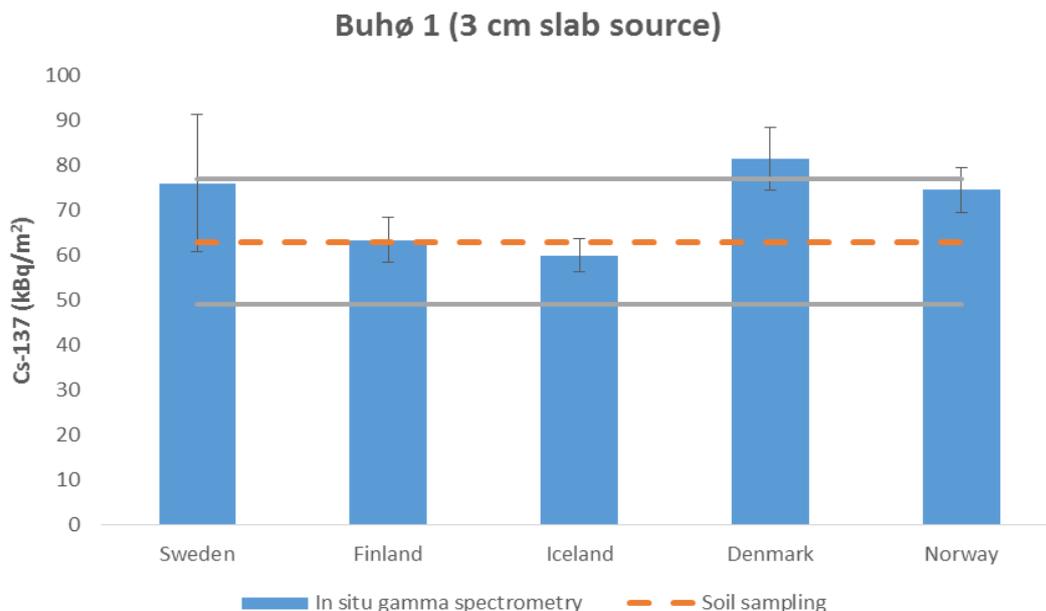
**Figure 14.** Detector system used for analysis of soil samples. Photo: T. Gäfvert

## 4. Results

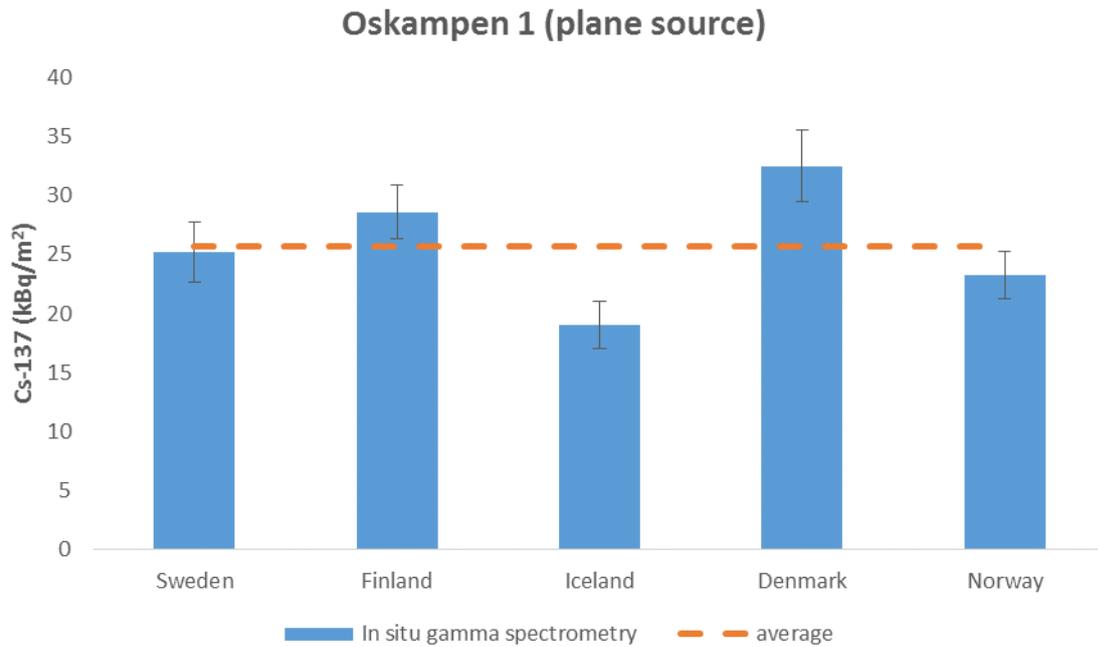
The reported results from the in situ measurements at Oskampen and Buhø are presented in Figures 15 – 23 and Table 4 below. The results are calculated with two different assumptions, a 3 cm thick homogenous slab source with a density of  $1.6 \text{ g/cm}^3$  and infinite plane source.



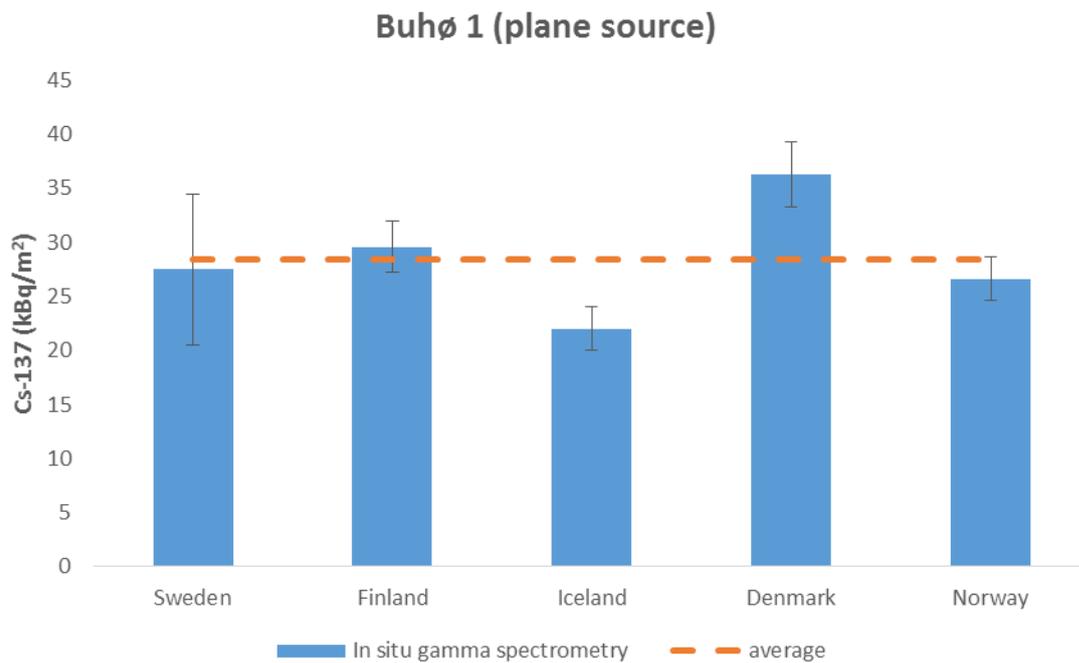
**Figure 15.** Reported results from reference point 1 at Oskampen, calculated with assumption of a 3 cm slab source with a soil density of  $1.6 \text{ g/cm}^3$ , together with decay corrected results from soil sampling in 2011. Grey lines indicate the average activity in soil samples  $\pm 1\sigma$ . In Situ measurement uncertainties are presented with  $k=2$ .



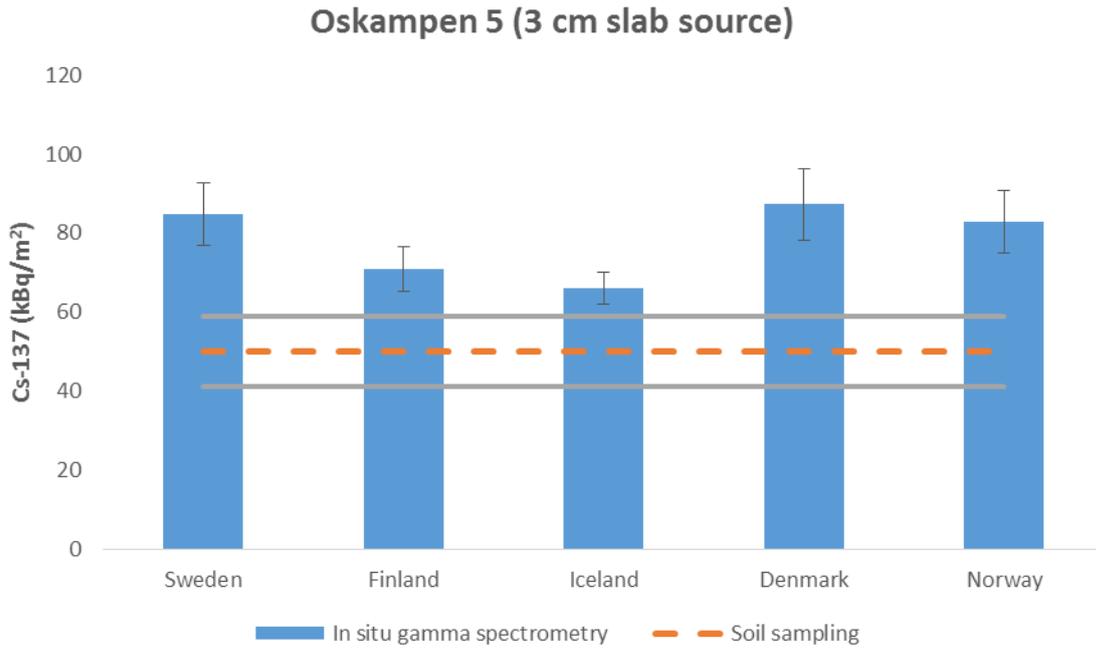
**Figure 16.** Reported results from reference point 1 at Buhø, calculated with assumption of a 3 cm slab source with a soil density of  $1.6 \text{ g/cm}^3$ , together with decay corrected results from soil sampling in 2011. . Grey lines indicate the average activity in soil samples  $\pm 1\sigma$ . In Situ measurement uncertainties are presented with  $k=2$ .



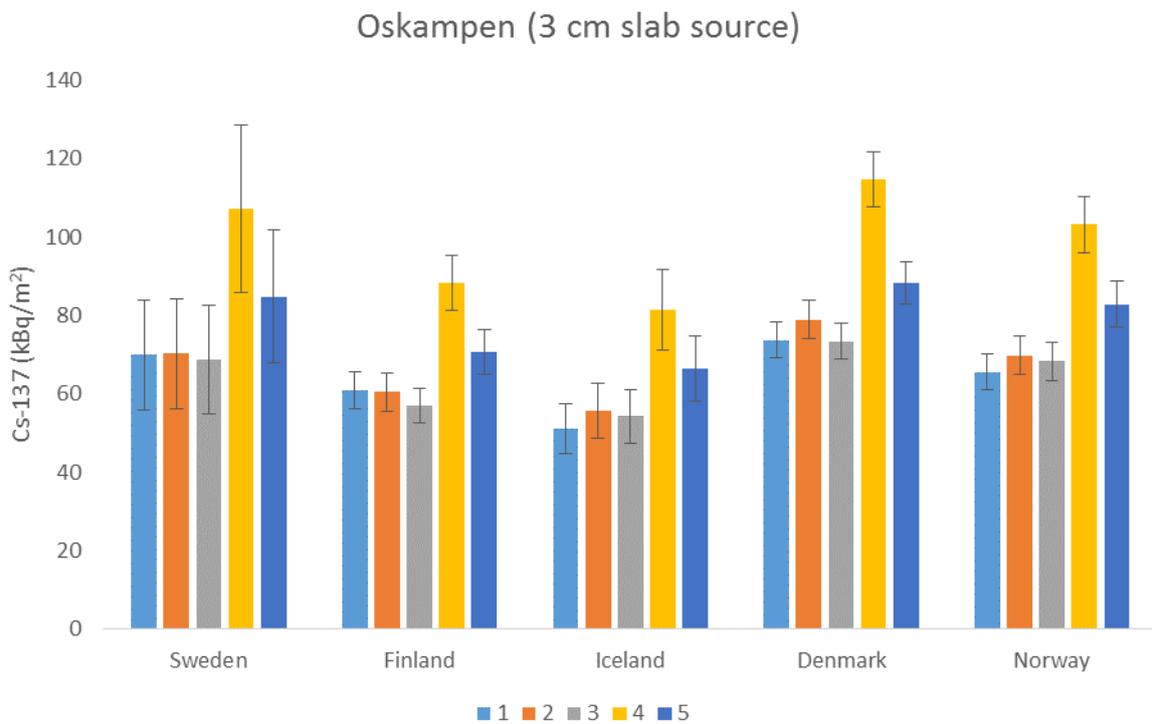
**Figure 17.** Reported results from reference point 1 at Oskampen, calculated with assumption of a plane source distribution of Cs-137. In Situ measurement uncertainties are presented with k=2.



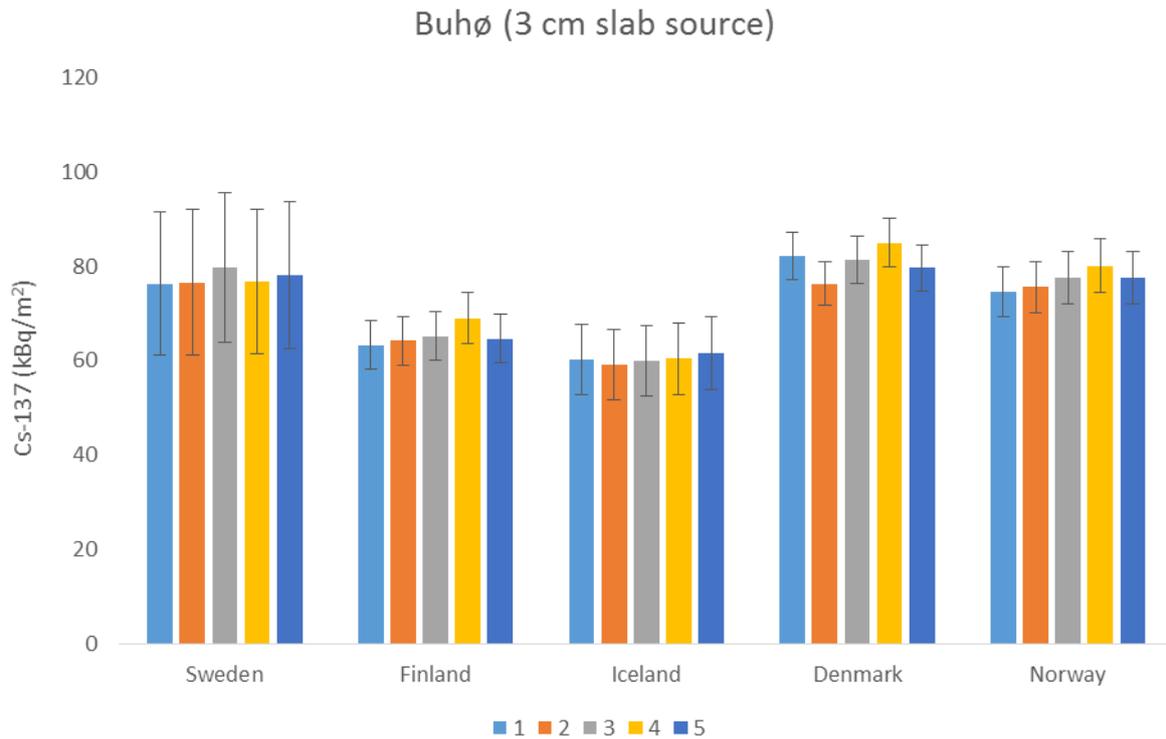
**Figure 18.** Reported results from reference point 1 at Buhø, calculated with assumption of a plane source distribution of Cs-137. In Situ measurement uncertainties are presented with k=2.



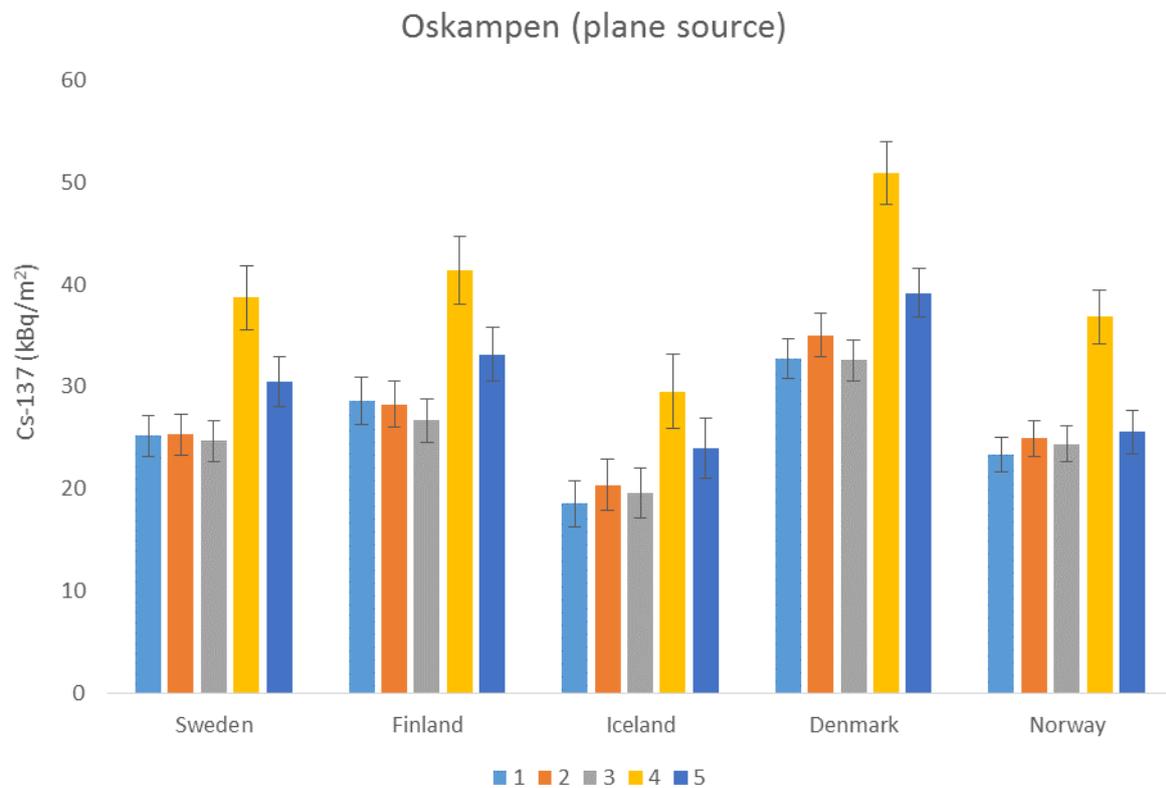
**Figure 19.** Reported results from point 5 at Oskampen, calculated with assumption of a 3 cm slab source with a soil density of  $1.6 \text{ g/cm}^3$ , together with results from soil sampling in 2016. Grey lines indicate the average activity in soil samples  $\pm 1\sigma$ . In Situ measurement uncertainties are presented with  $k=2$ .



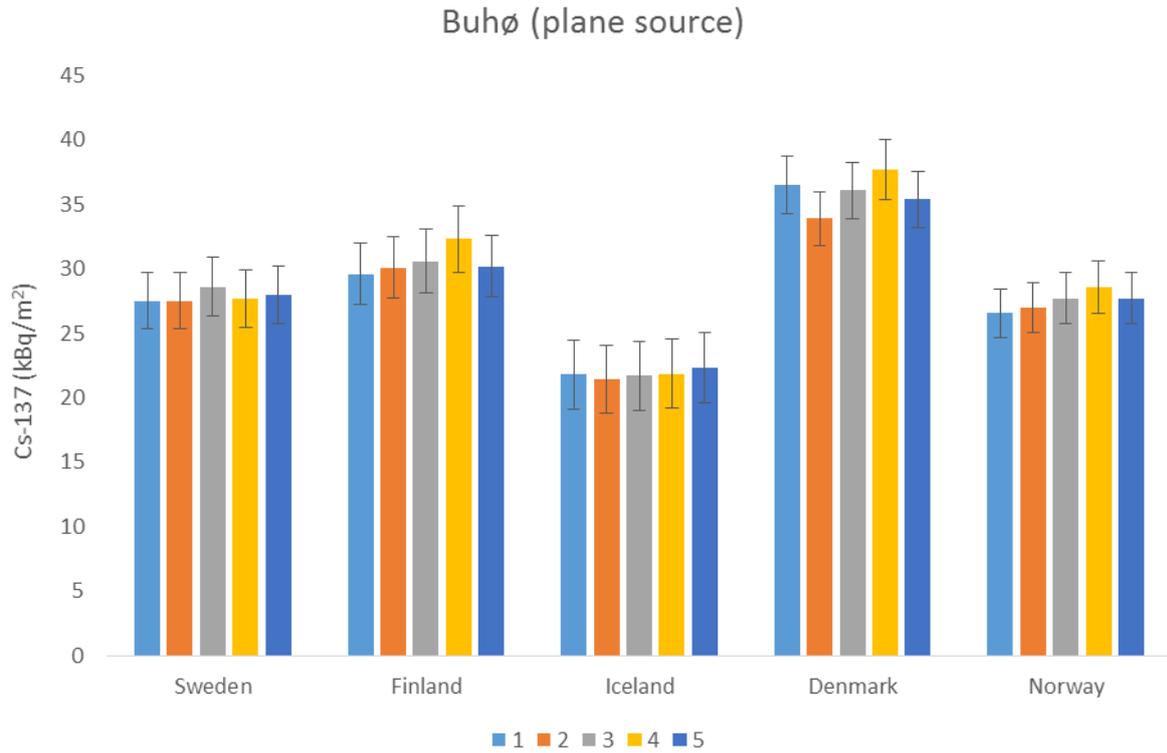
**Figure 20.** Reported results from measurement points 1-5 at Oskampen, calculated with assumption of a 3 cm slab source with a soil density of  $1.6 \text{ g/cm}^3$ . In Situ measurement uncertainties are presented with  $k=2$ .



**Figure 21.** Reported results from measurement points 1-5 at Buhø, calculated with assumption of a 3 cm slab source with a soil density of 1.6 g/cm<sup>3</sup>. In Situ measurement uncertainties are presented with k=2.



**Figure 22.** Reported results from measurement points 1-5 at Oskampen, calculated with assumption of a plane surface source. In Situ measurement uncertainties are presented with k=2.



**Figure 23.** Reported results from measurement points 1-5 at Buhø, calculated with assumption of a plane surface source. In Situ measurement uncertainties are presented with  $k=2$ .

**Table 4.** Reported findings (other than Cs-137) at measurement point 2, 3 and 4 at Oskampen (O) and Buhø (B).

	<b>O2,B2</b>	<b>O3,B3</b>	<b>O4,B4</b>
Finland	-	Am-241	-
Denmark	Cs-134	Am-241	-
Sweden	Cs-134	Am-241	-
Iceland	Cs-134	Am-241	Co-57
Norway	Did not participate (arranged the exercises).		

## 5. Discussion and Conclusions

In Figure 15 and 16, the reported results from Oskampen 1 and Buhø 1 (calculated with a 3 cm slab model for the activity distribution of Cs-137 in the soil) and the decay corrected results from soil sampling in 2011 are compared. All teams were skilled and trained enough to be able to deliver the results in time, and all teams reported results that agreed reasonably well both with results from soil sampling in 2011 and with results from the other teams. Bearing in mind the different methods, radioactive standard sources for calibration etc. used by the different teams, the observed difference is not remarkable.

In Figure 17 and 18 the results from Oskampen 1 and Buhø 1, calculated with plane surface source model (surface equivalent deposition), is shown. Assuming that all Cs-137 is distributed on top of the soil, result in a calculated deposition of about 50 % of the realistic value in Figure 15 and 16 (it requires only about half the activity of Cs-137 to produce the same full energy peak in the gamma spectra for a plane source compared to the more realistic slab source). One can see that the results from Sweden, Finland and Norway are similar while the results from Denmark is slightly higher and the results from Iceland slightly lower. The lower results from the Icelandic team were explained by the use of a somewhat old efficiency calibration file. A possible reason for the slightly higher results from the Danish team could come from the method used for efficiency calibration of the detector system, where the Danish team was the only team that used a mathematically calibrated detector. All other teams used radioactive point reference sources for efficiency calibration.

It can also be noted that in these cases, with gamma spectra dominated by the 662 keV photons, it was sufficient to use a LaBr<sub>3</sub>(Ce)-detector to measure the deposition of Cs-137. The results from the Finnish team agreed very well with the results from soil sampling in 2011.

In 2011 the two locations were selected after the dose rate had been examined and found to be relatively even over both areas. However, after the soil cores had been analysed at the laboratory, it was evident that the activity was not as homogeneously distributed as expected. The ratio between the highest and lowest result from soil sampling at both sites was around 40 (min: 15 kBq/m<sup>2</sup>, max: 585 kBq/m<sup>2</sup>). For a deposition pattern such as in Jotunheimen, it is obvious that *in situ* gamma spectrometry can be very time saving method to analyze the average activity deposition. The result will be an average over an area corresponding to the field of view of the detector, which for a detector placed one meter above ground (and a typical shallow buried Cs-137 fallout) corresponds to a circular area with a radius of about 10 m, or an area of around 300 m<sup>2</sup> (Miller and Schebell, 1993). In comparison, extensive soil sampling (e.g. 30 cores with a diameter of 10 cm) will only represent an area of around 1 m<sup>2</sup>. With this kind of heterogeneity it is also obvious that taking too few soil core samples can give results deviating largely from the average deposition in the area.

The results from the soil sampling at Oskampen 5 and the *in situ* gamma spectrometry are shown in Figure 19. The results from soil sampling are roughly 40 % lower than the results from *in situ* gamma spectrometry. This may result from geometrical effects (the area around was not as open and flat as assumed in the calibration) or that an insufficient number of soil samples were collected to get a representative average of the deposition of Cs-137. The reported results from all measurement points are presented in Figure 20 – 23. The general trend in these results are similar as for Figure 14 and 15.

In Table 4, the reported findings in the gamma spectra are presented. All teams except the Finnish team used HPGe-detectors, and the reason they did not find Cs-134 and Co-57 was that the LaBr<sub>3</sub>(Ce)-detector did not have a sufficiently low detection limit to see the full energy gamma peaks in the gamma spectrum within 10 minutes acquisition time. Both the Swedish and Danish team correctly reported Am-241 and Cs-134, and the major reason for not finding Co-57 was that one did not look for something that was not expected to be found in the spectra. Both teams could easily identify the 122 keV peak at a second attempt. The Icelandic team correctly reported all three radionuclides in the first attempt.

During the workshop harmonization was discussed. At the moment, four of the participants have registered *in situ* gamma spectrometry in the IAEA RANET. It was recognized that IAEA RANET are underway to publish a guideline for their response and assistance products which has to be considered in this context. Harmonization of nuclear emergency assistance and response products also covers many different areas and it was suggested that this may be the theme for a new NKS-project.

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Author(s)	T Gäfvert <sup>1</sup> , J Boson <sup>2</sup> , T Karhunen <sup>3</sup> , G Jónsson <sup>4</sup> , S Juul Krogh <sup>5</sup> , J Drefvelin <sup>1</sup> , P O Hetland <sup>1</sup> , L Skuterud <sup>1</sup> , P Reppenhagen Grim <sup>5</sup> , P Smolander <sup>3</sup> , K Guðnason <sup>4</sup> , P Frisk <sup>2</sup> B Winther <sup>5</sup> , C Andreis <sup>5</sup>
Affiliation(s)	<sup>1</sup> NRPA, <sup>2</sup> SSM, <sup>3</sup> STUK, <sup>4</sup> IRSA, <sup>5</sup> DEMA
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Abstract	Having the necessary skills and tools for radiological site characterization is very important in both early and late phases of an incident involving radioactive deposition over large areas. <i>In situ</i> gamma spectrometry is, compared to soil sampling, a rapid method to measure the deposition from fresh fallout after a nuclear accident. With an operative detector system, results can be generated in minutes after the measurements. The NKS Nordic <i>in situ</i> intercomparison (NISI) project provided a platform for comparing equipment, methods and results from <i>in situ</i> gamma spectrometric site characterizations. A one-day practical field exercise was carried out in the Jotunheimen area of Norway, which is an ideal location for this type of measurement as it contains large flat areas with significant levels of deposited Cs-137 from the Chernobyl accident in sites that are virtually undisturbed by industrial or agricultural influences. All teams were skilled and trained enough to be able to deliver the results in time, and all teams reported results that agreed well both between the countries and between the results from earlier soil sampling in 2011.
Key words	<i>In situ</i> gamma spectrometry, intercomparison, emergency preparedness