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Radiation survey meters used for environmental monitoring

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Abstract

The Nordic dosimetry group set up the GammaRate project to investigate how its expertise could be used to assure appropriate usage of survey meters in environmental monitoring.

Considerable expertise in calibrating radiation instruments exists in the Nordic radiation protection authorities. The Swedish, Finnish, Danish and Norwegian authorities operate Secondary Standard Dosimetry Laboratories (SSDLs) that provide users with calibration traceable to internationally recognised primary standards. These authorities together with the Icelandic authorities have formally cooperated since 2002 in the field of radiation dosimetry.

Dosimetry is the base for assesment of risk from ionising radiation and calibration of instruments is an imported part in dosimetry. The Nordic dosimetry group has been focused on cancer therapy. This work extends the cooperation to the dosimetry of radiation protection and environmental monitoring. This report contains the formal, theoretical and practical background for survey meter measurements.

Nordic standards dosimetry laboratories have the capability to provide traceable calibration of instruments in various types of radiation. To verify and explore this further in radiation protection applications a set of survey instruments were sent between the five Nordic countries and each of the authority asked to provide a calibration coefficient for all instruments. The measurement results were within the stated uncertainties, except for some results from NRPA for the ionchamber based instrument. The comparison was shown to be a valuable tool to harmonize the calibration of radiation protection instruments in the Nordic countries.

Dosimetry plays an important role in the emergency situations, and it is clear that better traceability and harmonised common guidelines will improve the emergency preparedness and health.

Key words

Dosimetry, radiation protection, radiation survey meter, calibration, comparison, operational quantities

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Report from the NKS-B GammaRate
Contract: AFT/B(11)4

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Contents

1 Introduction

The GammaRate project was set up with the Nordic dosimetry group to investigate how its expertise could be put into use in assuring appropriate usage of survey meters in environmental monitoring.

Considerable expertise in calibrating radiation instruments exists among Nordic radiation protection authorities. The Swedish, Finnish, Danish and Norwegian authorities operate Secondary Standard Dosimetry Laboratories (SSDLs) that provide users with calibration traceable to internationally recognised primary standards. These authorities together with the Icelandic authorities have formally cooperated since 2002 in the field of radiation dosimetry with a group of experts that meets each year.

Calibrations of instruments are essential in medical applications especially where large and precisely defined radiation doses need to be delivered to patients. This is the case in radiation cancer therapy where the main focus of the Nordic SSDLs has been.

The Nordic dosimetry group does not see calibration as the only control needed for the appropriate use of any instrument. A valid calibration certificate does not ensure that a reading from an instrument is a correct or a relevant measure of the quantity of interest. The energy response, the sensitivity, the accuracy, the time-constant and the directivity are among features that must be appropriate for the intended application

Survey meters are used in many and different application. The user of a meter knows best what his application is and what requirement it places on his equipment. These requirements should define his needs for a protocol defining what testing and calibrations are needed. There is no single protocol that is appropriate for all survey meters, there are however many standards and guidelines that can assist the user and this report will point at some of them.

In some application of survey meters there is a legal requirement for regular and traceable calibration. Some overview on the legal requirements and what traceable calibration means is given in this report. These calibrations are sometimes provided by the producers of the equipment.

Nordic standard dosimetry laboratories have the capability to provide traceable calibration of instruments in various types of radiation. To verify and explore this further a project was set up where a set of survey instruments was sent between four of the Nordic countries and each of the authority asked to provide a calibration coefficient for all of them in some selected types of radiation. The results of this project will be given.

This report will give a short view into the framework for radiation dosimetry and their quantities and units. Some specifications for dosemeters are discussed, and instrument characteristics, maintenance and testing. The total scheme of quality in monitoring and dose assessment is not included in this report, but you will find an overview of the uncertainties in dose assessment. In appendixes some periodic and performance tests are recommended. The report also proposes a new fundamental principle in radiation safety and security thinking. The fact that dosimetry founds the assessment of risk from ionising radiation, lead to the formulation of a new fundamental principle.

2 Framework for radiation protection dosimetry

2.1 Infrastructure, facilities, knowledge and skills needed for dosimetry.

National metrological authorities in the Nordic countries have designated the duties regarding measurements of ionising radiation to the radiation protection authorities. Four of the five countries have organised this task in secondary standard dosimetry laboratories (SSDLs), a network of the International Atomic Energy Agency (IAEA) described in the SSDL Charter [1], see figure 1. The fifth country, Iceland operates a limited dosimetry calibration and measurement service. The dosimetry of ionising radiation started up in the North in the 1920th and they hold primary standards until the end of 1970th. The reason for changing from primary to secondary standards was that a lower uncertainty in the calibrations was achieved with fewer resources. The dose measurement traceability is now to the Bureau International des Poids et Mesures (BIPM) and primary standard dosimetry laboratories (PSDLs) in Europe or the USA.

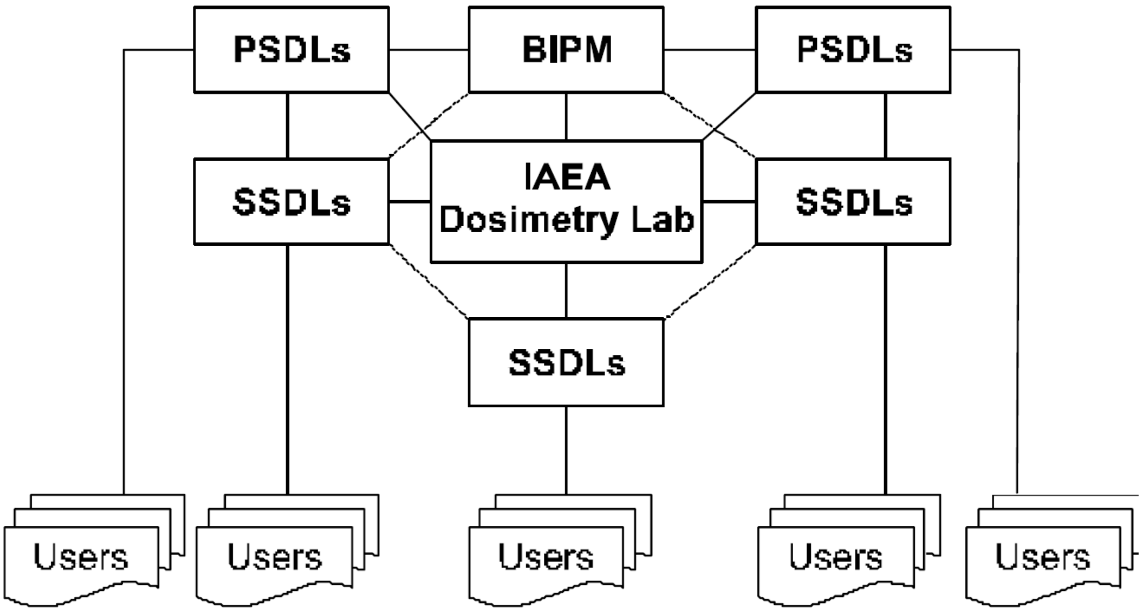


Figure 1 The global metrological links of the international measurement system for radiation dosimetry [1]

The Nordic radiation protection and nuclear safety authorities published in 2006 a report on the dosimetric capabilities, resources, needs and plans [2]. The dosimetry working group collected information on dosimetry in all the Nordic counties. At that time 19 persons were working in the dosimetry field. In addition to calibration dosimetric services the dosimetry laboratories are performing dosimetry simulations based on Monte Carlo calculations, experimental dosimetry and on-site calibration and measurements.

The IAEA published in 2006 the ten revised Safety Fundamentals [3]. These fundamental principles are based on the assessment of radiation risks, which exclusively are determined from dosimetry. This fact seems not to be reflected in the formulation of the principles. It has therefor been proposed an eleventh principle:

An effective legal and governmental framework for metrology of ionizing radiation must be established and maintained.

This statement was proposed in this project as a consequence of recommendations and requirements in documents referred to in this document [1, 2, 3, 4, 5, 6, 7, 8, 9, 10]. A legal base for dosimetry at the SSDLs in the Nordic countries will underpin the recommendations, requirements and guidelines for radiation safety and security. Metrology of ionising radiation will then have a recognised status in the international framework of radiation protection and nuclear safety.

2.2 A description of the legal requirements

The International Commission on Radiological Protection (ICRP) published new recommendations in 2007 [6]. ICRP recommends moving to a situation-based approach applying the principles of justification and optimisation of protection to all controllable exposure situations characterised as <u>planned, emergency, and existing</u> exposure situations.

The IAEA recommendations provide general guidance on the assessment of the doses to critical groups of the population due to the presence of radioactive material or due to radiation fields in the environment.

The term environment is used both for working environment, out in nature and all other places people stay, where monitoring of ionising radiation is needed.

In the IAEA safety guide No. RS-G-1.8 [11] the responsibilities are given, applied to the radiation and nuclear safety regulatory body, and the governmental and metrological support to the calibration activities.

In relation to the control of discharge practices, the regulatory body has the following general responsibilities:

1. Ensuring, by means of establishing and implementing appropriate regulations, that the public and the environment are protected;
2. Ensuring that the operator complies with the appropriate regulations and regulatory requirements, including those in respect of carrying out such source and environmental monitoring as may be necessary;
3. Providing assurance that judgements concerning the safety of the public are based upon valid information and sound methods.

With regard to specific responsibilities in the area of monitoring, the regulatory body:

1. Should establish technical requirements for monitoring arrangements, including arrangements for emergency monitoring and quality assurance, and should regularly review them;
2. Should check the monitoring data provided by operators;
3. Should provide evidence that can satisfy the public that authorized sources of exposure are being suitably monitored and controlled.

2.3 International framework for ionising radiation metrology, the CCRI(I)

The General Conference on Weights and Measures (CGPM) lays down the rules for quantities, units, derived units, prefixes and other matters see the SI brochure [12]. The secretariat of the CGPM is the BIPM. For metrology of ionising radiation the Consultative Committee for Standards of Ionizing Radiations (Comité consultatif pour les étalons de mesure des rayonnements ionisants, CCEMRI) was set up in 1958. Its name was changed to Consultative Committee for Ionizing Radiation (CCRI) by the CIPM in 1997. Present activities concern matters related to the definitions of quantities and units, standards for x-ray, γ-ray, charged particle and neutron dosimetry, radioactivity measurement and the international reference system for radionuclides (SIR), and advice to the CIPM on matters related to ionizing radiation standards.

Different quantities are used in radiation dosimetry, but only two units, the gray and the sievert. Both of these units are derived units. For more information see the SI brochure [12]. The CCRI work is organised in three sections: CCRI(I); dosimetry of x- and gamma rays, charged particles , CCRI(II); measurement of radionuclides and CCR(III); neutron measurements. So section I of the CCRI will decide on metrological developments in practical and theoretical dosimetry. The executive secretary of CCRI(I) is employed at the BIPM.

2.4 The Calibration and measurements capabilities (CMCs) in dosimetry.

On international bases BIPM maintain a database containing calibration and measurement services worldwide, see http://kcdb.bipm.org/appendixC/default.asp. You may in the seven physics areas find ionizing radiation as one, and then choose by country or branch. In branch dosimetry is one of three options. There is a list of quantities and also a list of sources. This characterisation of dosimetry was developed ten years ago in order to guide the customer to the calibration laboratory services.
Another source for overviewing the Nordic dosimetric capabilities is given in the Nordic report No 8 [2]. The needs for dosimetry and the status of it were given.

2.5 Radiation facilities

The IAEA has given recommendations on the calibration of radiation protection monitoring instruments in 1999[4]. Requirements for facilities are given in this Safety Report Series (SRS) No. 16, but here only some characteristics for the mostly used radiation protection beams are referred to.
The quantity air kerma should be used for calibrating the reference fields and reference instruments. Radiation protection survey meters should be calibrated in terms of dose equivalent quantities.
The recommended reference x-ray radiation is the narrow spectrum series characterised in ISO 4037-1:1995 [13]. The characteristics are given in table 1 (table VIII in SRS No. 16). Characteristics of some of the radionuclide sources are given in table 2 (table XVII in SRS No. 16).

Table 1 Characteristics of Narrow spectrum series. [4]

Radiation quality	Mean energy $\bar{E}$ (keV)	Resolution *Re* (%)	Tube potential (kV)[a]	Additional filtration (mm)[b]				First HVL (mm)[c]	Second HVL (mm)[c]
				Pb	Sn	Cu	Al		
N-10	8	28	10				0.1	0.047 Al	0.052 Al
N-15	12	33	15				0.5	0.14 Al	0.16 Al
N-20	16	34	20				1.0	0.32 Al	0.37 Al
N-25	20	33	25				2.0	0.66 Al	0.73 Al
N-30	24	32	30				4.0	1.15 Al	1.30 Al
N-40	33	30	40			0.21		0.084 Cu	0.091 Cu
N-60	48	36	60			0.6		0.24 Cu	0.26 Cu
N-80	65	32	80			2.0		0.58 Cu	0.62 Cu
N-100	83	28	100			5.0		1.11 Cu	1.17 Cu
N-120	100	27	120		1.0	5.0		1.71 Cu	1.77 Cu
N-150	118	37	150		2.5			2.36 Cu	2.47 Cu
N-200	164	30	200	1.0	3.0	2.0		3.99 Cu	4.05 Cu
N-250	208	28	250	3.0	2.0			5.19 Cu	5.23 Cu
N-300	250	27	300	5.0	3.0			6.12 Cu	6.15 Cu

[a] The tube potential is measured under load.

[b] Except for the five lowest energies, where the recommended inherent filtration is 1 mm Be, the total filtration consists of the additional filtration plus the inherent filtration adjusted to 4 mm aluminium.

Table 2 Radionuclide sources and high energy photon radiations [4]

Radiation quality	Energy of radiation (MeV)	Half-life (d)	Air kerma rate constant[a] ($\mu Gy \cdot h^{-1} \cdot m^2 \cdot MBq^{-1}$)	Conversion coefficient for normal incidence		Conversion coefficient for the slab phantom (normal incidence)		Conversion coefficient $H_p(0.07)/K_a$ ($Sv \cdot Gy^{-1}$)	
				$Hc(0.07)/K_a$ ($Sv \cdot Gy^{-1}$)	$H^*(10)/K_A$ ($Sv \cdot Gy^{-1}$)	$H_p(0.07)/K_a$ ($Sv \cdot Gy^{-1}$)	$H_p(10)/K_a$ ($Sv \cdot Gy^{-1}$)	Pillar phantom	Rod phantom
S-Co	1.1733 1.3325	1 925.5	0.31		1.16		1.15		
S-Cs	0.6616	11 050	0.079		1.20	1.25	1.21		
S-Am	0.05954	157 788	0.003	1.59	1.74		1.89	1.39	1.14
R-^{12}C	4.44				1.12		1.11		
R-^{19}F	6.13–7.12				1.11		1.12		
R-Ti(n,K)	5.14				1.11		1.11		
R-Ni(n,K)	6.26				1.11		1.11		
R-^{16}O	6.13–7.12				1.11		1.12		

[a] The value of the air kerma rate constant is only valid for an unshielded point radionuclide source. It is given only as a guide. Air kerma rates at the exposure positions should be measured by using a secondary ionization chamber.

3 Operational quantities

ICRP 103(2007) [6] defines the quantities that are used in radiation protection; equivalent dose and effective dose estimate the probability for late/stochastic effects. Effective and equivalent doses (box to the right in figure 1) are quantities that are not measurable, therefore operational quantities are used for the assessment of effective dose and equivalent dose in tissue or organs. Different types of operational quantities are used for external irradiation. ICRU 51(1993) [14] defines operational quantities for external irradiation. Area monitoring quantities are ambient dose equivalent and directional dose equivalent. For individual monitoring personal dose equivalent are used.
For internal exposures no operational quantities are defined, estimation of equivalent dose or effective dose is done by measurements of air or tissue concentration of activity together with biological models.

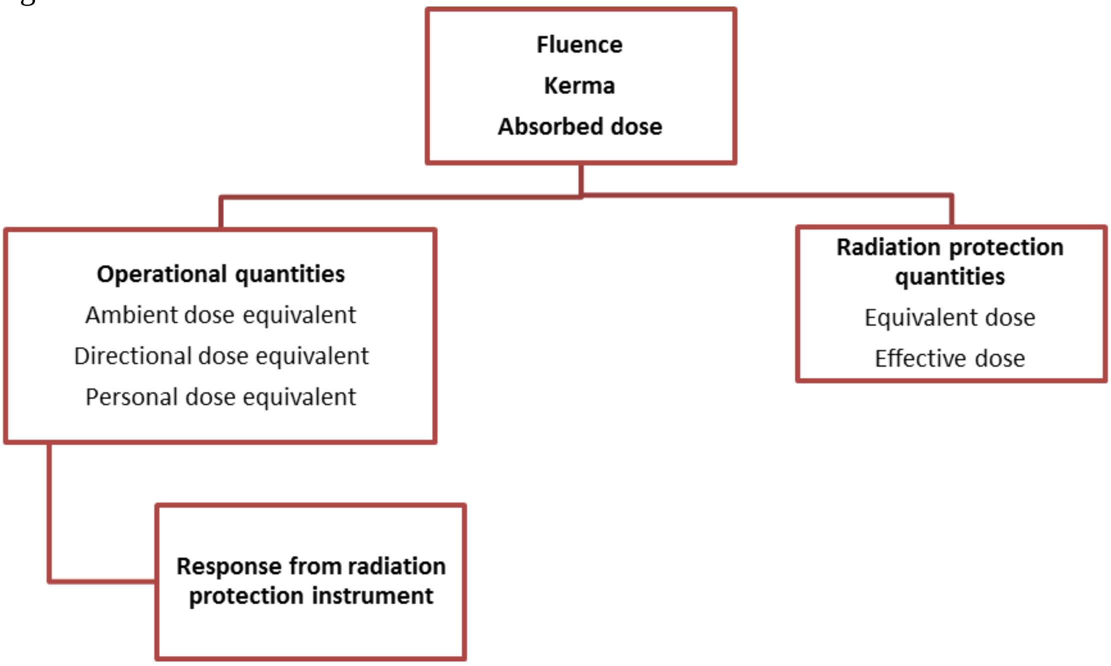


Figure 1 Relationship of quantities for radiological protection monitoring purposes.

The operational quantity dose equivalent, *H*, (upper box to the left) is

$$H=Q(L)\cdot D$$

D is the absorbed dose and *Q(L)* is a quality factor depending of the type of particle and the energy of the particles passing through the volume where the energy deposits. *Q(L)* using the connection between relative biological effectiveness, RBE, and ionising density. *Q(L)* depends on linear energy transfer, LET, of the particles.

In the estimation of *H* a simplified version of the human body is used, the ICRU sphere made of PMMA with 30 cm in diameter. Ambient dose equivalent, $H^*(d)$ is the dose equivalent in a point on the depth *d* mm on the radius in the 'ICRU sphere' on the direction to an expanded and parallel radiation field. Directional dose equivalent, $H'(d,\Omega,)$ is the same but with an angle Ω.

For strongly penetrating radiation, photons above 12 keV and neutrons *d*=10 mm are used and for weakly penetrating radiation, photon below 12 keV and beta particles, *d*=0.07 mm are used (ICRU 51, 1993).

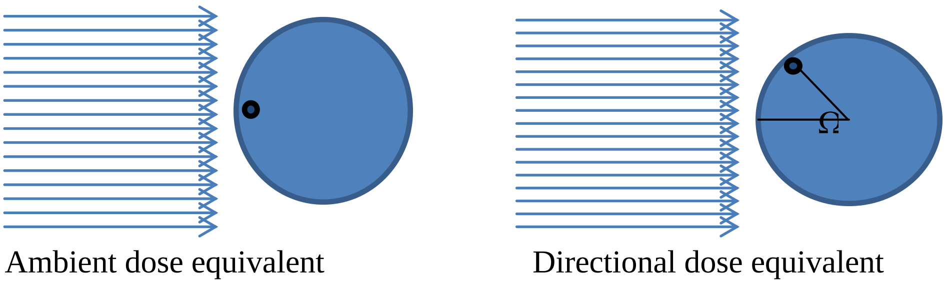


Figure 2 The different dose equivalents

Personal dose equivalent is dose equivalent in ICRU tissue on depth *d* behind a point where the dosemeter is placed. Depth d=10 mm is recommended for the assessment of effective dose and for hands and feet depth d=0.07 mm is recommended, see overview in table 3.

Table 3

Purpose	Operational dose quantities	
	Area monitoring	Individual monitoring
Control of effective dose	Ambient dose equivalent, *H*(10)*	Personal dose equivalent, *Hp(10)*
Control of doses to the skin, the hands and feet and the	Directional dose equivalent, *H'(0.07,Ω)*	Personal dose equivalent, *Hp(0.07)*
Control of doses to the lens of the eye	-	Personal dose equivalent, *Hp(3)*

3.1 Quantities and units used for contamination monitors.

Contamination of a radionuclide on a surface can be stated as activity per area unit.
But the number of particles that emits from the surface from a plane radiation source from a given radionuclide and from a given activity is depending on the amount of self-absorption in the radiation source, the amount of back scattering and the type of material behind the source. Self-absorption lower the amount of emitted particles and back scattering increases the amount of emitted particles, see figure 3 from ISO 7503:1 1988 [15]. Therefore, a calibration factor based on activity is very dependent on the source construction; a calibration factor based on emission rate instead is independent on the construction and environment.
Most of the area contamination monitors used shows counts per second, cps, i.e. the number of detected particles per second.

The efficiency of an area contamination monitors, ε_i, is;

$$\varepsilon_i = \frac{n - n_B}{q_{2\pi}} = \frac{n - n_B}{E \cdot W}$$

and the calibration factor for area contamination monitor is given by IAEA (2000) [4];

$$N = \frac{E}{n - n_B}$$

n number of measured pulses per second, cps
n_B number of measured back ground pulses per second, cps
E the emission per second from the radiation source per area unit in a 2π geometry
W the area of the window of the contamination monitor

The relationship between the activity and measured pulses is:

$$A = \frac{n - n_B}{\varepsilon_i \cdot S \cdot \varepsilon_S} = \frac{1}{N \cdot S \cdot \varepsilon_S}$$

n measured number of pulses per second, cps
n_B measured number of back ground pulses per second, cps
ε_i area contamination meters efficiency
S the area of the plane radiation calibration source
ε_S the efficiency of the radiation source
N the calibration factor of the area contamination meter

The efficiency of the radiation source is determined by measurements. If no measurements can be performed, for example in a contamination situation, estimation has to be done. It is difficult to estimate the efficiency because it is very dependent on the radiation source structure and backing material. ISO 7503:1 recommends using 0.5 for efficiency for beta with energy higher than 0.4 MeV, and 0.25 for alpha source and beta source with energy lower than 0.4 MeV.

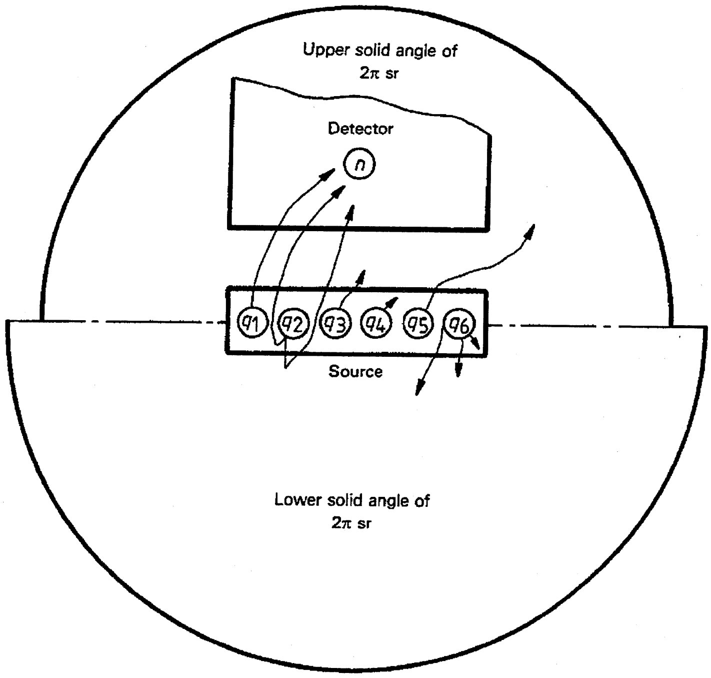


Figure — Cross section of a source-detector combination

The definitions of terms given in table 1 are classified by cross-reference to the figure. The additional term "intrinsic instrument efficiency, I_i" is sometimes needed and is defined as "the quotient of count rate induced on the detector by the number of particles incident on the detector per unit time". For an ideal source (no self-absorption, no back-scatter), the value of ε_s is 0,5. For a real source, the value of ε_s is usually less than 0,5, but may also be greater than 0,5 depending on the relative importance of self-absorption and back-scatter processes.

The maximum values of ε_i and I_i are 1.

Table 1 — Definition of terms

Term	Symbol	Unit	Definition
Activity of a source[1]	A	Bq	$A = q_1 + q_2 + q_3 + q_4 + q_5 + q_6$
Surface emission rate of a source	$q_{2\pi}$	s^{-1}	$q_{2\pi} = q_1 + q_2 + q_3 + q_5$
Efficiency of a source	ε_s	[2]	$\varepsilon_s = \frac{q_1 + q_2 + q_3 + q_5}{q_1 + q_2 + q_3 + q_4 + q_5 + q_6} = \frac{q_{2\pi}}{A}$
Instrument efficiency	ε_i	[2]	$\varepsilon_i = \frac{n}{q_1 + q_2 + q_3 + q_5}$
Intrinsic instrument efficiency	I_i	[2]	$I_i = \frac{n}{q_1 + q_2}$
Response of the instrument to an activity A	R_i	[2]	$R_i = \varepsilon_i \times \varepsilon_s = \frac{n}{A}$

1) This simplified definition of activity can only be used under the restrictions mentioned in clause 1. Strictly speaking, the activity should be defined as

$$A = \frac{1}{\varepsilon_d}(q_1 + \ldots + q_6)$$

where ε_d is the number of particles of the considered type produced per decay.

However, for the nuclides considered in this part of ISO 7503 (see table 3), a value of 1 may be assigned to ε_d.

2) All the efficiencies are dimensionless.

Figure 3 Giving the explanations of the efficiency, from ISO 7503-1 [15]

4 Specifications for dosemeters

4.1 Survey meters

Multi-purpose survey meter

A multi-purpose survey meter can be used for various measurement purposes: its rated dose rate range usually extends from 0.1 µSv/h up to 10 Sv/h, and it can be equipped with an external beta detector. Recommended characteristics are listed below. Specific performance characteristics for meters of different dose rate ranges are given in the standards IEC 60846-1:2009 [8] and IEC 60846-2:2007 [9]. Measurement quantities: $H^*(10)$, $H'(0.07)$, ^{90}Sr-activity per unit area, ^{90}Sr-beta particle emission rate (a high-quality equipment can detect also other, less-energetic beta particles and alpha particles).

Recommended characteristics:

- Easy to use, capable of outdoor measurements (in dark, wet and cold conditions), immune against electromagnetic disturbances, easy to wash.
- External beta detector for the measurements of area contamination. Detection threshold shall be 4 Bq cm^{-2} for ^{90}Sr/^{90}Y beta emitter. The increased response from 4 Bq cm^{-2} (in terms of ^{90}Sr-activity per unit area) shall be at least three times the standard deviation of response due to 0.2 µSv/h natural background.
- Standard batteries should be used for emergency preparedness purposes. Spare batteries should be available.
- Continuous audible signal for dose rate detection.
- Clear indication of dose rate range. Dose rate unit (*e. g.* µSv/h or mSv/h) shall be displayed clearly.
- Re-readable accumulated dose value (displayed after switching the meter off and on).
- During dose rate detection via continuous audible signal, audible alarms should be able to be switched off (visible alarm indications are ok).

Recommended options:

- Pole detector (*e. g.* 5 m long telescope arm) for high dose rate measurements.
- LAN connection.
- Audible alarms (with adjustable dose rate thresholds).
- Analog display for fast detection of dose rate gradients.

A multi-purpose survey meter and its supporting equipment shall endure long-term storing and transport in outdoor conditions. Recommended 'Degree of protection provided by enclosure' is IP 65 [16] (there is no water inside the enclosure after the test).

Single-purpose survey meter

A single-purpose survey meter can be used for measurements of $H^*(10)$ in a limited dose rate range: its rated dose rate range may extend from 0.1 µSv/h up to 10 mSv/h, only (scintillation detectors, other solid-state detectors). Recommended characteristics are listed below. Specific performance characteristics of an ambient dose equivalent meter are given in IEC 60846-1:2009 [8].

Recommended characteristics:

- Batteries classified for emergency preparedness purposes.
- Continuous audible signal for dose rate detection.
- ‘Degree of protection provided by enclosure’ IP 54 [16] (there is no water inside the enclosure after the test).

Direct reading personal dose equivalent meter

Direct reading personal dose equivalent meters can be used for on-line measurements of $H_p(10)$ and $H_p(0.07)$: its rated range may extend from 1 µSv up to 10 Sv. Recommended characteristics are listed below. Specific performance characteristics are given in IEC 61526 [17]. Measurement quantities: $H_p(10)$ and $H_p(0.07)$. Photon, beta and neutron radiation.

Recommended characteristics:
- Batteries classified for emergency preparedness purposes and equipment for standard batteries.
- Audible alarms (with adjustable dose rate thresholds).
- ‘Degree of protection provided by enclosure’ IP 54 [16] (there is no water inside the enclosure after the test).

Passive integrating dosimetry system for environmental and personal monitoring

Direct Ion Storage (DIS) dosemeter can be used for on-line measurements of $H_p(10)$, $H^*(10)$ and $H_p(0.07)$: its rated range may extend from 1 µSv up to 10 Sv. Specific performance characteristics are given in IEC 62387-1 [18]. Measurement quantities: $H_p(10)$, $H^*(10)$ and $H_p(0.07)$. Photon and beta radiation.

In principle, all (hand-held or worn) instruments described in this chapter can be used as survey meters for emergency preparedness purposes. In addition, installed meters can be used as a part of the environmental monitoring network. Their recommended characteristics can be thought of as those of a single-purpose survey meter.

4.2 Applications, advantage and limitations

By using the radiation performance characteristics from IEC standard 60846-1:2009 to calibrate the external detector of a multi-purpose survey meter, it will be calibrated in terms of the directional dose equivalent at 0.07 mm depth $H'(0.07)$ [8, 19].

For measurements of area contamination, the external detector is most commonly calibrated in terms of ^{90}Sr-beta particle emission rate or ^{90}Sr-activity per unit area (STUK Guide VAL 4, http://www.finlex.fi/data/normit/7311-VAL4sv.pdf.) [20].

IEC 60325 (2002-06) [21]: “Radiation protection instrumentation—Alpha, beta and alpha/beta (beta energy >60 keV) contamination meters and monitors” describes several tests in terms of ‘particle emission rate’ (beta and alpha sources) and in terms of ‘air kerma rate’ (gamma sources). They could be applied in case of high-quality equipment [21].

5 Instruments and instrument choice

5.1 Summary of instrument characteristics

The purposes of measuring ionising radiation are very different in the various situation of monitoring radiation. A sensitive meter is needed to detect planned and unplanned presence of radiation (e.g. controlled area, radiation shielding, spills, orphan sources, pollution). A numerically accurate meter is needed to estimate levels of known radiation (man-made or from natural sources). A meter capable of measuring photon-energies is needed for identifying type of radiation (e.g. is it a Cesium-137 or an Americium-241 source). Particularly one should be aware of the low energy cut off of the instrument in question.
An instrument has to be appropriate for the type and energy of the radiation to be measured and have sufficient sensitivity. It must also be acceptable in many other respects such as in terms of robustness, user friendliness and price.
After an instrument has been selected that optimizes the fulfilment of defined needs, it must be periodically and appropriately tested to ensure that it continues to do so.

5.2 Maintenance and care

Radiation protection instruments are relatively easy to maintain in comparison with many other pieces of equipment. An important item of general maintenance is looking after the battery box. Cables and connections must be inspected regularly if applicable.
All instruments require reasonable care during use and in storage. Temperature extremes and rapid changes should be avoided. Water spill on the instruments should be avoided. Batteries should be checked before use.
Malfunctioning is often detected during use. However if an instrument indicates unexpectedly high dose rate, assume the instrument reading is correct and leave the area as soon as possible. Do not assume that it is an instrument failure.

5.3 Pre-use and periodic testing

Instruments should be tested before they are first used to ensure that they conform to type test data. This testing should be designed to identify credible faults such as miscalibration or incorrect assembly of the detector. Pre-use testing also provides a baseline for subsequent routine testing. It is normally possible to select a restricted series of tests which can provide adequate confidence in an instrument's performance. Recommendations for tests are presented in table 4. The organization carrying out such tests should be recognized by the regulatory authority as competent to do so. In Appendix 1 recommendations for periodic tests are given. In Appendix 2a and 2b you will find two examples of performance tests.

Table 4 Summary of testing for workplace of survey instruments

Type of test	Test performed by	Frequency of testing
Type	Manufacturer or authorized type testing organization	Once, typically prior to marketing to end users
Pre-use	Manufacturer, end user or authorized testing organization	Once, prior to placing instrument into service
Periodic	End user or authorized calibration organization	Annually or more frequently, dependent upon stability of instrument and intended use
Performance	Authorized performance testing organization	As specified by regulatory authority, typically every 2–3 years

Periodic testing of workplace monitoring or survey instruments should be carried out at least once a year, and should involve a subset of the tests used in pre-use testing, selected to indicate any reduction in quality in an instrument's performance. Examples of reference radiations that may be used are:

1. For photon dose rate monitors, the 0.662 MeV gamma from ^{137}Cs;
2. For neutron dose rate monitors, ^{241}Am–Be neutrons;
3. For beta dose rate monitors, a $^{90}Sr/^{90}Y$ source plus a low energy beta source;
4. For beta contamination monitors, betas at or above the minimum energy for which the monitor is to be used.

Following testing, a sticker should be attached to the instrument giving relevant information, including the organization performing the test, the test certificate number, and the date of the test or date when the next test is due, as appropriate. Tests should be carried out by an organization that maintains reference radiation fields traceable to the national standards body. Testing should cover the range of dose rates that could reasonably be encountered. Ranges for which an instrument has not been tested should be clearly identified and documented.

6 Monitoring strategies

The general objective of operational monitoring programmes is the assessment of workplace conditions and individual exposures. The assessment of doses to workers routinely or potentially exposed to external sources of radiation constitutes an integral part of any radiation protection programme and helps to ensure acceptably safe and satisfactory radiological conditions in the workplace. Information from monitoring programmes should be used to estimate radiation doses to members of the public for comparison with dose criteria established by the regulatory body. Such criteria are usually specified in terms of limits on the annual radiation dose (in planned exposure situations), dose constraints or as intervention levels of the dose received by the critical group, i.e. the group of people or a (hypothetical) individual which is estimated to receive highest radiation doses. Naturally, the critical group should be carefully selected so that the collective or the mean effective dose of the group is useful for the basis of countermeasures – for instance, the habits of the representative individual should be similar to those of most highly exposed and not such that the extreme characteristics (concerning the dose) are unduly emphasized. In practice, the dose assessment is performed by calculating the doses that members of the critical group receive or could potentially receive. Results from source monitoring, environmental monitoring or individual monitoring, or from a combination of these, are used in these calculations.

In normal, controlled situations these monitoring programmes are extensive enough for dose assessment with a sufficient accuracy as required by the regulatory body. However, in case of large-scale emergency situation the capabilities of local authorities for doing in situ dose rate and nuclide concentration measurements are limited. At the early stages of the situation the dose assessments of the public are largely based on the estimated source term, supported by sporadic dose rate and activity concentration measurements in the field. These measurements, in spite of being few in number, are important in confirming the validity of the source term estimate and in planning the protective measures. In a large-scale situation the existing fixed dose rate measurement points are not sufficient for extensive mapping and monitoring and hand-held survey instruments are additionally needed. The dose rate measurements are not only used to monitor the environmental radiation levels but also the goods and traffic e.g. at the borders or regions close to the emergency site to determine the level of (surface) contamination. These monitors are plastic scintillators and employed with three spectral windows; low, medium and high. It is possible to discriminate the background and set alarm levels. The unit is counts per second. Hand-held survey instruments are also here additionally needed.

Emergency management system should be established to cope with possible radiological emergencies. Response plans should be established to protect individuals from the deterministic radiation effects and to reduce the risk of stochastic effects. Because of the unpredictable nature of the emergency exposure situations, exact plans cannot be prepared. However, plans for all possible scenarios should be developed to assess the overall exposure. Such plans inevitably include the threat assessment and the protection of the rescue workers, including individual monitoring and recording of the doses. Following different scenarios, plans should be prepared for what, where, when and who measures, what is the proper choice of the instrument, to ensure the representativeness of the measurements and to assess the safety of the measurer.

6.1 Monitoring networks

In this context a monitoring network refers to a network of stations which is set up to measure the ambient radiation levels at different locations in a country. The primary aim of such network is to detect an unknown release from of gamma emitting radionuclides a nuclear power plant or other sources, and notify if such happens. In other words they are early warning networks. These networks became more common following the Chernobyl accident in 1986, and today measurement data are exchanged between the European countries on a regular basis.

All countries in the Nordic region operate such network. The size, density and technology vary, but all measure in the unit ambient dose equivalent $H^*(10)$. This harmonized is due to EU legislation which requires that from 2011 dose-rate monitors have to report dose rate as $H^*(10)$, and have to be calibrated accordingly. The calibration has been done by the detector manufacturer on delivery. In addition Physikalisch-Technische Bundesanstalt (PTB) has provided follow-up calibration through a series of EURADOS intercomparison exercises [http://www.eurados.org/pdf/WG03.pdf, 22].

Additional calibration by a national SSDL will function as a quality test of the detector on regular basis and giving legal traceability to the measurements results. Usually such test should be done on both high dose rates (several mSv/h) and near background level (some hundreds nSv/h). The latter may prove difficult since it requires low background facilities.

6.2 Interpretation of monitoring results

The workplace monitoring programme does not directly give information on the doses to the individual workers. When radiation monitors are installed at fixed positions, the displayed dose rate may not be representative of the positions of the workers and thus the spatial variation of the radiation field and air concentration must be accounted for. Moreover, the exposure times and positions of individual workers should be recorded or otherwise assessed for reliable dose estimate based on workplace monitors. However, the exposure to external radiation fields may usually be estimated with sufficient accuracy by individual dose monitoring provided that the monitors (dosemeters) fulfil the associated requirements (such as the IEC standard 61526) and that the dosemeters are worn appropriately. The uncertainties in dose assessments are discussed below.

The dose from the inhaled or ingested radionuclides cannot be estimated with the individual monitoring using personal dosemeters or handheld dose rate monitors. The dose can be estimated with individual monitoring of radionuclides e.g. in urine or by whole body counting. Internal dose was not in the scope of this report and was left out.

The choice of quantity to be monitored needs to be set clearly – the hand-held survey instruments often measure the ambient dose equivalent (rate) ($H^*(10)$). The doses to individuals, or to a group of individuals, are usually reported as effective doses. The ICRP 103 [6] recommends the use of dose to the “representative person”. The correspondence between the measured ambient dose equivalent and the effective dose may have to be assessed e.g. when highly inhomogeneous exposures or short-range radiations are involved. It should also be remembered that the survey instruments do not generally measure the dose from the neutron radiation. The $H^*(10)$ may in some situations underestimate the effective dose, for instance in PA geometry. Detailed information on dose quantities, conversion coefficients and dose assessment for external radiation is given in ICRU report 57 [23].

7 Uncertainties in dose assessment

Monitoring, especially in emergencies, is an important information source for decision making and for the justification of countermeasures. However, as with any measurement, monitoring data have associated uncertainties that arise from technical uncertainties, the non-representativeness of measurements, and human errors. Human errors may stem e.g. from the erroneous reading of the instrument, from the unit conversions and from communicating the monitoring results.

The technical uncertainties in the monitoring data may arise e.g. from

1. Uncertainties in the calibration of the measurement instrument
2. Direction and dose rate dependence of the instrument response
3. Instrument overload
4. Insensitiveness of the instrument when dose rates close to the background level are measured
5. Instrument malfunction
6. The non-representativeness of the measurement may be caused by Spatial and temporal variability of the measured quantity
7. Unsuitable choice of the measurement instrument, e.g. insensitiveness to the radiation quality to be measured
8. Unsuitable measurand
9. Unintended shielding of the instrument
10. Non-standard measurement geometry, e.g. doing a surface contamination measurement at a wrong distance

These uncertainties cannot be eliminated but they should be reduced as far as possible by means of training, quality assurance procedures and proper choice of the instrument. Periodic tests for the survey meters should be carried out (see Section 6) to rule out the most obvious technical faults and uncertainties. Representativeness of the field measurements can be ensured by following an appropriate measurement scheme as described above and by doing repetitive measurements and measurements with larger area coverage. Whereas incorrect calibration may be detected and corrected at a later stage, other errors cannot readily be detected and corrected. The uncertainty associated with the measurement should be given and, if possible, representativeness of the measurement should be assessed already at the site of the measurement but also when measurement campaigns are planned. The IAEA has published a Syllabus on Medical Physics [24]. In Chapter 4 about radiation monitoring instruments, uncertainty of measurements with survey monitors is stated to be typically within ± 30 % under standard laboratory conditions. Out in the field the uncertainty for survey measurements will increase.

Regular training and exercises should be conducted for the staff to maintain the experience of personnel as an important precondition for high quality work, especially under stress in emergencies. In addition to technical operation of the instrument, the training should include the communication protocols.

8 Nordic comparison of radiation protection calibrations

A Nordic comparison of the measurement capabilities for the quantity ambient dose equivalent has been performed among STUK, NRPA, SSM and GR. The comparison was conducted following a ring shaped pattern with the instrument started in Sweden, then sent around to the other countries and at last back to Sweden. Four handheld instruments and one ionisation chamber were included in the comparison. The aim was to calibrate the instruments in ^{60}Co (1250 keV), ^{137}Cs (662 keV), ^{241}Am (60 keV) and two X-ray beams (80 kV and 150 kV) wit the ambient dose equivalent rate around 100 µSv/h. In the ^{137}Cs beam also a higher (H) or a lower (L) dose rate was used. The ambient dose equivalent calibration factor and the uncertainty was reported and evaluated. The measurements were carried out with the normal calibration procedure used at the laboratories. An example of a set up is given in figure 3.

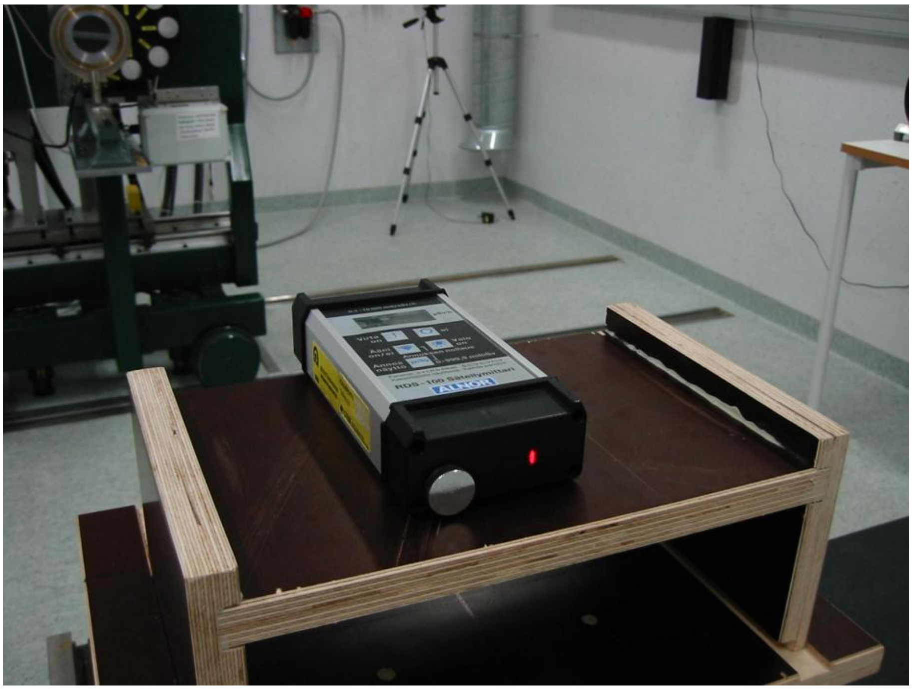


Figure 4 Calibration of a radiation protection instrument in an X-ray beam at STUK.

8.1 Instruments

The instruments taking part in the comparison are given in table 5. Four handheld instruments were included. A Victoreen Panoramic which is an ionisation chamber based instrument. It is an old type of instrument but selected as a good traditional instrument. This instrument is designed to measure kerma and could have large energy dependence for ambient dose equivalent. Two instruments with GM –tubes were selected, a Rados SRV-2000 and a Canberra Radiagem 2000. The GM-tube is energy compensated and they should have a good energy response. They were selected as GM-based instruments are inexpensive and very common in use. The last instrument was an Exploranium Gr-100 with a caesium-iodide thallium doped crystal as detector, which is a relatively new detector type for radiation protection instruments. The instrument measures cps in 5 channels and calculates the total cps and the ambient dose equivalent rate.

The last instrument was an Exradin A6 ionisation chamber which was included as a reference detector. It is a spherical ionisation chamber with the wall and the central electrode made of air-equivalent plastic, C-552 and the volume is 800 cm^3. No electrometer was included; instead each laboratory has to use their own electrometer during the measurements.

Table 5 Data of the instruments taking part in the comparison

Manufacturer	Model	Detector
Rados,	Intensimeter SRV-2000,	GM-tube
Victoreen,	Panoramic, 470 A,	Ion-chamber
Canberra	Radiagem 2000	GM-tube
Exploranium,	GR 100 N,	CsI, Th doped
Exradin ion-chamber	A6	Ion-chamber

8.2 Results and summary of the comparison

Figure 5 - 9 show the results for the ion camber and the four handheld instruments. In the figures the calibration coefficients are normalized with the mean calibration coefficient for that specific energy. A weighted uncertainty (k=2) is also included which corresponds to a confidence level of 95%.

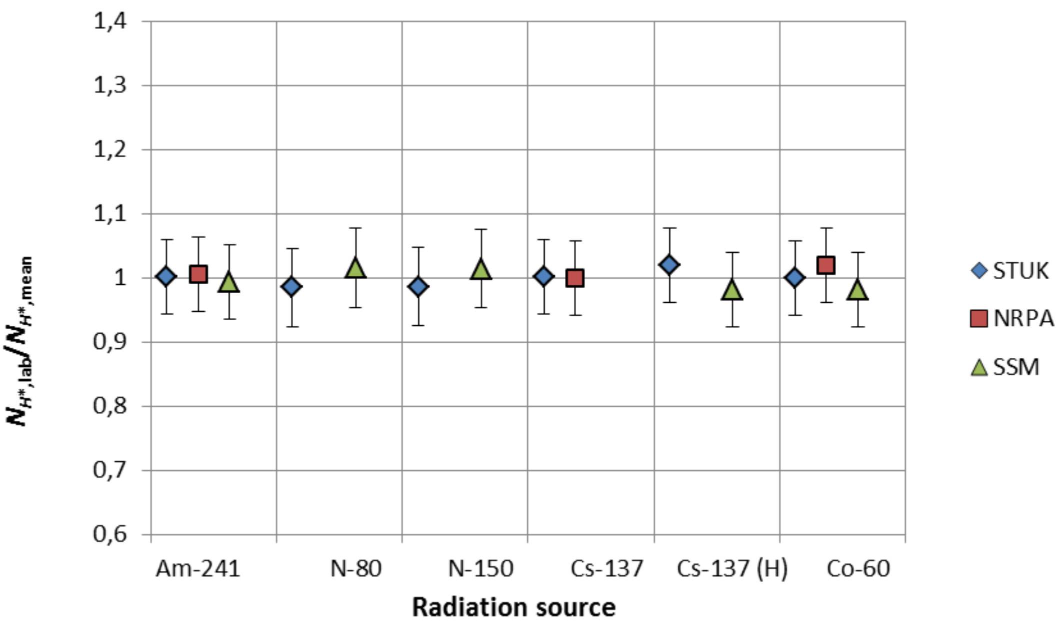


Figure 5 Normalized calibration factors for the Exradin A6 ionisation chamber.

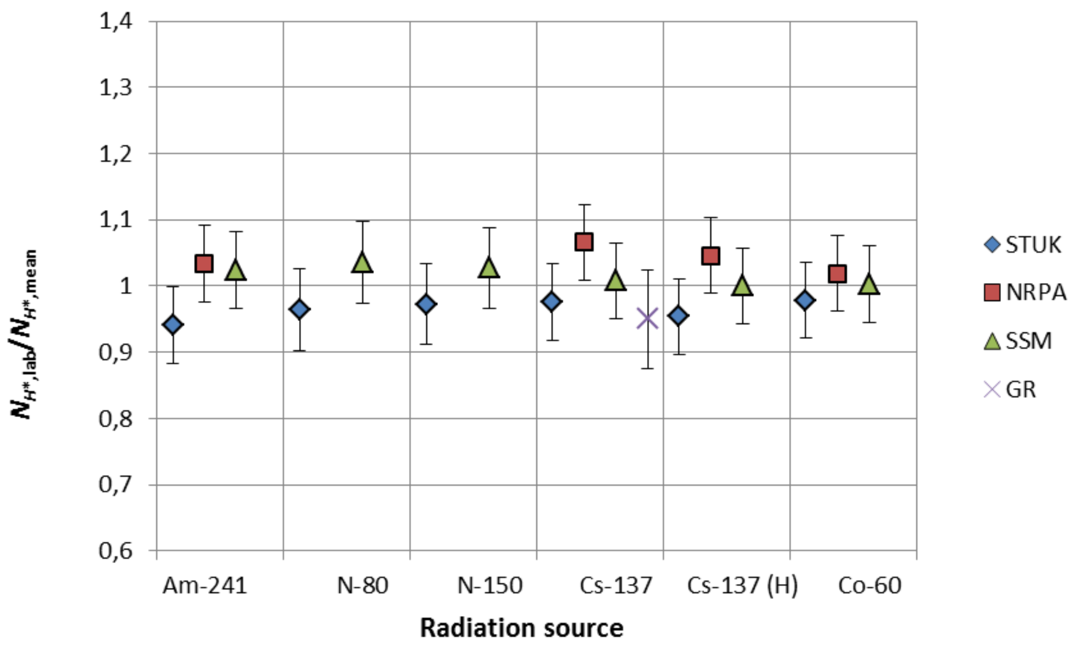


Figure 6 Normalized calibration coefficients for the instrument Rados SRV-2000

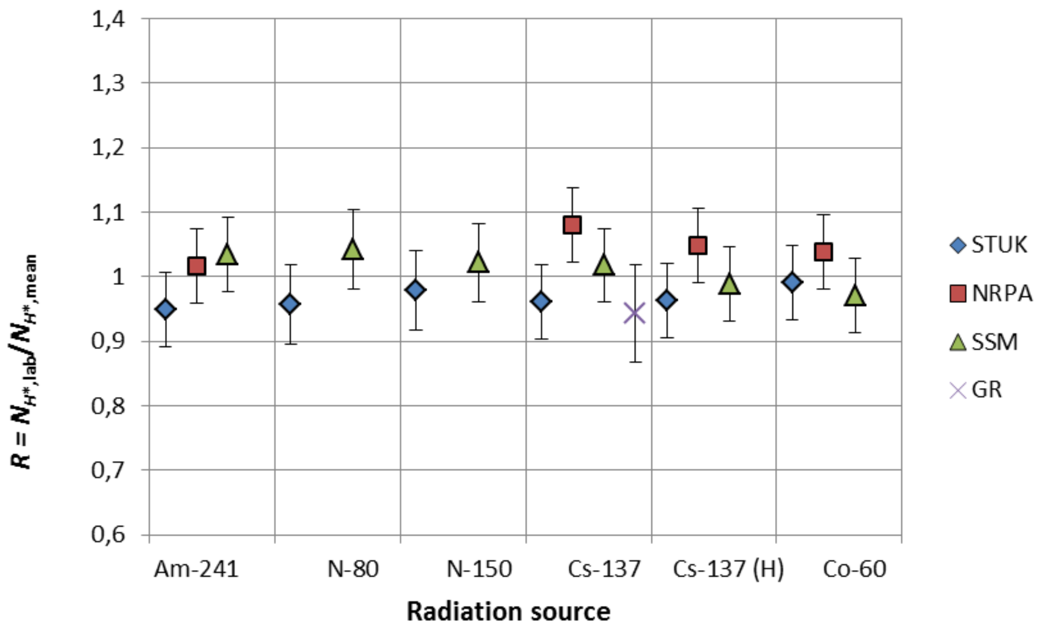


Figure 7 Normalized calibration coefficients for the instrument Canberra Radiagem 2000.

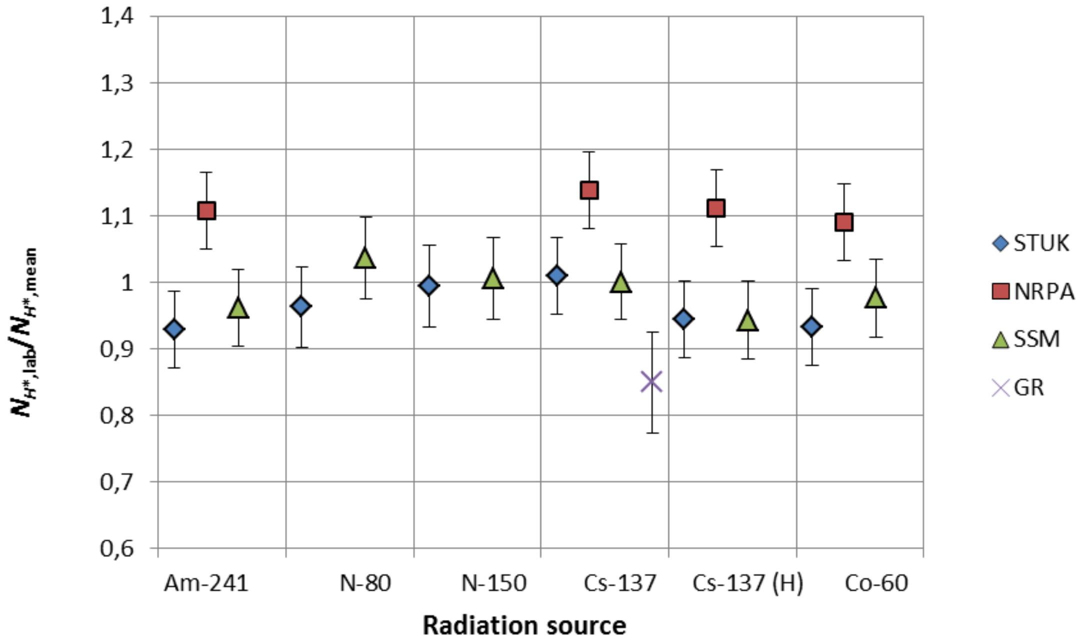


Figure 8 Normalized calibration coefficients for the instrument Victoreen Panoramic 470 A.

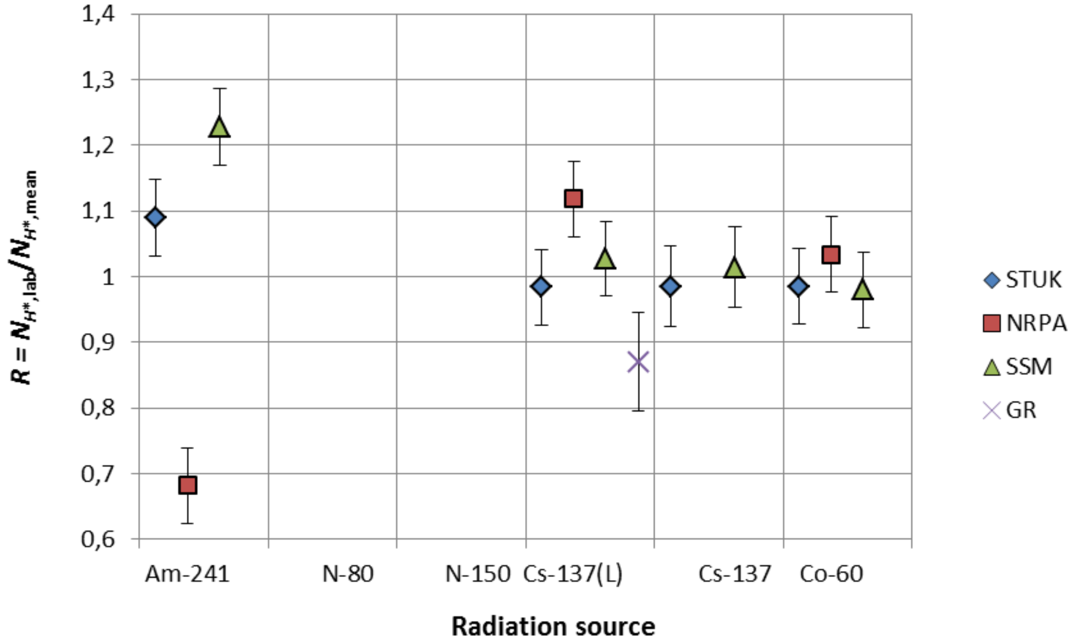


Figure 9 Normalized calibration coefficients for the instrument Exploranium GR-100, unit µSv/h.

8.3 Discussion of results from the comparisons

The good agreement within ± 2 % for the Exradin ion chamber shows that the determination of the ambient dose equivalent rate is in good agreement between Finland, Norway and Sweden for all beams. For the Exradin ion chamber the uncertainty analyses is probably very conservative for all countries.

For the GM-tube based instrument, Rados SRV-2000, the agreement between all countries is within the stated uncertainties. The spread is higher than for the ion chamber mainly depended on the statistical uncertainty due to the small GM-tube in the instruments. Similar results were obtained with the other GM-tube based instrument included in the comparison.

For the Victoreen Panoramic there is a significant deviation from the mean for Norway and Iceland. As only three or five countries, depending on the energy, took part in the investigation it is not possible to judge which of the countries that determine the most correct calibration coefficient.

For the Exploranium instrument it is no significant difference between the countries for the ^{137}Cs- and ^{60}Co-beams while it is a large spread in the results for ^{241}Am-beam. The large difference between Norway and Sweden is difficult to explain. The source and the equipment are similar and the main difference is the field size.

The comparison was shown to be a valuable tool to harmonize the calibration of radiation protection instruments in the Nordic countries.

9 Conclusions

In 1966 the Nordic Council recommended the Nordic governments to start up the Nordic medical physicist cooperation. It has since been a close informal dosimetry cooperating for many years. A mandate for the cooperation was approved by the Nordic radiation protection authorities in 2002. This work extends the cooperation into the dosimetry of radiation protection and environmental monitoring.

Results from comparisons in radiation protection calibrations are reported. The comparison was shown to be a valuable tool to harmonize the calibration of radiation protection instruments in the Nordic countries. Only Sweden, Finland and Norway have calibration capabilities for survey instruments. Denmark and Iceland perform tests using a single source. The measurement results were within the stated uncertainties, except for some results from NRPA and especially for Geiger-Müller-tube based instruments.

Reading of the many recommendations established the formulation of a new fundamental safety principle:

An effective legal and governmental framework for metrology of ionizing radiation must be established and maintained.

This principle underpins the work for safer risk assessment in use of radiation and environmental monitoring. Such a clear goal is in line with many international recommendations and guidelines. This new principle manages the radiation safety and security work towards better public health.

The report contains the formal, theoretical and practical background for survey meters measurements. Reference is given for the expert reader or who that wants to study this dose monitoring in more detail.

The NKS GammaRate project was valuable and it is informed about the calibration service and guidance documentation for radiation protection instrumentation. The ambient dose equivalent $H^*(10)$ is the quantity used for the mapping of a radiation emergency situation and for the assessment of the risk. This is the reason why this type of dosimetry plays an important role in the emergency situations, and it is clear that better traceability and harmonised common guidelines will improve the emergency preparedness and health.

10 References

1. International Atomic Energy Agency. SSDL Network Charter. The IAEA/WHO Network of secondary standard dosimetry laboratories. Vienna: IAEA, 1999. http://www-naweb.iaea.org/nahu/dmrp/SSDLReport/charter.asp (15.12.2011).
2. Bjerke H (ed) Resources, needs and plans. Report on Nordic radiation protection co-operation, no. 8.Osteras: Norwegian Radiation Protection Authority, 2006. http://www.nrpa.no/archive/Internett/Publikasjoner/Annet/Nordisk%20rapport_No8.pdf (15.12.2011).
3. International Atomic Energy Agency, IAEA. Fundamental safety principles. Safety standards; no. SF-1. Vienna: IAEA, 2006. http://www-pub.iaea.org/MTCD/publications/PDF/Pub1273_web.pdf (15.12.2011)
4. International Atomic Energy Agency, IAEA. Calibration of radiation protection monitoring instruments. Safety Report Series No. 16. Vienna: IAEA, 2000. http://www-pub.iaea.org/MTCD/publications/PDF/P074_scr.pdf (15.12.2011)
5. International Commission on Radiation Units and Measurements, ICRU. Fundamental Quantities and Units for Ionizing Radiation. ICRU Report 60. Bethesda, MD: 1998.
6. International Commission on Radiological Protection. The 2007 Recommendation of the International Commission on Radiological Protection. ICRP Publication 103. Annals of the ICRP 2008; 37/(2-4). Amsterdam: Elsevier, 2007.
7. Scott C, Woods M, Burgess P. The Examination, Testing and Calibration of Portable Radiation Protection Instruments. Measurement Good Practice Guide No. 14. Teddington: National Physical Laboratory, NPL, 1999. http://publications.npl.co.uk/dbtw-wpd/exec/dbtwpub.dll?&QB0=AND&QF0=ID&QI0=%202286%20&TN=NPLPUBS&RF=WFullRecordDetails&DL=0&RL=0&NP=4&AC=QBE_QUERY (15.12.2011)
8. International Electrotechnical Commission, IEC. Radiation protection instrumentation - Ambient and/or directional dose equivalent (rate) meters and/or monitors for beta, X and gamma radiation - Part 1: Portable workplace and environmental meters and monitors. IEC International standard 60846-1. Genève: IEC, 2009.
9. International Electrotechnical Commission. Radiation protection instrumentation - Ambient and/or directional dose equivalent (rate) meters and/or monitors for beta, X and gamma radiation - Part 2: High range beta and photon dose and dose rate portable instruments for emergency radiation protection purposes. IEC International standard 60846-2. Genève: IEC, 2007.
10. International Electrotechnical Commission. High range beta and photon dose and dose rate portable instruments for emergency radiation protection purposes. IEC International standard 61018. Genève: IEC, 1991.
11. International Atomic Energy Agency. Environmental and source monitoring for purpose of radiation protection. Safety guide No. RS-G-1.8. Vienna: IAEA, 2005. http://www-pub.iaea.org/MTCD/publications/PDF/Pub1216_web.pdf (15.12.2011)
12. Bureau International des Poids et Mesures. The international system of units. 8th eddition. Sèvres Cedex: BIPM, 2006. http://www.bipm.org/utils/common/pdf/si_brochure_8.pdf (15.12.2011)
13. International Organisation for Standardisation. X and gamma reference radiation for calibrating dosemeters and doserate meters and for determining their response as a function of photon energy – Part 1: Radiation characteristics and production methods. ISO International standard 4037-1:1996. Genève: ISO, 1996.

14. International Commission on Radiation Units and Measurements. Quantities and Units in Radiation Protection Dosimetry. ICRU Report 51. Bethesda, MD: ICRU, 1993.
15. International Organisation for Standardisation. Evaluation of surface contamination – Part 1: Beta-emitters (maximum beta energy greater than 0.15 MeV) and alpha-emitters. ISO International standard 7503-1:1988. Genève: ISO, 1988.
16. International Electrotechnical Commission. Degrees of protection provided by enclosures (IP Code). IEC International standard 60529, edition 2.1. Genève: IEC, 2001.
17. International Electrotechnical Commission. Radiation protection instrumentation - Measurement of personal dose equivalents *Hp*(10) and *Hp*(0.07) for X, gamma and beta radiations - Direct reading personal dose equivalent and/or dose equivalent rate dosemeters. IEC International standard 61526:2010. Genève: IEC, 2010.
18. International Electrotechnical Commission. Radiation protection instrumentation: Passive integrating dosimetry systems for environmental and personal monitoring for external photon and beta radiation using electronic devices for data evaluation: Part 1: General characteristics and performance requirements. IEC International standard 62387-1 edition 1.0 Genève: IEC, 2007.
19. International Organisation for Standardisation. Nuclear energy: Reference beta-particle radiation: Part 3: Calibration of area and personal dosemeters and the determination of their response as a function of beta radiation energy and angle of incidence. ISO International standard 6980-3: 2006. Genève: ISO, 2006.
20. Säteilyturvakeskus. Kvalitets- och granskingskrav för bärbara strålningsmätare. STUK anvisning VAL 4. Helsinki: STUK, 2008. http://www.edilex.fi/stuklex/sv/lainsaadanto/saannosto/VAL4 (15.12.2011)
21. International Electrotechnical Commission. Radiation protection instrumentation: Alpha, beta and alpha/beta (beta energy >60 keV) contamination meters and monitors. IEC International standard 60325 edition 3.0. Genève: IEC, 2002.
22. Sáez-Vergara JC et al. The second EURADOS intercomparison of national network systems used to provide early warning of a nuclear accident. Radiation Protection Dosimetry 123(2): 190 - 208.
23. International Commission on Radiation Units and Measurements, ICRU.Conversion coefficients for use in radiological protection against external radiation. ICRU Report 57. Bethesda, MD: ICRU, 1998.
24. Pogorsak EB (ed). Radiation Oncology Physics. A handbook for teachers and students. International Atomic Energy Agency. Vienna: IAEA, 2005. http://www-naweb.iaea.org/nahu/dmrp/pdf_files/ToC.pdf (15.12.2011)

Appentix 1 Periodic tests

Periodic tests should be designed to provide confidence that the instrument continues to meet the needs of its user.

A protocol for annual testing should be written with specified tests and acceptance limits. A failed instrument should be taken out of use.

Acceptance limits should be appropriate for the use of the instrument. Instrument used in radiation protection do not normally need great precision, for instance for defining limits of closed areas.

All sources used for testing should offer traceability to national standards, directly or indirectly by being checked by instruments that offer such traceability. The sources may be a Cs-137 source and an Am-241 source or X-ray beams of specified beam quality.

For a photon dose rate meter a protocol for annual testing may include the following:

1) Battery tests, mechanical tests and test of audible signal as appropriate.
2) Background dose rate measured, to be recorded and compared to known rate for the area.
3) Response to high dose rates. Exposing the instrument to above limit dose (e.g. 10 times the limit) should result in an overload indication.
4) Linearity of response. Measure at least one known dose rate per decade up to 80% maximum. Deviation up to 30% may be acceptable.
5) Energy response. Measuring two dose rate responses near the lower end of the energy spectrum applicable for the meter.

Some of the following may or may not be applicable:

1) Directional dependency. Needs not normally be tested annually.
2) For meters with source type detection. Test if meter recognises the isotopes it is designed to recognise.
3) Dose test. For instruments measuring accumulated dose.
4) Time constants. For instruments used in searching for sources, a time constant appropriate for the speed with which the source may be passed, may need to be specified and tested.
5) For meters with Beta detection, the dose rate from a Beta source (e.g. Sr-90) should be measured and compared to a pre-recorded value.

11 Appendix 2a Performance tests

Dose rate measurements using a collimated ^{137}Cs point source[a)].

Five measurements in the range of 1µSv/h – 10mSv/h are performed.
The 4 lowest at a distance of 1m (different shielding) and the highest at a distance of .25m (no shielding)

The average doserate of 10 measurements are compared with the reference value. Acceptance limit is +/- 20%.

Linearity.

The 5 measured values are plotted against the reference values and the trend line $y=a\cdot x$ is calculated. The least-squares fitting process produces a value r-squared which is also shown.

An example of reporting from the testing is given in figure 10.

Comment on ^{137}Cs point source

a) QSC Global calibration device model 773. Activity of the ^{137}Cs source is determined with a precision of ± 7 %

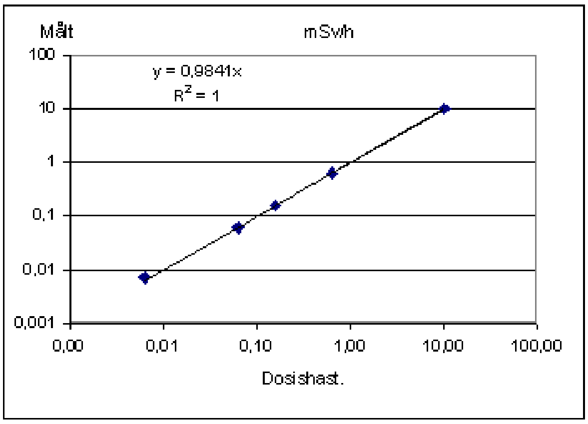
Sundhedsstyrelsen
Statens Institut for Strålebeskyttelse

Periodisk test af gamma dosishastighedsmålere

Dato: 19. april 2010 Instrument: ______________
Serie nr.: ______________

Cs-137 kilde aktivitet og dato					
mCi	MBq	GBq	til dato	antal dage	halveringskonstant
198,1	7329,7	7,3297	18-12-2009		6,3154E-05 d-1
		7,1360	15-02-2011	424,0	
gammakonstant for Cs-137			0,089		

Dosehast. mSv/h	målt værdi mSv/h	afv. i %
10,16	10	-2%
0,64	0,63	-1%
0,16	0,16	1%
0,06	0,06	-6%
0,006	0,007	10%



____
test foretaget af

Instrumentet er kalibreret med en QSC Global calibration device model 773 (SN 642). Aktiviteten af Cs-137 kilden er bestemt med er præcision på +/- 7 %.

Figure 10 Example of report from test of survery meter.

12 Appendix 2b Performance test

1) <u>Low dose rate measurement:</u> Average dose rate indication is compared with the reference value ≥ 0.1 μSv/h.[a] A 3.7 MBq ^{137}Cs source may be used in a specially designed low-background room. Acceptance limits of calibration coefficient 0.50…1.50.

2) <u>Doserate measurements using uncollimated ^{241}Am point sources</u>.
Measurements using two different dose rates over the rated range: 1st 1-10 μSv/h and 2nd 10-100 μSv/h. Two ^{241}Am point sources at a distance < 1 m may be used. Average dose rate indications are compared with the reference values.[b] Acceptance limits of calibration coefficient 0.60…1.40.

3) <u>Doserate measurements using collimated ^{137}Cs point sources</u>.
Measurements using two different dose rates over the rated range: 1st 10 μSv/h to 2 mSv/h and 2nd ≥ 20 mSv/h. Two ^{137}Cs point sources or two irradiation distances may be used. Average dose rate indications are compared with the reference values.[c] Acceptance limits of calibration coefficient 0.60…1.40.

4) <u>Doserate measurements using collimated ^{60}Co point sources</u>.
Measurements using two different dose rates over the rated range: 1st 10 μSv/h to 2 mSv/h and 2nd ≥ 20 mSv/h. Two ^{60}Co point sources or two irradiation distances may be used. Average dose rate indications are compared with the reference values.[c] Acceptance limits of calibration coefficient 0.60…1.40.

If possible, all the measurements are be performed in a dose mode (most survey meters are able to measure the accumulated dose).

In addition to the tests above, an overload test may be performed using a ^{60}Co therapy source at a dose rate of 1-10 Sv/h (the dose rate depends on the rated range of the meter tested [5]). The meter shall indicate “overload” or equivalent indication throughout a 5 min overload test period, and shall function normally 5 min after the test.

See performance test certificate in figure 11.

[a] Uncertainty (2sd) of reference dose rate ≤ 10% . Secondary standard calibrated in terms of air kerma rate at ISO S-Cs radiation quality. Calibration of reference instrument every 5th year in a primary laboratory.
[b] Uncertainty (2sd) of reference dose rate ≤ 5%. Secondary standard calibrated in terms of air kerma rate at ISO N-80 x-ray radiation quality. Calibration of reference instrument every 5th year in a primary laboratory.
[c] Uncertainty (2sd) of reference dose rate ≤ 5%. Secondary standard calibrated in terms of air kerma rate at ISO S-Cs and S-Co radiation qualities. Calibration of reference instrument every 5th year in a primary laboratory.

Performance test certificate **No. ____________**

1. Survey meter			
Model and type:			
Serial number:			
Owner/Institute/Dep.:			
Responsible person:			
2. Performance test			
Overall inspection:		x/o	
Operation manual:		x/o	
Low dose rate measurement:			
Source 1: [Bq, m]			
Reference dose rate: [μSv/h]			
Measured dose rate: [μSv/h]			
Calibration coefficient:			
Doserate measurements using ^{241}Am point sources:			
Source 1: [Bq, m]		Measured dose rate: [μSv/h]	
Reference dose rate: [μSv/h]		Calibration coefficient:	
Source 2: [Bq, m]		Measured dose rate: [μSv/h]	
Reference dose rate: [μSv/h]		Calibration coefficient:	
Doserate measurements using ^{137}Cs point sources:			
Source 1: [Bq, m]		Measured dose rate: [μSv/h]	
Reference dose rate: [μSv/h]		Calibration coefficient:	
Source 2: [Bq, m]		Measured dose rate: [μSv/h]	
Reference dose rate: [μSv/h]		Calibration coefficient:	
Doserate measurements using ^{60}Co point sources:			
Source 1: [Bq, m]		Measured dose rate: [μSv/h]	
Reference dose rate: [μSv/h]		Calibration coefficient:	
Source 2: [Bq, m]		Measured dose rate: [μSv/h]	
Reference dose rate: [μSv/h]		Calibration coefficient:	
Overload tested:		x/o	
Approval:		x/o	
Date:			
Approved by:			

Figure 11 Example of test certificate from performance testing of survey meter.

13 Appendix 3 The NKS GammaRate workshop 2008

A workshop on the NKS GammaRate was arranged at NRPA 28. – 29. October 2008. Abstracts from the presentations follow below.

The Nordic SSDLs had presented their dosimetry capabilities in 2006, in report No 8 on Nordic radiation protection co-operation [2]. The instrumentation and service for calibration in different radiation beams for each country were given there.

It was arranged for a setup in the laboratory for a calibration of two portable dosemeters. A secondary standard dosemeter calibrated at BIPM was used as reference. This was a practical action referring to facilities and capabilities needed for a calibration.

The workshop focused on harmonisation of the service and meeting the needs for the emergency preparedness people.

13.1 Presentations in the workshop of the invited speakers

Radiation protection dosimetry – external radiation. Tor Wøhni, NRPA.

Tor Wøhni gave a lecture on the basic dosimetric quantities for radiation protection, as defined by ICRU [14] and ICRP 103[6]. The relation between physical quantities, operational quantities and protection quantities was presented. Optimal response characteristics for measurement devices like hand monitors were also discussed.

Measuring resources in Sweden. Jan-Erik Grindborg, SSM.

In the presentation *Measuring resources in Sweden* Jan-Erik Grindborg shortly described the main measuring resources in Sweden. The presentation describes the resources at the national measuring preparedness laboratories, districts, rescue service, police and medical service, military authorities, customs and cost guards and administrative province with nuclear power. Also the national warning assemblies were described. The main conclusion was that there is a lot of measuring instrument but their calibration status is sometimes unclear.

Existing Practices for Testing & Calibrating Portable RP Instruments. Þorgeir Sigurdsson, GR.

Thorgeir Sigurdsson argued that there already was some consensus among different stakeholders on what tests should be performed on portable instruments even if such consensus had not been formulated by international agencies. He presented and drew his conclusion from the following: A good practice guide nr 14 from NPL on portable meters [7], instructions accompanying a Cesius-137 calibration source from Amersham and from calibration documents from SAIC for a GR-135 meter, popular among first responders.

Basic description of radiation monitors usage. Þorgeir Sigurdsson, GR.

In the other presentation Thorgeir argued for the dosimetry-group to take note of user requirements of first responders that differed from hospital practices and were not restricted to accurate dose or dose-rate measurements. Sensitivity and response time were among the issues. He suggested the WS-group noted the instrument list that had been listed for the FAT teams of IAEA (Fast Action Team, groups of experts that can be mobilized internationally in case of emergency). These instruments must have some stated capabilities, such as a car born gamma rate measuring system that needs 0.05 µSv/h sensitivity.

Thorgeir presented as an example information on a mobile gamma rate measuring system that STUK has designed and assembled with Sigurdur Emil Pálsson at IRPI as a co-operating partner.

Dose Rate Monitoring Network in Finland. Teemu Siiskonen, STUK

Introduction. The Finnish dose rate monitoring network, with 254 stations, covers extensively the whole country. The main purpose of the network is to provide a real-time dose rate map in Finland and to create alarms when the dose rate exceeds a pre-determined limit. The monitoring stations are based on the embedded technology, with diverse options for connecting various radiation and environmental probes. Special emphasis in designing the network was on automated, reliable and secure data transfer between the stations and the end-users.

General description of the monitoring station. Vendor and software independency are critical for a system that is expected to have a long lifespan. With this in mind the Finnish stations are built around embedded Linux computers. All software is either open source or written in STUK.

The monitoring station has the eight connectors: five RS-232 ports, one RS-485 port, one ethernet connection and one USB connection. These connections allow virtually unlimited types of detectors to be used at the station. At the moment the stations are equipped with dose rate probes and a rain detector. In the future some stations will be equipped with spectrometers for acquiring more detailed data on the radiation field at the station. All stations have a local database for storing the measurement data. The database offers a standard interface to software and greatly facilitates the data management.

The data transfer between the station and headquarters is based on a secure radio network meant for the government authorities. The data from the dose rate detector and the rain detector are read with one-minute intervals. The results are stored in a local database at the station. Every ten minutes an analysis program reads the data from the database and calculates average and standard deviation for testing the validity of the data. These analysed results are again stored to the local database. Finally, the results are sent to STUK and to the Regional Emergency Centre.

The strength of the data collection architecture is its flexibility: Dose rate or rain detectors can be easily changed to another model made by another company. The only change needed for the installation is to develop the software which controls the detector. The rest of the station (software) remains unchanged.

Radiation Detectors. At the moment the stations are equipped with two Geiger-Müller (GM) tubes for low dose rate measurements and one GM tube for high dose rate measurements. Having two GM tubes for low dose rate measurements has two major advantages: Firstly, the sensitivity close to the background level is better and, consequently, small changes close the background level can be detected. Secondly, two independent detectors enable the validation of the results and helps in avoiding alarms caused by the hardware failures.

Commercially available spectrometers ($LaBr_3$) have been tested at some stations. With these detectors nuclide identification is possible. The information on which nuclide or nuclides cause the elevated dose rate is essential when planning countermeasures for protecting people. The dose rate analyses based on the energy spectrum measurements also have a better sensitivity compared to simple dose rate measurements with GM tubes.

Communication. The dose rate monitoring networks are mainly built for early warning purposes. The reliability of the communication is thus essential for the operation of the whole system. This goal is achieved with a Finnish TETRA based secure radio network meant for the government authorities (VIRVE). This network has a data service similar to GSM/GPRS. VIRVE was chosen as a primary data channel of the monitoring network. As a back-up, TETRA text message service is used. In addition to STUK, the data are sent to local emergency response centres. Having the alarms in two places creates redundancy in the response.

All stations read their results at the same time intervals (10 minutes), yielding almost a real-time dose rate map of the country. If a station fails to send its results, the backup procedure is launched after a delay of three minutes. Because the results are sent continuously with short intervals, there is no need for different operation modes. This is ideal for the operational use.

The data connection is open all the time. Therefore, the network administrators can open a remote connection to a station and the software can be upgraded without visiting the remote site. The two-way communication capability helps in resolving the operational problems.

Knowing the background - Understand the Crisis. Jan Erik Dyve, NRPA.

Measurement of the natural background establishes references values for evaluation of the consequences after nuclear fallout. Two of the preparedness and response related measurement resources monitors the background on a national level. Radnett is an early warning network with 28 stations. Its main task is to detect and alert in case of increase in radiation levels caused by a nuclear or radiological accident. Second resource is the Civil Defence which has 120 patrols performing more than 800 manual measurements at 400 fixed locations per year.

Harmonizing measurements improves the quality of the data. This includes procedural harmonization to make sure every measurement is done in the same way, and harmonize the response of the instrument through calibration. On a European level the ambient dose equivalent rate ($dH^*(10)$/dt) has been established as the operational quantity for early warning networks. In 2008 NRPA participated in an intercomparison hosted by Physikalisch-

Technische Bundesanstalt (PTB). The aim was to determine the response of a Radnett station compared to the ambient dose equivalent standard of PTB. Through this intercomparison Radnett and other European early warning networks are harmonized.

Based on the experience from PTB, NRPA will continue work for a national harmonization of the emergency response measurement resources. This will be archived by establishing a secondary ambient dose equivalent standard at the SSDL hosted by NRPA, and develop procedures for performing calibration of different instruments. The aim is to improve the quality of background measurements and the trust in measurements done during a nuclear emergency.

Mobile measurements – LIVEX, DEMOEX, equipment, methods. Mark Dowdall, NRPA.

The LIVEX 2001 exercise was held between the 16th and 20th of September 2001 in Boden, Sweden where the activity of most relevance within the context of this workshop was the Gamma Search activity involving the location of hidden radioactive sources of various isotopes and activities using carborne and handheld radiometric instruments such as simple spectrometers and dose rate systems. Typical instruments employed during the exercise included large volume (16 l) NaI systems, standard sized NaI detectors (3 x 3 in) and GM or scintillator based dose meters. Sources featured in the exercise included ^{60}Co, ^{137}Cs, ^{241}Am, ^{192}Ir, ^{99}Mo and ^{226}Ra of activities ranging between 500 kBq and 40 GBq. Of these sources, some 50% were located by the teams with lower percentages being correctly identified and quantified within 25% of the actual value. Identification of isotopes was based on spectral information from NaI detectors primarily with activity estimates based on a number of methods including efficiency determinations having been made using a reference source in similar circumstances or various functions using gamma constants – either by hand or integrated into software. The main problems associated with instrumentation during the LIVEX exercise were in relation to the effect of scattering on spectral instruments and instabilities in dose meters for determining activities. The second exercise discussed was the DEMOEX exercise of 2006 held between the 30th of September 2006 and the 5th of October 2006. During this exercise, NRPA employed a plastic scintillator dose meter and 3 x 3 in NaI spectrometers as well as a Thermo Eberline FH 40 GL-10 with FHZ 672 E-10 proportional counter/plastic scintillator probe and a Saphymo SPP2 NF NaI search probe. Scattering was mitigated to some extent using a lead collimator on the Saphymo and spectrometers. Performance was improved during DEMOEX as a result of changes made in the equipment employed and how it was employed.

Standards and guides. Antti Kosunen, STUK

In the end of the workshop Antti Kosunen gave a lecture on the standards and guides related to the workshop topic. The IEC standards IEC 60846-1 Portable workplace and environmental meters and monitors [8], IEC 60846-2 High range beta and photon dose and dose rate portable instruments for emergency radiation protection purposes [9], IEC 61018 High range beta and photon dose and dose rate portable instruments for emergency radiation protection purposes [10], IAEA. Safety Report Series No. 16. Calibration of radiation protection monitoring instruments, Measurement Good Practice Guide No. 14. The Examination, Testing and Calibration of Portable Radiation Protection Instruments [7] and STUK: VAL 4. [20].

13.2 Concluding remarks from the workshop

From the information given in the workshop the situation for emergency preparedness dosimetry was different in the Nordic countries. Some presented well established traceable calibrations and routines for quality control, but systems were missing in some other places.

For a type of instrumentation the experience in use of it were mandatory for an effective dosimetry. Especially it was pointed at advanced instrumentation; this may not cause better understanding of the emergency situation. If the operator has little or no experience in using it, an actual mapping of the radiation environment will not be good. It will require special skills from the operator to make a true report of the radiation environment.

The picture in this GammaRate project of the calibration service and guidance documentation for radiation protection instrumentation is given for the workshop participants. The ambient dose equivalent *H*(*10) is the quantity used for the mapping of a radiation emergency situation and for the assessment of the risk. This is the reason why this type of dosimetry plays an important role in the emergency situation, but better traceability and harmonised common guidelines will improve the preparedness.

Needs were expressed as:

1. Develop and maintain a national standard for ambient dose equivalent H*(10)
2. Calibration procedures for different instruments
3. Guidance of on-site calibration procedures for permanent measurement stations
4. Harmonise and improve the quality of measurements made during a nuclear or radiological emergency.

List of participants

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Figure 12 Participants in the workshop (9 first in the list).

Title: Radiation survey meters used for environmental monitoring

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Abstract

The Nordic dosimetry group set up the GammaRate project to investigate how its expertise could be used to assure appropriate usage of survey meters in environmental monitoring.

Considerable expertise in calibrating radiation instruments exists in the Nordic radiation protection authorities. The Swedish, Finnish, Danish and Norwegian authorities operate Secondary Standard Dosimetry Laboratories (SSDLs) that provide users with calibration traceable to internationally recognised primary standards. These authorities together with the Icelandic authorities have formally cooperated since 2002 in the field of radiation dosimetry.

Dosimetry is the base for assesment of risk from ionising radiation and calibration of instruments is an imported part in dosimetry. The Nordic dosimetry group has been focused on cancer therapy. This work extends the cooperation to the dosimetry of radiation protection and environmental monitoring. This report contains the formal, theoretical and practical background for survey meter measurements.

Nordic standards dosimetry laboratories have the capability to provide traceable calibration of instruments in various types of radiation. To verify and explore this further in radiation protection applications a set of survey instruments were sent between the five Nordic countries and each of the authority asked to provide a calibration coefficient for all instruments. The measurement results were within the stated uncertainties, except for some results from NRPA for the ionchamber based instrument. The comparison was shown to be a valuable tool to harmonize the calibration of radiation protection instruments in the Nordic countries.

Dosimetry plays an important role in the emergency situations, and it is clear that better traceability and harmonised common guidelines will improve the emergency preparedness and health.

Key words: Dosimetry, radiation protection, radiation survey meter, calibration, comparison, operational quantities

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