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Radiological protection — Low dose rate calibration of instruments for environmental and area monitoring

Radioprotection — Étalonnage d'instruments à faible débit de dose pour la surveillance de zone et de l'environnement

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Foreword

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This document was prepared by Technical Committee ISO/TC 85, *Nuclear energy, nuclear technologies and radiological protection*, Subcommittee SC 2, *Radiological protection*.

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Introduction

The ISO 4037 documentary standard is an International Standard for the calibration of dosemeters in X and gamma-ray reference fields. The air kerma rate range for which the standard applies is above 1 $\mu Gy \cdot h^{-1}$ being nearly equivalent to 1 $\mu Sv \cdot h^{-1}$ in terms of the operational quantities. The standard however does not address dosemeters that are currently available for environmental monitoring that can measure below 1 $\mu Sv \cdot h^{-1}$. The reliability of environmental monitoring equipment is important for the evaluation of potential dose of the general public during any radiation incident such as an accident that could occur at a nuclear power plant or at any radiation facility.

This document extends the scope of ISO 4037 for calibrating area and environmental type monitors to dose rates below 1 $\mu Sv \cdot h^{-1}$ to improve the reliability of environmental monitoring.

Three detector calibration methods are described in Clause 5 of this document for 3 different situations: ground level facilities with normal background levels (see 5.2), ground level facilities with lower than normal background levels (see 5.3) and underground facilities with lower than normal background levels (see 5.4). Clause 6 discusses routine checks while Clause 7 is dedicated to the calibration of environmental and area dosemeters that are fixed in place. These methods are based on free-in-air and simultaneous irradiation procedures, derived from those described in ISO 29661. This document extends the dose rate range of ISO 4037-1 below 1,0 $\mu Sv \cdot h^{-1}$. The specific uncertainty components are described for these calibration methods.

Radiological protection — Low dose rate calibration of instruments for environmental and area monitoring

1 Scope

This document specifies the calibration methods under laboratory conditions for dosemeters used for environmental and area monitoring of X and gamma-rays with respect to the operational quantities of the International Commission on Radiation Units and Measurements (ICRU)[1].

This document extends the dose rate range of ISO 4037-1 below 1,0 $\mu Sv \cdot h^{-1}$. The specific uncertainty components are described for these calibration methods.

This document also specifies the method for routine checking of active area dosemeters. Routine checking is not a calibration, nor does it replace a calibration, but it is a simple and effective method to routinely verify that the performance of the equipment is continuously maintained after calibration and that the calibration is still valid.

This document does not deal with the special requirements for the calibration of spectrometer-based environmental dosemeters and passive dosemeters.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 4037-1, *Radiological protection — 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 4037-2:2019, *Radiological protection — X and gamma reference radiation for calibrating dosemeters and doserate meters and for determining their response as a function of photon energy — Part 2: Dosimetry for radiation protection over the energy ranges from 8 keV to 1,3 MeV and 4 MeV to 9 MeV*

ISO 4037-3:2019, *Radiological protection — X and gamma reference radiation for calibrating dosemeters and doserate meters and for determining their response as a function of photon energy — Part 3: Calibration of area and personal dosemeters and the measurement of their response as a function of energy and angle of incidence*

ISO 29661, *Reference radiation fields for radiation protection — Definitions and fundamental concepts*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 29661 and the following apply.

ISO and IEC maintain terminology databases for use in standardization at the following addresses:

— ISO Online browsing platform: available at https://www.iso.org/obp

— IEC Electropedia: available at https://www.electropedia.org/

3.1
environmental dosemeter
area dosemeter designed to measure ambient dose equivalent (rate) from natural background radiation and man-made sources of radiation in the environment

Note 1 to entry: Man-made sources of radiation include residues from nuclear tests and accidental or deliberate dispersion of radionuclides used in medical and/or industrial applications. Natural background radiation includes cosmic radiation and radiation produced by the primordial radioisotopes.

3.2
standard instrument
secondary standard or other appropriate instrument, whose calibration is traceable to a primary standard

3.3
scattered radiation
radiation which, during passage through a material, has been deviated from its original direction or changed in energy

3.4
ultra-low ambient dose equivalent rate
ambient dose equivalent rate below 0,01 $\mu Sv \cdot h^{-1}$

3.5
ultra-low background facility
irradiation facility where the background ambient dose equivalent rate is reduced to ultra-low ambient dose equivalent rate levels

Note 1 to entry: The most promising approach to achieve these ambient dose equivalent rate levels is to use a facility located deep underground where the flux of secondary cosmic radiation is reduced by at least two orders of magnitude relative to its value at ground level. To additionally reduce the influence of primordial radionuclides the site of a salt mine should be selected.

Note 2 to entry: The requirement of an ultra-low ambient dose equivalent rate of 0,01 $\mu Sv \cdot h^{-1}$ is a compromise between feasibility to achieve such a small ambient dose equivalent rate and the necessity to have low background radiation compared to the ambient dose equivalent rates at which the calibrations are carried out.

3.6
shadow cone
cone shaped shielding material used to evaluate only the *scattered radiation* (3.3) originating from a radiation source

Note 1 to entry: The shadow cone is used to block the direct radiation from the source.

Note 2 to entry: The shadow cone is a cone-shaped lead shield with a cross section large enough to hide the detector to be calibrated and thick enough (about 6,5 cm for ^{137}Cs and about 12,5 cm for ^{60}Co) to reduce direct radiation by a factor of one thousand or larger. It is installed with a support at approximately the centre of the distance between the gamma-ray source and the instrument to be calibrated on the central axis of the beam.

3.7
low ambient dose equivalent rate
ambient dose equivalent rate below 1 $\mu Sv \cdot h^{-1}$

3.8
inherent background
indicated value due to radiation emitted from radionuclides intrinsic to the detector assembly or electronic noise from the detector and/or its electronics

3.9
coefficient of variation
ratio of the standard deviation s to the arithmetic mean $\bar{x}$ of a set of n measurements x_i given by the following formula:

$$V = \frac{s}{\bar{x}} = \frac{1}{\bar{x}} \sqrt{\frac{1}{n-1} \sum_{1}^{n} (x_i - \bar{x})^2}$$

[SOURCE: IEC 60050-394:2007, 394-40-14]

4 Symbols

The symbols used are given in Table 1.

Table 1 — Symbols

Symbol	Meaning	Unit
r_0	distance from the source to the point of test where the reference ambient dose equivalent rate is given	m
r	distance from the source to the dosemeter in a calibration measurement	m
$\dot{H}_0$	ambient dose equivalent rate at r_0	Sv·h^{-1}
$\dot{H}$	ambient dose equivalent rate at r	Sv·h^{-1}

5 Calibration methods under laboratory conditions

5.1 Characterization of the radiation field using a reference source

5.1.1 General

A gamma-ray source that produces an ambient dose equivalent rate of less than 1 µSv·h^{-1} at the reference distance shall be used as a reference standard. The characterization procedure shall be performed in the calibration room specified in ISO 4037-1. The dose rate, $\dot{H}_0$, shall be determined with a standard instrument.

5.1.2 Characterization procedure of the reference radiation field

The reference source shall be placed inside a shielded enclosure with a collimator that has an adequate opening angle, positioned in a calibration room such that the contribution of scattered radiation at the reference distance is less than 5 %.

The reference source without a collimator could be used provided that short distances are used (<1 m) and also scattered radiation shall be less than 5 % of the ambient dose equivalent at the point of test.

Reference sources shall be used to establish a low dose rate reference field using a standard instrument calibrated in terms of the ambient dose equivalent. The standard instrument shall be used to realize the dose equivalent rate, $\dot{H}_0$. The calibration distance r shall be selected such that the standard instrument is completely submerged within the cone of the homogeneous beam and that scattered radiation from the room boundaries (i.e. floor, ceiling and walls), the irradiator structure and other scattering objects contribute less than 5 % to the ambient dose equivalent due of the primary field.

The contribution of the room scattering radiation should be estimated by the shadow-cone measurement.

Sources that have the same encapsulation and the same radionuclide as the reference source, but different activities may be calibrated using activity ratios provided the activity of the reference source is well-known and has been calibrated using a well-type ionization chamber.

The standard instrument can also be calibrated in terms of air-kerma provided an appropriate conversion coefficient from the air-kerma to the ambient dose equivalent is applied.

5.1.3 Characterization procedure of the radiation field at a distance *r*

As discussed in the previous subclause, reference sources shall be used to establish a low dose rate reference field $\dot{H}_0$ using a standard instrument calibrated in terms of the ambient dose equivalent. The standard instrument shall be placed at a reference distance r_0 from the source and used to realize the dose equivalent rate $\dot{H}_0$ at such distance. For distances r other than the reference distance r_0, the dose rate $\dot{H}_0$ shall be derived by using following Formula (1):

$$\dot{H} = \dot{H}_0 \cdot \frac{r_0^2}{r^2} \tag{1}$$

The contribution to the ambient dose equivalent of scattered radiation from the facility boundaries, the irradiator structure and other scattering objects at a distance, *r*, relative to the reference value of the well-collimated photon beam, shall be below 5 %. After correcting for air attenuation, the ambient dose equivalent rate should be proportional within 5 % to the inverse square of the distance from the source centre to the detector centre. If this is not the case, the scattered radiation contribution shall be determined using the shadow cone technique.

5.1.4 Uncertainty for the calibration of the radiation field using the reference source

ISO 4037-3 shall be used as a reference to estimate the uncertainty. At least, the following uncertainty components shall be considered:

a) the uncertainty of $\dot{H}_0$ measured with the standard instrument at distance r_0 including the effect of nonuniformity;

b) the uncertainty due to scattered radiation from the room and/or other objects in the room;

c) the uncertainty due to the fluctuation of the indicated value of the instrument/item in the measurements for background radiation and the gamma-rays from the reference source;

d) the uncertainty due to the positioning of the instrument at the point of test.

The uncertainty of $\dot{H}_0$ with the standard instrument can be reduced by using a large volume ionization chamber. When a large ionization chamber is used, the effect of the non-uniformity of the irradiation field should be evaluated.

If the difference due to scattered radiation at r_0 has been determined, it should be corrected for unless the difference is less than 1 % of the reference dose.

5.2 Ground level facilities with normal background dose levels

5.2.1 General

The calibration range may be extended to low dose equivalent rates at the facilities specified by ISO 4037-1. The calibration of detectors is performed under the same conditions used to calibrate the radiation field using the reference source described in 5.1. These are ground level facilities with a normal background dose level.

5.2.2 Dose equivalent rate evaluation using the inverse square of distance

The dose equivalent rate at an arbitrary distance, *r*, may be determined based on the dose equivalent rate at the reference distance, r_0, as described previously using Formula (1). Typically, the reference distance used is r_0= 1 m. The contribution from the room scattering radiation shall be estimated using a high-sensitivity detector which enables measuring low ambient dose equivalent rate. The calibration may be performed if the effect of the room scattering radiation is lower than 5 % of the ambient dose equivalent rate. The contribution of the scattered radiation needs to be accounted for.

5.2.3 Detector calibration procedure

The calibration procedure shall follow ISO 4037-2:2019, Clause 8. The calibration results can be greatly affected by the source-to-detector distance so that the source-to-detector distance shall be determined with a standard uncertainty of less than 1 %. The coefficient of variation of the indicated value without the source should not exceed 10 % of the reference ambient dose equivalent, as a criterion for the calibration field.

5.2.4 Uncertainty contributions to the detector calibration uncertainty

ISO 4037-3 shall be used as a reference to estimate the uncertainty of the detector calibration. At least, the following uncertainty contributions shall be considered:

a) the uncertainty of the dose equivalent rate at the certain distance determined by extrapolation method with the inverse square law;

b) the uncertainty due to the variation of the indicated value of the dosemeter in the measurements for background radiation and the gamma-rays from the reference source.

5.3 Ground level facilities with added shielding at lower than normal background levels

5.3.1 General

In ground level facilities, normal background dose equivalent rates are usually 0,05 μSv·h−1 to 0,1 μSv·h−1, which is often of the same order as the dose equivalent rate at which the dosemeter is irradiated for calibration. Under such conditions, it is difficult to perform an accurate calibration in a short time. One possible way to solve this challenge is by reducing the background dose equivalent rate, which can be accomplished by shielding the irradiation volume in a ground level facility referred to as a ground level facility with added shielding.

5.3.2 Description of the ground level facility with added shielding

To reduce the background dose equivalent rate, a large shield box may be used, such as the one shown in Annex A. A high Z material, such as lead, is effective as a shielding material. The calibrations shall be performed in a collimated radiation field to reduce scattered radiation within the shield box. When a high Z material is used as a shielding material, a suitable liner shall be installed to absorb the characteristic X-rays emitted from the high Z material. Such a liner could be copper, tin and copper, a stainless-steel plate, or other suitable materials. If multiple shielding materials are used, the effective atomic number should decrease from highest to lowest towards the point of measurement. As shown in the illustration given in Annex A, the use of a shield box can help reduce background levels at the point of test quite significantly up to one order of magnitude.

5.3.3 Detector calibration procedure

To reduce the influence from back-scatter-factor of the shield box described in 5.3.2, the point of test shall be set between the centre of the shield box and the reference source. The dose equivalent rate at each point of test shall be determined by a standard instrument traceable to a primary standard measurement. When using a large standard instrument, such as the large spherical cavity ionization chamber shown in Annex A, a correction for non-uniformity shall be made.

5.3.4 Uncertainty contributions to the detector calibration uncertainty

ISO 4037-3:2019, Clause 9 shall be used as a reference to estimate the uncertainty of the detector calibration. At least, the following uncertainty components shall be considered:

a) the uncertainty of the non-uniformity correction caused from using large standard instruments;

b) the uncertainty of setting the position of the dosemeter.

When calibrating a dosemeter in a shield box, the distance from the reference source to the point of test is usually 50 cm or less. Therefore, a correction to account for the non-uniformity of the photon field in the vicinity of the large standard instrument used is required, and the associated uncertainty shall be taken into account. Because of the short source-to-detector distance, the uncertainty of setting the position of the detector shall be also considered.

5.4 Underground facilities with ultra-low background dose levels

5.4.1 General

These facilities are used as reference sites for calibrations, as well as for scientific and technological studies and shall fulfil the requirements of ultra-low background facilities.

These facilities shall be well suited for investigating and measuring the inherent background of radiation detectors, which is needed for the characterization of environmental dosemeters with respect to background ionizing radiation in the environment (see Annex B) and for providing mostly radiation background-free calibrations of highly sensitive environmental dosemeters.

The calibration procedure in these facilities shall be consistent with 5.1.2.

5.4.2 Description of the facility

To establish an underground facility, which fulfils the requirements of ultra-low background facilities, the following technical solutions should be required.

The depth below the surface of the ground should be large enough such that the flux of secondary cosmic radiation is reduced by at least two orders of magnitude compared to that of ground level.

The materials used to construct and furnish the underground facility should have low specific activities so that the background ambient dose equivalent rate is consistent with ultra-low dose equivalent rates.

The mean radon activity concentration should be kept small enough so that the background ambient dose equivalent rate is consistent with ultra-low dose equivalent rates.

Radioactive sources should be stored in a container so that the ambient dose rate due to source storage is negligible and does not increase the background limit above ultra-low dose equivalent rate levels.

5.4.3 Uncertainty contributions to the detector calibration uncertainty

ISO 4037-3 shall be used as a reference in considering the detector calibration uncertainty. When measuring low ambient dose equivalent rates at ultra-low background facilities, at least the following uncertainty components shall be considered:

a) the uncertainty of the reference value of the ambient dose equivalent (rate) at the point of test;

b) the uncertainty of the radiation background at the point of test;

c) the uncertainty due to the fluctuation of the indicated values of the dosemeter;

d) the uncertainty due to the inherent background of the dosemeter.

6 Routine checking

6.1 General

It may be necessary to perform routine checks of area or environmental dosemeters depending on their usage and condition. A routine check is not a detector calibration, and it is not meant to replace a calibration. Instead it provides a simple and effective method for routinely verifying that the performance of the equipment is continuously maintained after calibration and that the calibration is still valid. Routine checks are generally achieved by confirming that the instrument readings reproduce when exposed to a low radioactivity gamma-ray source for which the detector's response is well known. The time interval of routine checks shall be within the period defined by national regulations. Where no such regulations exist, the time interval should not exceed two years.

6.2 Description of the method

6.2.1 Introduction

Routine checks are performed by irradiating the dosemeter with a check source device. The indicated value due to the irradiation with the check source after a certain period from the last calibration shall be compared with the indicated value due to the irradiation with the check source determined directly after the calibration.

6.2.2 Irradiation setup for regular checking

The geometric arrangement conditions of area or environmental dosemeters and the gamma-ray source for routine checks shall be the same arrangement as when the indicated value directly after the calibration was obtained. The coefficient of variation due to repeated measurements with the same dosemeter and check source device shall not exceed 0,05.

The geometric arrangement conditions may be reproduced by using a jig specially designed for each area or environmental dosemeter. The jig may be provided by the manufacturer of the dosemeter.

The gamma-ray source to be used is preferably either ^{137}Cs or ^{60}Co. A radiation source built into an area or environmental dosemeter may be used.

The built-in check source is also applicable for routine checks.

6.2.3 Criteria for routine checks

The indicated value shall be compared with the indicated value determined using the same check source directly after the calibration. The indicated value shall be corrected for the decay of the gamma-ray source. The correction factor shall be known with a precision of less than ±1 %. The difference of the indicated value determined with the check source directly after the calibration and the indicated value during the routine check shall not exceed the criterion set beforehand, 20 % is recommended.

It is possible to use the same check source for a large number of dosemeters of the same type. In this case, measurements with the check source device might not be available directly after calibration for all dosemeters, and the indicated value after calibration shall therefore be determined using at least five dosemeters of the same type. The criterion shall consider additional uncertainties due to small product fluctuations of the dosemeters. The limit for the indicated value shall be reduced by the coefficient of variation determined using at least five dosemeters of the same type multiplied by 2,5. The upper and lower limit of the indicated value, M_{max} and M_{min}, can thus be expressed in terms of the mean and standard deviation, M_{mean} and σ, of the indicated values corrected by the individual calibration for the measurements with at least five different dosemeters directly after calibration, as given by Formulae (2) and (3):

$$M_{max} = 1{,}2 \cdot M_{mean} - 2{,}5 \cdot \sigma \tag{2}$$

$$M_{\mathrm{min}} = 0{,}8 \cdot M_{\mathrm{mean}} + 2{,}5 \cdot \sigma \tag{3}$$

NOTE The factor of 2,5 ensures that practically all dosemeters remain inside the criterion set beforehand (in this case ±20 %).

7 On-site calibration

7.1 General

For locations in which environmental dosemeters are firmly fixed and difficult to remove and transport to the calibration laboratory, the paragraphs below provide a method for on-site calibration of the fixed monitoring system.

This subclause specifies calibration of environmental dosemeters that are firmly fixed and difficult to send to irradiation facilities such as the ones described in 5.2 through 5.4.

The area dosemeters fixed on the building walls or equivalent are not covered in this document.

7.2 The method using a portable calibrated radioactive source

7.2.1 General

For on-site calibrations, a portable radioactive source calibrated in terms of the ambient dose equivalent can be used (defined in 7.2.2). The contribution of the scattered radiation to the ambient dose equivalent (rate) at the point of test shall be below 5 %. Calibrated irradiation systems shall be used when the contribution of the scattered radiation to the ambient dose equivalent (rate) at the point of test is above 5 %.

7.2.2 Portable calibrated radioactive source

A portable calibrated irradiation system consists of a collimated gamma-ray ^{137}Cs or ^{60}Co reference source. The aim is to keep the scattered radiation below 5 % in term of the ambient dose equivalent (rate). The calibration of these reference sources shall comply with requirements described in 5.1.2.

7.2.3 Procedure of calibration

The portable calibrated source shall be positioned at a well-known distance from the dosemeter that is fixed to the wall. The distance between the reference point of the dosemeter and the reference source shall be measured with a standard uncertainty of less than 0,5 %. Formula (1) shall be used for determining the ambient dose equivalent rate produced by the source at the detector position. The ambient dose equivalent (rate) at the point of test shall be corrected to account for the decay of the calibrated radioactive source.

The calibration distance shall be selected such that the active volume of the dosemeter is completely submerged within the cone of the homogeneous beam and scattering from surrounding objects is minimized.

7.2.4 Uncertainty contributions to the detector calibration uncertainty

Uncertainty contributions shall comply with requirements described in 5.1.4.

7.3 The method using a reference standard instrument

7.3.1 General

This method shall be applied for on-site calibrations with complex scattering conditions.

7.3.2 The calibration instruments

The distance from the gamma-ray source to the reference instrument and that from the source to the dosemeter shall be the same. The horizontal or vertical irradiation can be used, but the irradiation direction shall be the same for the reference standard and the area dosemeter.

The calibration distance shall be selected such that the active volumes of the dosemeter and reference instrument are submerged completely within the cone of the homogeneous primary beam.

7.3.3 Uncertainty contributions

Uncertainty contributions shall comply with requirements described in 5.1.4 and shall be complemented with uncertainty component due to the simultaneous irradiation of two environmental dosemeters (the dosemeter and the reference instrument).

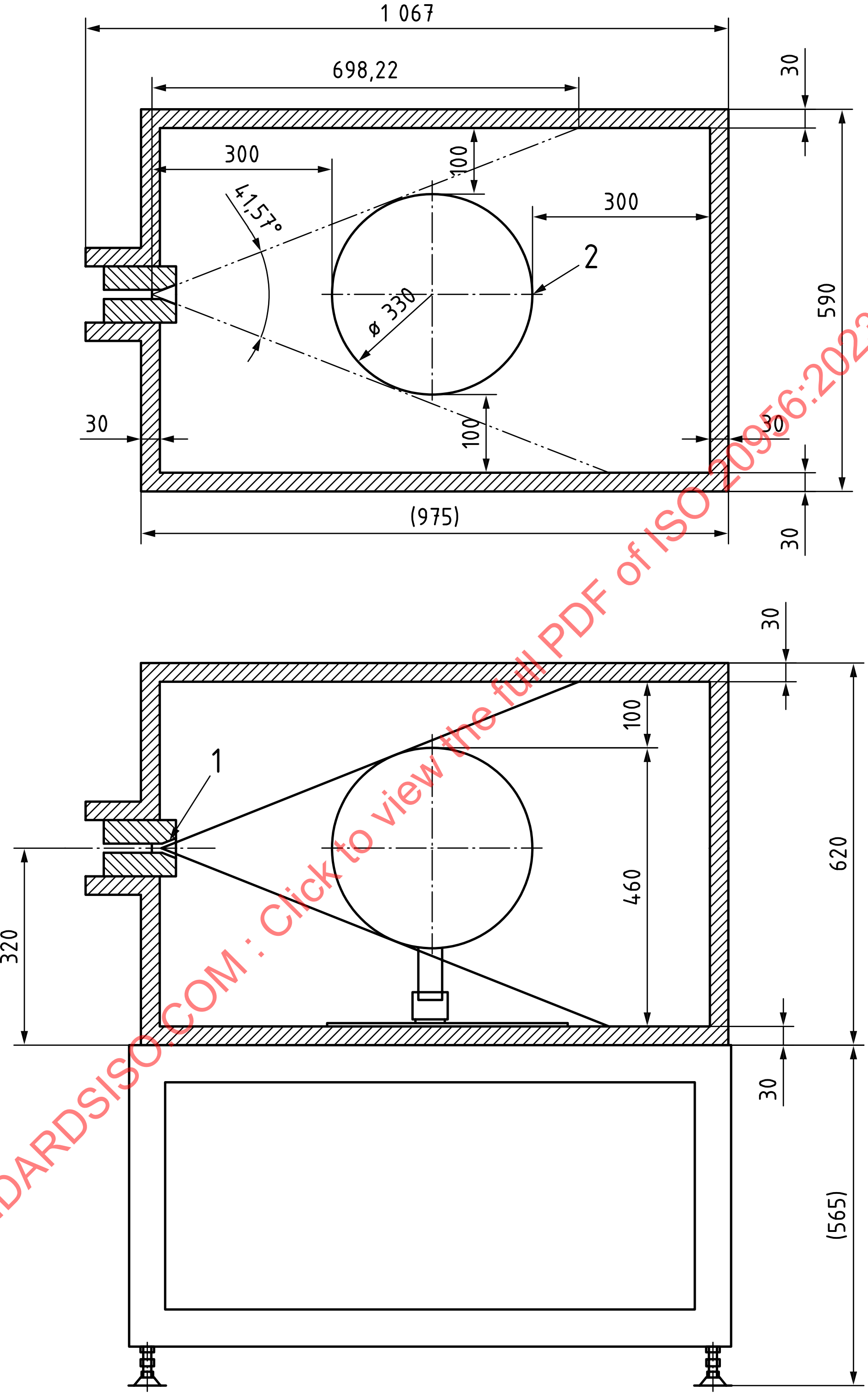
Annex A
(informative)

Example of a ground level facility with added shielding

A.1 Shielding box

Cross sectional schematic of a shielding box is shown in Figure A.1. The inner size of the irradiation volume is 100 cm × 56 cm × 56 cm, and it is surrounded by a 30 mm lead wall to reduce background radiation. Additionally, 2 mm stainless steel and 1 mm Al plates are mounted on the inner side of the lead wall for shielding the characteristic X-rays from lead. The distance from the source to the reference point is about 63 cm. The background ambient dose equivalent rate outside of the shield box is about 0,09 $\mu Sv \cdot h^{-1}$ while the background ambient dose equivalent rate inside the shield box is reduced to 0,01 $\mu Sv \cdot h^{-1}$.

Dimensions in millimetres



Key

1 gamma-ray source

2 ionization chamber

Figure A.1 — Shielding box[2]