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Evaluating the performance of continuous air monitors —

Part 2: Air monitors based on flow-through sampling techniques without accumulation

Évaluation de la performance des dispositifs de surveillance de l'air en continu —

Partie 2: Moniteurs d'air basés sur des techniques d'échantillonnage par circulation sans accumulation

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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*.

A list of all the parts in the ISO/TR 22930 series can be found on the ISO website.

Any feedback or questions on this document should be directed to the user's national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

Introduction

Sampling and monitoring of airborne activity concentration in workplaces are critically important for maintaining worker safety at facilities where dispersible radioactive substances are used.

The first indication of a radioactive substance dispersion event comes, in general, from a continuous air monitor (CAM) and its associated alarm levels. In general, the response of a CAM is delayed in time compared to the actual situation of release.

The knowledge of a few factors is needed to interpret the response of a CAM and to select the appropriate CAM type and its operating parameters.

The role of the radiation protection officer is to select the appropriate CAM, to determine when effective release of radioactive substances occurs, to interpret measurement results and to take corrective action appropriate to the severity of the release.

The objective of ISO/TR 22930 series is to assist radiation protection officer in evaluating the performance of a CAM.

ISO/TR 22930 series describes the factors and operating parameters and how they influence the response of a CAM.

This document deals with monitoring systems based on flow-through sampling techniques without accumulation.

Evaluating the performance of continuous air monitors —

Part 2: Air monitors based on flow-through sampling techniques without accumulation

1 Scope

The use of a continuous air monitor (CAM) is mainly motivated by the need to be alerted quickly and in the most accurate way possible with an acceptable false alarm rate when significant activity concentration value is exceeded, in order to take appropriate measures to reduce exposure of those involved.

The performance of this CAM does not only depend on the metrological aspect characterized by the decision threshold, the limit of detection and the measurement uncertainties but also on its dynamic capacity characterized by its response time as well as on the minimum detectable activity concentration corresponding to an acceptable false alarm rate.

The ideal performance is to have a minimum detectable activity concentration as low as possible associated with a very short response time, but unfortunately these two criteria are in opposition. It is therefore important that the CAM and the choice of the adjustment parameters and the alarm levels be in line with the radiation protection objectives.

This document describes

— the dynamic behaviour and the determination of the response time,

— the determination of the characteristic limits (decision threshold, detection limit, limits of the coverage interval), and

— a possible way to determine the minimum detectable activity concentration and the alarms setup.

Finally the annexes of this document show actual examples of CAM data which illustrate how to quantify the CAM performance by determining the response time, the characteristics limits, the minimum detectable activity concentration and the alarms setup.

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 11929-1, *Determination of the characteristic limits (decision threshold, detection limit and limits of the coverage interval) for measurements of ionizing radiation — Fundamentals and application — Part 1: Elementary applications*

ISO 16639, *Surveillance of the activity concentrations of airborne radioactive substances in the workplace of nuclear facilities*

IEC 60761-1, *Equipment for continuous monitoring of radioactivity in gaseous effluents — Part 1: General requirements*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 11929-1, ISO 16639, IEC 60761-1 and the following apply.

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

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

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

3.1
annual limit on intake
ALI
derived limit for the amount of radioactive substance (in Bq) taken into the body of an adult worker by inhalation or ingestion in a year

[SOURCE: ISO 16639:2017, 3.7]

3.2
continuous air monitor
CAM
instrument that continuously monitors the airborne activity concentration on a near real-time basis

[SOURCE: ISO 16639:2017, 3.10]

3.3
decision threshold
value of the estimator of the measurand, which when exceeded by the result of an actual measurement using a given measurement procedure of a measurand quantifying a physical effect, it is decided that the physical effect is present

Note 1 to entry: The decision threshold is defined such that in cases where the measurement result, y, exceeds the decision threshold, y^*, the probability of a wrong decision, namely that the true value of the measurand is not zero if in fact it is zero, is less or equal to a chosen probability α.

Note 2 to entry: If the result, y, is below the decision threshold, y^*, it is decided to conclude that the result cannot be attributed to the physical effect; nevertheless, it cannot be concluded that it is absent.

[SOURCE: ISO 11929-1:2019, 3.12]

3.4
derived air concentration
DAC
concentration of a radionuclide in air that, if breathed over the period of a work year, would result in the intake of one ALI for that radionuclide

Note 1 to entry: The DAC is calculated by dividing the ALI by the volume of air breathed by reference man under light-activity work during a working year (in Bq m^{-3}).

Note 2 to entry: The parameter values recommended by the International Commission on Radiological Protection for calculating the DAC are a breathing rate of 1,2 $m^3 \cdot h^{-1}$ and a working year of 2 000 h (i.e. 2 400 m^3).

Note 3 to entry: The air concentration can be expressed in terms of a number of DAC. For example, if the DAC for a given radionuclide in a particular form is 0,2 Bq m^{-3} and the observed concentration is 1,0 Bq m^{-3}, then the observed concentration can also be expressed as 5 DAC (i.e. 1,0 divided by 0,2).

Note 4 to entry: The derived air concentration-hour (DAC-hour) is an integrated exposure and is the product of the concentration of a radioactive substance in air (expressed as a fraction or multiple of DAC for each radionuclide) and the time of exposure to that radionuclide, in hours.

[SOURCE: ISO 16639:2017, 3.12]

3.5
detection alarm level
S0
value of time-integrated activity concentration activity concentration corresponding to an acceptable false alarm rate

Note 1 to entry: When S0 increases false alarm rate decreases.

Note 2 to entry: Others values of alarm level higher than S0 can also be set up for operational reasons.

3.6
detection limit
smallest true value of the measurand which ensures a specified probability of being detectable by the measurement procedure

Note 1 to entry: With the decision threshold according to 3.3, the detection limit is the smallest true value of the measurand for which the probability of wrongly deciding that the true value of the measurand is zero is equal to a specified value, β, when, in fact, the true value of the measurand is not zero. The probability of being detectable is consequently $(1-\beta)$.

Note 2 to entry: The terms detection limit and decision threshold are used in an ambiguous way in different standards (e.g. standards related to chemical analysis or quality assurance). If these terms are referred to one has to state according to which standard they are used.

[SOURCE: ISO 11929-1:2019, 3.13]

3.7
limits of the coverage interval
values which define a coverage interval

Note 1 to entry: The limits are calculated in the ISO 11929 series to contain the true value of the measurand with a specified probability $(1-\gamma)$.

Note 2 to entry: The definition of a coverage interval is ambiguous without further stipulations. In this standard two alternatives, namely the probabilistically symmetric and the shortest coverage interval are used.

Note 3 to entry: the coverage interval is defined in ISO 11929-1:2019, 3.4, as the interval containing the set of true quantity values of a measurand with a stated probability, based on the information available.

[SOURCE: ISO 11929-1:2019, 3.16 modified – Note 3 to entry has been added]

3.8
measurand
quantity intended to be measured

[SOURCE: ISO 11929-1:2019, 3.3]

3.9
minimum detectable concentration
time-integrated activity concentration or activity concentration measurements and their associated coverage intervals for a given probability $(1-\gamma)$ corresponding to the first alarm level S0

3.10
model of evaluation
set of mathematical relationships between all measured and other quantities involved in the evaluation of measurements

[SOURCE: ISO 11929-1:2019, 3.11]

3.11
potential missed exposure
PME
time-integrated activity concentration or maximum activity concentration, as applicable, that can acceptably be missed

Note 1 to entry: the value of PME is defined according to ALARA/ALARP principles, and below legal limits.

Note 2 to entry: In order to be alerted when a measurement is likely to exceed the value of PME, an alarm level S1 is set up. The PME is then the upper limit of the coverage interval for a given probability (1−γ) of time-integrated activity concentration or activity concentration measurements corresponding to S1.

[SOURCE: ISO 16639:2017, 3.18]

3.12
response time
time required after a step variation in the measured quantity for the output signal variation to reach a given percentage for the first time, usually 90 %, of its final value

Note 1 to entry: The intrinsic response time is related to the measurement principle and its associated model of evaluation of an ideal detector (without taking account of the counting time of the detector).

[SOURCE: IEC 60761-1:2002, 3.15]

4 Symbols

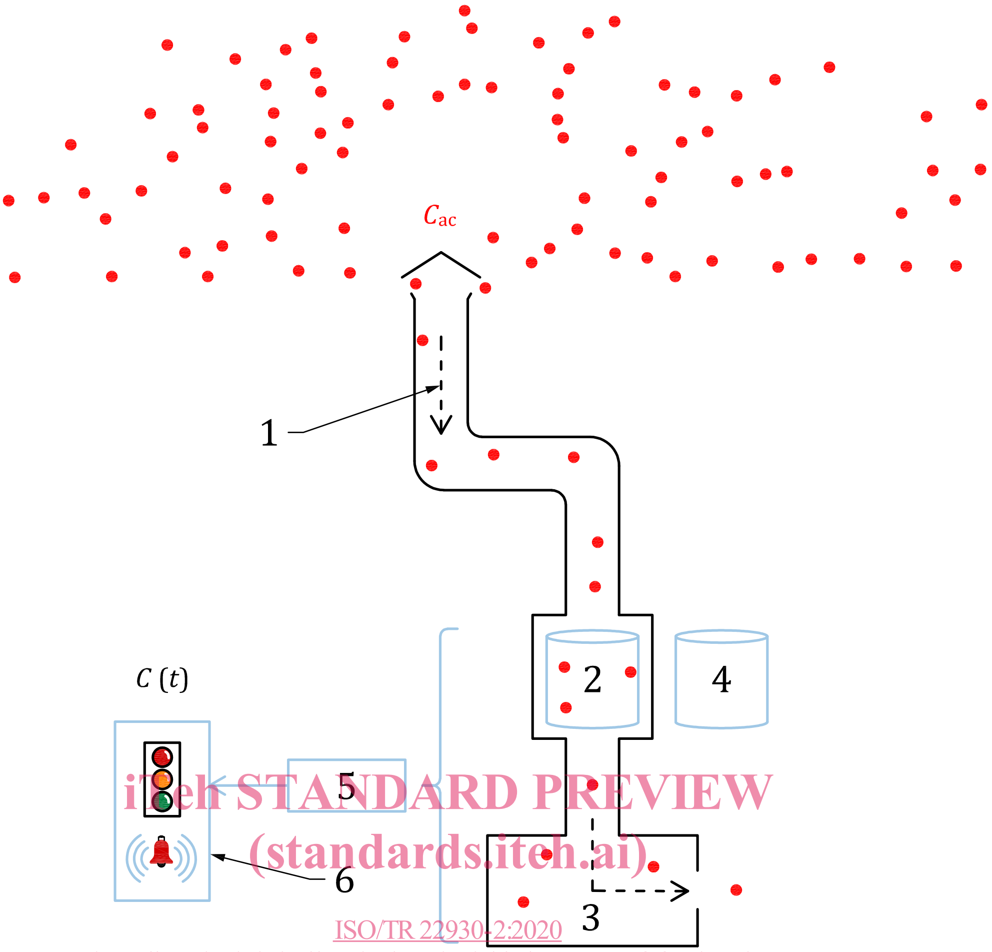
$a(t)$	Activity going through the detection volume at a time t, in Bq
c	Activity concentration, in Bq·m^{-3}
c_{ac}	Actual activity concentration, in Bq·m^{-3}
c^{*}	Decision threshold of the activity concentration, in Bq·m^{-3}
$c^{\#}$	Detection limit of the activity concentration, in Bq·m^{-3}
$c^{\triangleleft}$	Lower limit of the coverage interval of the activity concentration for a given probability (1−γ), in Bq·m^{-3}
$c^{\triangleright}$	Upper limit of the coverage interval of the activity concentration for a given probability (1−γ), in Bq·m^{-3}
$c(t)$	Activity concentration measured at a time t, in Bq·m^{-3}
$c_{\mathrm{ac}}(t)$	Actual activity concentration measured at a time t, in Bq·m^{-3}
c_{g}	Gross primary measurement of the activity concentration, in Bq·m^{-3}
$c_{\min}$	Minimum detectable activity concentration, in Bq·m^{-3}
$c_{\min}^{\triangleleft}$	Lower limit of the coverage interval of the minimum detectable activity concentration for a given probability (1−γ), in Bq·m^{-3}
$c_{\min}^{\triangleright}$	Upper limit of the coverage interval the minimum detectable activity concentration for a given probability (1−γ), in Bq·m^{-3}
$c_{0,i}$	Activity concentration of the i^{th} measurement of a series of gross measurements (with i = 1, ..., n) which represent a background situation, in Bq·m^{-3}
$\overline{c_0}$	Mean value of $c_{0,i}$, in Bq·m^{-3}

I_{min}	Minimum amount of current registered by the measuring detector (with $I_{min} = \frac{Q_{min}}{t_C}$ in A
$I_{min,cd}$	Minimum amount of current registered by the compensating detector (with $I_{min,cd} = \frac{Q_{min,cd}}{t_{C,cd}}$), in A
$I_g(t)$	Instantaneous gross current of the measuring detector at a time t, in A
$I_g(t,t_C), I_g$	Gross current during the counting time t_C of the measuring detector at a time t, in A
$I_{g,cd}(t)$	Instantaneous gross current of the compensating detector at a time t, in A
$I_{g,cd}(t,t_{C,cd}), I_{g,cd}$	Gross current during the counting time $t_{C,cd}$ of the compensating detector at a time t, in A
I_0	Background current of the measuring detector, in A
$I_{0,cd}$	Background current of the compensating detector, in A
K	Detection alarm setup parameter corresponding to the chosen acceptable false alarm rate level, dimensionless
k	Quantile of a standard normal distribution, if $k_{1-\alpha} = k_{1-\beta}$, dimensionless
$k_{1-\alpha}$	Quantile of a standard normal distribution for a probability (1−α), dimensionless
$k_{1-\beta}$	Quantile of a standard normal distribution for a probability (1−β), dimensionless
$k_{1-\frac{\gamma}{2}}$	Quantile of a standard normal distribution for a probability $\left(1-\frac{\gamma}{2}\right)$, dimensionless
N	Number of atoms on the media filter, dimensionless
$n_g(t,t_C)$	Gross count during the counting time t_C of the measuring detector at a time t, dimensionless
Q_{min}	Minimum amount of electric charge that induces a pulse registered by the measuring detector, in C
$Q_{min,cd}$	Minimum amount of electric charge that induces a pulse registered by the compensating detector, in C
q	Flow rate, in $m^3 \cdot s^{-1}$
$r_g(t)$	Instantaneous gross count rate of the measuring detector at a time t, in s^{-1}
$r_g(t,t_C), r_g$	Gross count rate during the counting time t_C of the measuring detector at a time t, in s^{-1}
$r_{g,cd}(t)$	Instantaneous gross count rate of the compensating detector at a time t, in s^{-1}
$r_{g,cd}(t,t_{C,cd}), r_{g,cd}$	Gross count rate during the counting time $t_{C,cd}$ of the compensating detector at a time t, in s^{-1}
r_0	Background count rate of the measuring detector, in s^{-1}
$r_{0,cd}$	Background count rate of the compensating detector, in s^{-1}
s_0	Standard deviation of the activity concentration at a series of i measurements which represent a background situation

t_C	Counting time of the measuring detector, in s
$t_{C,cd}$	Counting time of the compensating detector, in s
t_F	Duration of airborne release, in s
t_R	Response time, in s
t_{RI}	Intrinsic response time, in s
t_0	Counting time of the measuring detector for background measurement, in s
$t_{0,cd}$	Counting time of the compensating detector for background measurement, in s
$t_{1/2}$	Half-life, in s
V	Detection volume, in m^3
w	Calibration factor, in $Bq·m^{-3}·s$ or $Bq·m^{-3}·A^{-1}$
δ	Correction factor related to sampling (sampling point representativity, radioactive decay, ...), dimensionless
ε_D	Detector efficiency, in $Bq^{-1}·s^{-1}$ or $A·Bq^{-1}$
λ	Decay constant, in s^{-1}

5 Measuring principle

A representative sample of ambient air to be monitored containing an activity concentration $c_{ac}(t)$ at a time t is continuously captured through a transport line then goes through a detection volume without being retained. In parallel, a detector continuously measures the activity going through the detection volume. Then a processing algorithm calculates the activity concentration $c(t)$ and the suited alarms on the basis of the evolution of the activity going through the detection volume of air sampled and the installation or not of an ambient compensating detector. The processing algorithm can also, if necessary, take into account influence quantities which may perturb the measurement result (see Figure 1).



Key

1 transport line

2 detector

3 sampling pump

4 media filter

5 processing algorithm

6 alarm processing unit

Figure 1 — Model of the sampling and alarming

6 Study of dynamic behaviour

This clause describes the evolution over time of the activity concentration $c(t)$ during the sudden appearance of an actual activity concentration c_{ac}. The dynamic behaviour is quantified by the response time. The response time t_R is due to the intrinsic response time t_{RI} related to the measurement principle and its associated model of evaluation, the time delay provided by the counting time t_C of the activity going through the detection volume, the renewal rate of the detection volume and also the duration of the processing algorithm. This latter duration is not taken into account in this document but it should be kept in mind.

It is considered in the following that the actual concentration to be measured c_{ac} changes over time in steps of duration t_F:

$$c_{ac}(t)=c_{ac} \qquad \text{when } 0 \le t < t_F \qquad (1)$$

