METROLOGY ASSURANCE OF CONTAMAT FHT 111 M AND MICROCONT II SURFACE CONTAMINATION MONITORS

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Abstract: The report presents the methods for calibration of Contamat FHT 111 M and MicroCont II surface contamination monitors. The devices are part of the contamination measurement equipment in the organizational structures at Kozloduy NPP plc and State Enterprise for Radioactive Waste: Specialized Enterprise for Units 1-4 Decommissioning and State Enterprise for Radioactive Waste and they are used for both monitoring of the allowable levels and monitoring of the non-spreading of radioactive contamination - an important aspect of ensuring radiation protection and safe operation of the plant.

Key words: contamination monitor, metrology assurance, metrology, calibration.

1. Introduction

The measurement of ionizing radiation is performed in many areas of the production and monitoring activities carried out at Kozloduy NPP plc as the area of radiation protection is being of special importance for these measurements.

The calibration is an important activity in terms of metrology assurance when measuring alpha /beta activity. Calibration requires solid knowledge about the specifics of the measurement, its performance and result assessment. The calibration provides for qualitative assessment, which shows to what extend a certain objective is feasible with a given equipment when applying a specific measuring method.

The calibration is carried out by trained specialists who are well familiar with

- measurement equipment
- calibration methods
- applied software.

The calibration is carried out

- upon delivery of new equipment
- after repair of the equipment
- periodically in compliance with the working documents of the relevant organizational structures
- after unsatisfactory result of the check of basic error
- upon deviations from the requirements identified during external laboratory monitoring.

Contamat FHT 111 M and MicroCont II surface contamination monitors is equipment broadly used for radioactive contamination measurement. They are part of the radiation monitoring equipment at Kozloduy NPP plc, as well as the organizational structures of the State Enterprise for Radioactive Waste Management: Units 1-4 Decommissioning Department and RAW Department.

The Contamat FHT 111 M and MicroCont II surface contamination monitors are a portable measuring system with universal usage for detection of alpha, beta and gamma surface contamination. The main module is a measuring system with microprocessing control and LC display.

There is a software installed with several programme versions and level of access for different measurements. Depending on the level of access, different functions are allowed or limited.

The contamination monitor automatically stores the setting of the software version and selects it again after the device is switched on. The work with software via a PC requires a connector adapter which should be connected to the 8-pin coupling in the front of the monitor.

The CONTAMAT FHT 111 M and MicroCont II contamination monitors are characterized with a robust structure, high performance, suitability and easy to use. There are several detectors for the different types of measurements.

Detectors of CONTAMAT FHT 111 M type contamination monitors, window area 166 cm^2:

- argon - carbon dioxide flow-type counter
- butane-flow-type counters
- xenon counter.

Detectors for MicroCont II type contamination monitor:

- gas flow-type detector, window area 177 cm^2
- permanent gas filling detector , window area 232 cm^2
- plastic scintilator, window area 176 cm^2

Methods for metrology check and calibration are developed for metrology support of these contamination monitors at Ionizing Radiation

Measurement Laboratory of Kozloduy NPP plc.

The methods for metrology check provides for the conditions, methods, and equipment used for metrology check and processing of results.

The calibration methods define the conditions, equipment, procedures and processing of the results used for calibration of the portable CONTAMAT FHT 111 M and MicroCont II monitors for apha and beta surface contamination .

The metrology support provides for accurate and reliable measurements with equipment used in different organizational strictures at Kozloduy NPP plc , which perform monitoring of non-fixed surface contamination of the rooms, items and equipment in the controlled area (CA).

The proper calibration is a prerequisite for proper assessment of activity.

This report provides for calibration methods of contamination monitors.

2. Calibration method

The principles described in the international standards and good international practice are applied to equipment calibration.

The measurement efficiency of the measuring equipment (ε), which is the relation between the net number of the recorded impulses per unit of time to the particle emission rate or activity of the reference radioactive sources (RAS), as well as its uncertainty and minimum detectable activity are defined in the process of calibration. The calibration method is determination of the relation between the readings of the measuring equipment and values of the quantity generated by the reference radioactive sources. The measurements are performed according to the direct measurement method.

3. Requirements to the used sources

The CONTAMAT FHT 111 M and MicroCont II type contamination monitors are calibrated with wide-area reference radioactive sources having the active area 100 cm^2.

When calibrating the contamination monitors with alpha emitters, the calibration is performed with source with 241Am or 23Pu nuclide.

For calibration of surface contamination monitors with beta emitters, sources with the following nuclides are used:

^{60}Co (E_{max} = 0,318 MeV)
^{137}Cs (E_{max} =0,510 MeV)
^{36}Cl (E_{max} = 0,714 MeV)
^{204}Tl (E_{max} = 0,770 MeV)
^{90}Sr/^{90}Y (E_{maxSr} = 0,51 MeV, E_{maxY} = 2,26MeV).

For the needs of radiation monitoring, Kozloduy NPP plc uses the nuclides of ^{241}Am, ^{60}Co and ^{137}Cs.

The characteristics of the used wide-area reference radioactive sources should be in compliance with the recommendations of ISO 8769/1988 "Reference sources for the calibration of surface contamination monitors – Beta-emitters (maximum beta energy greater than 0,15 MeV) and alpha-emitters", [1].

4. Preparation for calibration

Before calibration, it is necessary to check the operating parameters of contamination monitor. The check is performed in compliance with the technical documentation of the device and in accordance with УК.МО.МТ.810 "Methods for metrology check of Contamat FHT 111 M type surface contamination monitor, [2].

The compliance with the environmental requirements is checked.

Calibration performance

The calibration operations for each of the measurement parameters are as follows:

- background measurement
- measurement of reference radioactive sources
- determination of the measurement efficiency
- calculation of the calibration factor
- evaluation of the expanded uncertainty of measurement efficiency
- determination of the detection level and minimum detectable activity, which allows to assess the suitability of the equipment and selected measurement conditions
- determination of the range of allowable values of the equipment background
- connection of the calibration results to the indications of reference radioactive source.

5.1. Measurement performance

A series of m measurements of the count rate n_b of the background impulses, whereas $m \geq 10$ is carried out.

A series of m measurements of the count rate n is carried out, whereas $m \geq 10$, with reference radioactive source in compliance with the repeatability of measurement parameter.

For the needs of radiation monitoring at Kozloduy NPP plc, it is recommended that the distance between the active surface of the source and the protective shield of the input window of detection unit is h = 2 mm for alpha emitters and h = 10 mm for beta emitters.

5.2. Processing of the calibration results

The mathematical model of the function defining the efficiency of the device ε, which provides for the relation between the response of the measuring device and the M_{rs} value set by the reference radioactive source is as follows:

$$\varepsilon = \frac{n_0}{M_{rs}} f_h f_\xi f_\eta$$

whereas

n_0 - net count rate , [s^{-1}];

M_{rs} – value of the parameter set by the reference radioactive sources according to the radioactive source certificate measured by the time of measurement, [s^{-1}] or [Bq] depending on the calibration target

f_h – correction factor taking into account the repeatability of the measurement parameter (distance between the reference radioactive source and detector)

f_ξ – correction factor taking into consideration the non-linearity of measurement within the measuring range

f_η – correction factor taking into consideration the uniformity of the detector unit.

The correction factors in the model function reflect the quantities which do no have impact on the determination of efficiency but do have impact on its uncertainty and is considered as equal to 1.

Depending on the requirements of the user, the calibration can be performed compared to the external radiation and /or activity of the reference radioactive source.

The efficiency to external radiation of reference radioactive sources is evaluated as:

$$\varepsilon_{2\pi} = \frac{n_0}{q_{2\pi}}, \text{ [s}^{-1}\text{/s}^{-1}\text{]}$$

The efficiency to the activity of reference radioactive source is evaluated as:

$$\varepsilon_A = \frac{n_0}{A} \quad \text{[s}^{-1}\text{/Bq]},$$

whereas

$q_{2\pi}$ и A are the evaluated values of the quantity set by the reference radioactive source:

$$q_{2\pi} = q_{2\pi,0} \cdot \exp(-\text{h } 2\frac{\Delta t}{T_{1/2}}), \text{ [s}^{-1}\text{]}$$

$$A = A_0 \cdot \exp(-\ln 2\frac{\Delta t}{T_{1/2}}), \text{ [Bq]}$$

$q_{2\pi}$ and A_0 are the values of the parameter set by the reference radiative sources as of the reference date according to the certificate of the reference radioactive source

- Δt is the period of time between the reference date and moment of measurement

- $T_{1/2}$ is the half-life period of the radionuclide used during calibration.

5.3. Assessment of the inputs

- of background count rate:

$$\bar{n}_b = \frac{\sum_{j=1}^{m} n_{b,j}}{m}, \text{ [s}^{-1}\text{]}$$

- of count rate of the reference source

$$\bar{n} = \frac{\sum_{j=1}^{m} n_j}{m}, \text{ [s}^{-1}\text{]}$$

- of net count rate:

$$n_0 = \bar{n} - \bar{n}_b, \text{ [s}^{-1}\text{]}$$

5.4. Root square uncertainty of the input quantities

5.4.1. Relative uncertainty of the measurement $\delta(n_0)$, [%]

$$\delta(n_0) = \frac{\sigma(n_0)}{n_0}.100 = \frac{\sqrt{\sigma^2(\bar{n}) + \sigma^2(\bar{n}_b)}}{\bar{n} - \bar{n}_b}.100,$$

whereas

- $\sigma(\bar{n}_b) = SD(\bar{n}_b) = \sqrt{\frac{\sum_{j=1}^{m}(n_{b,j} - \bar{n}_b)^2}{m(m-1)}}$, [s^{-1}] (contribution of the background count rate)

$\sigma(\bar{n}) = SD(\bar{n}) = \sqrt{\frac{\sum_{j=1}^{m}(n_j - \bar{n})^2}{m(m-1)}}$, [s^{-1}], (contribution of the reference radiation source count rate), from which the net count rate contribution is obtained.

$$\sigma(n_0) = \sqrt{\sigma^2(\bar{n}) + \sigma^2(\bar{n}_b)}$$

5.4.2. The relative uncertainty of the value of the parameter set by the reference radioactive source (particle emission rate from the surface of the reference radioactive source or activity):

$$\delta(q_{2\pi}) = \frac{U_{M_{rs}}}{k}, [\%],$$

whereas

$U_{M_{rs}}$ - expanded uncertainty indicated in the calibration certificate of the reference radioactive source

k - coverage factor taken from the calibration certificate of the reference radioactive source

5.4.3. Relative uncertainty of non-linearity:

$$\delta(\xi) = \frac{\xi}{2\sqrt{3}} \ [\%],$$

whereas

ξ – non-linearity within the measuring range defined during the check.

5.4.4. The relative uncertainty of the distance between the surface of the reference radioactive source and the window area of the device - for the needs of the current methods, the values indicated in the table are used:

h	mm	1 ± 1	2 ± 1	3 ± 1	5 ± 1	10 ± 1
$\delta(h)$, %	^{241}Am	5.1	5.2	5.4	6.0	8.6
	^{60}Co	2.4	2.5	2.5	2.7	3.1

5.4.5. Relative uncertainty of the uniformity of detector unit

$$\delta(\eta) = \frac{SD(\overline{n}_\eta)}{\overline{n}_\eta}.100 \ [\%],$$

whereas

$\overline{n}_\eta$ - average value of the count rate measured with a source with window area of 1 cm^2 per 24 (6 x 4) and non-overlapping similar sections

$SD(\overline{n}_\eta)$ – root square deviation of the average value $\overline{n}_\eta$.

The contributions of the inputs to the uncertainties of the measurement are defined as:

$$u_i(\varepsilon) = c_i.\delta(x_i)/div,$$

whereas

c_i - sensitivity factors taking into account the contribution of the uncertainty of each of the inputs, as for the functional dependence in the model of the efficiency of their values is accepted for $c_i = |1|$;

δ(x_i) – relative standard uncertainty of the i-th input parameter;

div – parameters whose value depends on the type of the distribution and selected confidence interval

i=(1, 2, 3,…, N) - a sequence number of the input.

5.5. Combined and expanded uncertainty

The combined relative uncertainty of the measurement is defined as follows:

$$u(\varepsilon) = \sqrt{u^2(n_0) + u^2(M_{rs}) + u^2(h) + u^2(\xi) + u^2(\eta)},$$

whereas

$u^2(n_o)$, $u^2(M_{rs})$, $u^2(h)$, $u^2(\xi)$, $u^2(\eta)$ are reassessed contributions of the inputs n_o, $M_{rs}(q_{2\pi}$ *or* $q_A)$, f_h, f_ξ и f_η.

The expanded uncertainty of the efficiency ε of measuring device is calculated according to the formula:

$$U(\varepsilon) = k \cdot \varepsilon \cdot u(\varepsilon)$$

k = 2 - coverage factor (for normal distribution of the measurement parameter and confidence interval probability of about 95 %).

Processing of the calibration results is performed according to the requirements of Manual EA-4/02 Evaluation of the Uncertainty of Measurement in Calibration, [3].

The calibration results are defined in the calibration report and calibration certificate in compliance with the requirements of BDS EN ISO/IEC 17025 General requirements for the competence of testing and calibration laboratories, [4].

6. Detection level and minimum detectable activity

The detection level provides for assessment of the specific measurement conditions, minimum background count rate for which with a certain confidence probability can be claimed that there is activity.

The detection level is defined as

$$L_d = \frac{k^2}{t} + 2L_c \ [s^{-1}],$$

whereas

$$L_c = k \cdot \sqrt{\frac{\overline{n}_b}{T} + \frac{\overline{n}_b}{t}}, [s^{-1}]$$

L_c - critical level

n_b - background count rate, [s^{-1}]

t – surface contamination measurement time, [s]

T – background measurement time, [s]

k = 1,645 - one–sided confidence intervals factor

Minimum detectable rate of particle emission is calculated as:

$$DL = \frac{L_d}{\varepsilon_{2\pi}}, \text{ [s}^{-1}\text{]}$$

minimum detectable activity is calculated as:

$$MDA = \frac{L_d}{\varepsilon_A} \text{ [Bq]},$$

whereas

$\varepsilon_{2\pi}$ and ε_A - efficiency of the measuring device for the given radionuclide.

7. Identification of the interval of allowable values of the reference parameters

For the needs of the internal laboratory monitoring when calibrating, the allowable values of the new reference parameters for pre-defined conditions are determined.

The stability of the equipment performance is controlled with the internal laboratory monitoring. The monitoring covers the parameters and processes which directly influence the measurement result:

– equipment background

– repeatability of the efficiency with reference source.

The reference source is stored by the relevant plant organizational structure. The source may be different from the one used for calibration of the device and it is not necessary to be certified.

8. Conclusion

The presented methodology for calibration of portable CONTAMAT FHT 111M and MicroCont II contamination monitors for alpha and beta surface contamination measurements is developed in compliance with the requirements of the international regulations.

It is designed to comply with the requirements for providing traceability of the measurement results when calibrating the alpha and beta surface contamination equipment.

9. Reference

[1] International Standard ISO 8769/1988 “Reference sources for the calibration of surface contamination monitors – Beta-emmiters (maximum beta energy greater than 0,15 MeV) and alpha-emitters”

[2] УК.МО.МТ.810 Methods for metrology check of Contamat FHT 111 surface contamination monitor

[3] EA-4/02 Evaluation of the Uncertainty of Measurement in Calibration

[4] BDS EN ISO/IEC 17025 General requirements for the competence of testing and calibration laboratories

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