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SAFETY GUIDE IN THE USE OF ATOMIC ENERGY

"RECOMMENDATIONS ON ACCOUNTING OF NUCLEAR MATERIALS DURING THEIR PHYSICAL INVENTORY IN MATERIAL BALANCE AREAS AND ANALYSIS OF ITS RESULTS"

(RB-065-17)

I. General

1. The safety guide in the use of atomic energy "Recommendations for accounting of nuclear materials during their physical inventory in the material balance areas and analysis of its results" (RB-065-17) (hereinafter referred to as the Safety Guide) haы been developed in compliance with Article 6 of the Federal law No. 170-FZ dated November 21, 1995 "On Atomic Energy Use" for promoting compliance with the requirements of the items 14, 53, 55 - 60, 65, 68 - 70 of the Federal Rules and Regulations in the field of atomic energy use "The Basic Rules on nuclear materials record and control" (NP-030-12) approved by the order of the Federal Environmental, Industrial and Nuclear Supervision Service No. 255 dated April 17, 2012 (registered by the Ministry of Justice of the Russian Federation on August 17, 2012, registration No. 25210 (hereinafter the Basic Rules).

2. This Safety Guide contain the Rostekhnadzor recommendations for accounting of nuclear materials (hereinafter NM) in their physical inventory (hereinafter PI) in the material balance area (MBA) and analysis of its results.

3. This Safety Guide shall be applicable to the activity of personnel in PI of NM in MBA for assuring state record and control of NM at the organizations handling NM.

4. Any other techniques (methods) different from the ones specified in this Safety Guide may be used for compliance with the requirements of the Basic Rules subject to substantiation of the selected techniques (methods) for safety assurance.

II. Recommendations for nuclear materials accounting in the material balance areas

5. In accordance with item 56 of the Basic Rules PI shall be completed by accounting for each NM in the MBA within the material balance inventory period (hereinafter MBIP), determination of the inventory difference (hereinafter ID) and its accuracy with subsequent statistical analysis of the ID significance in accordance with the criteria established in item 69 and 70 of these Basic Rules.

6. The source documents in PI of NM and NM accounting is the physical inventory list (hereinafter PIL) of NM. It shall be made after the termination of any transformations of NM in the MBA (except the areas of separation and radiochemical plants, using continuous technology of NM processing) or NM displacements, including their shipment and receipt.

If NM at the start of PI is in the MBA, the integrity of accounting data thereof cannot be confirmed by the given access control means (hereinafter the ACM) to NM, condition monitoring of inventory items (hereinafter II) and/or confirmatory measurements with the exclusion of NM with respect thereof the use of calculation methods is allowed, then inventory measurements of such NM shall be made before the start of performance of the basic PI procedures, enter the obtained data in PIL and start PI taking.

7. The accounting data of all NM registered in the books at the MBA shall be included on the start date of PI of NM independent of their belonging, including NM received from other MBA or organizations and held in safe custody, and NM remaining in the work in progress.

Accounting data of NM at the time of PI of NM in the work in progress shall be entered in PIL based on the accounting measurement results, if impossible based on the calculations in accordance with the procedures applicable at the organization.

8. Accounting data of NM transferred to other organizations or MBA for which at the time of PIL formation confirmation of their receipt was not received by the receiver and recording in its MBA shall be included in PIL by a separate section. In addition, the dates of transfer, number and other data of the supporting documents and invoices in compliance thereof the NM were transferred shall be specified.

9. Data for each element, isotope accounted in MBA shall be grouped document-wise by the types of NM, strata (groups of individual IE or lots with same or close in the manufacturing tolerance limits physical, chemical characteristics and isotopic compositions), package lots specifying the location of each II and present to the inventory committee in the form convenient for comparing the actual and accounting data.

10. At the initial stage of PI taking make sure of the conformity of ACM data and data of accounting documents. The following shall be used for verifying such conformity:

physical inventory list (hereinafter PIL) of NM for this MBA of the preceding PI;

all reports on changes in inventory quantity (hereinafter RCIQ) of NM in this MBA for MBIP;

set of accounting documents.

Moreover, verification shall be made of the correctness of documentary recorded accounting data first on the basis of PIL data of preceding PI taking and all changes taking place for MBIP and recorded in RCIQ and then the conformance of PIL data to the document-wise recorded accounting data shall be determined.

11. Information on physical inventory of NM in MBA during PI taking shall be obtained based on:

results of accounting and confirmatory measurements;

verification results of the conformance of identification characteristics of II to data given in the accounting documents;

results of application of ACM to NM;

results of use of the calculation methods;

data in the data sheets, forms, acts, protocols and other information media for the connections, mixtures, alloys and products, inventory items, containing NM, and NM in the form of simple substances (hereinafter the products).

12. Scope of confirmatory measurements of those NM which during MBP and during PI were not subject to transformations and accounting measurements, and consistency of the results of previous accounting measurements was provided by application of ACM, is determined based on the scope of application of AM to NM and results of monitoring their state, state of II and probabilities of detecting shortage (excess) of threshold quantity for each NM, stipulated for them in Appendix No. 8 and item 70 of the Basic Rules.

13. In calculating the scope of sampling for the confirmatory measurements only different types of ACM applied to NM (for example, seals and surveillance systems) shall be considered, for which documentary recorded results of verifications confirming the absence of unauthorized access to NM for MBIP is available. For example, two seals on the container with NM or seal on the safe in which the container with NM is located also under seal shall be considered as ACM of one type.

14. If several types of ACM are applied to NM, then for possibility of accounting each of them in determining the scope of sampling for the confirmatory measurements of each shall be verified with documentary record of the results.

The video surveillance system may be considered as ACM only if they provide regular record of the events taking place and the documentation procedure of the results of their application is stipulated.

If the product contains several NM (for example, uranium and plutonium), the sampling size shall be determined for each NM and established based on the larger value.

The recommendations for determining the scope of random sampling of NM II for confirmatory measurements are given in Appendix No. 1 to this Safety Guide.

15. All ACM to NM shall be verified for detecting the facts of unauthorized access to NM in PI taking of NM. The condition of seals shall be checked, state and data of other ACM analyzed including the video surveillance systems, if they are installed at the places of NM handling.

If II design, which does not allow removing the NM without breach of its integrity, is used as one of the types of ACM to NM at the organization, then during PI of NM instrument or visual inspection shall be made of the integrity of II design and documentary record of its results provided.

16. In those cases when the consistency of the values of NM mass determined earlier was confirmed by ACM to NM, and by visual inspection of the II state and/or by confirmatory measurements, these values may be used as accounting data in PI of NM.

17. If the results of inspection of ACM does not allow confirm the absence of unauthorized access to NM or indicate that unauthorized access to NM had taken place, then for these II confirmatory measurement shall be performed, and in the event of statistically significant difference accounting measurements shall be performed.

Statistically significant difference between the results of accounting and confirmatory measurements for the quantitative parameters of nuclear materials, inventory items and products shall be defined with the confidence probability of 0.99.

18. Preliminary reconciliation check of the of attributive indicators shall be performed for II with respect thereof it is required to perform confirmatory measurements.

identifier (numbe);

location (room, rack, place, cell number);

integrity of seals and their identification;

integrity.

The type of confirmatory measurements shall be determined in the regulatory documents of the organization considering the existing engineering and technology options at the organization.

19. The inclusion of II in the scope of sampling in the confirmatory measurements shall be made from the numbered list of verified II of each stratum for specific attributive indicators of II in random order by any known or available method in PI taking. Besides, II transferred to other organizations or MBA for which at the time of PIL formation confirmation of their receipt was not received by the receiver and recording in its MBA shall not be included in such a numbered list.

20. In analysis of the results of PI for detection of anomalies in the accounting and monitoring of NM, which were not subject to transformations and accounting measurements in MBIP special attention shall be paid to actual and documented quantity of II, availability or non-availability of the facts of unauthorized access to NM, divergence value of the results of accounting and confirmatory measurements of NM.

At confidence coefficient 0.99 the allowed divergence value of the results of accounting and confirmatory measurements of NM shall be established within the following limits: .

21, The following shall be specified in making PIL along with the fulfilment of the requirements of item 83 of the Basic Rules and Recommendations of item 9 of this Safety Guide for each II in the lot:

serial number of II;

product designation;

identification number of II;

seal number on II;

gross weight of II;

weight of NM;

tracking number of document (data sheet, history file).

Moreover, based on the documents on transfer of NM to PIL the accounting data of NM transferred to other organizations or MBA for which at the time of forming PIL the confirmation of their receipt by the receiver and recording in its MBA was not received shall be presented in PIL by a separate section.

22. If during verification of ACM for NM and performance of random confirmatory measurements of the accounting parameters (characteristics) NM, II, occurrence products have not been detected, then the accounting parameters (characteristics) of NM, products determined earlier shall be entered in PIL for each II.

In case of detection of any statistically significant discrepancy between the results of accounting and confirmatory measurements, and (or) any violation of integrity of seals and ACMs, including those applied for the purpose of physical protection of premises, where RM is handled, in accordance with the item 60 of the Basic Rules the reasons of occurrence of such discrepancy or violation shall be found out. If shortage (excess) is detected new accounting measurements are made, alterations are made to the accounting documents and new reporting documents are prepared.

III. Recommendations for analysis of nuclear materials accounting results in the material balance areas

23. In conformance with the item 56 of the Basic Rules the PI taking of NM shall be completed by accounting the NM in MBA, which is based on the conformance determination of the physical inventory of NM in MBA established following this PI taking of NM and documented quantity of NM in MBA at the start of PI taking of NM (end of this MBA).

The inventory difference (hereinafter ID) for the total quantity of each NM accounted in the MBA shall be calculated using the equation:

ID = AQ - DQ = AQ - (IQ+INC - DEC),

where AQ is the actual available quantity of nuclear materials in the MBA determined following this physical inventory taking;

DQ is the documented quantity of nuclear materials in the MBA as of the beginning of the physical inventory taking (the end of this MBP);

INC is the documented increase of nuclear material quantity in the MBA for this MBP due to all supplies and production;

DEC is the documented decrease of nuclear material quantity in the MBA for this MBP due to all shipments from the MBA, nuclear transformations and losses;

IQ is the documented quantity of nuclear materials in the MBA as of the beginning of this MBP.

If accounting measurements of NM were not performed in MBA or in the PI process, then ID = 0.

24. In performing PI of NM in the form of II, the detection of the following confirmed by investigations shall be confirmed an anomaly in the accounting and monitoring of NM:

shortages, or excess of II;

divergence of the values of actually available NM quantity and data of accounting documents exceeding the stipulated limits including that determined based on statistically significant divergence between the results of accounting and/or confirmatory measurements of the quantitative parameters of NM, II, products;

ID module exceeding the stipulated quantities;

25. In calculating the accuracy of ID  the "accuracy transfer method" shall be used, when  is calculated based on the errors of accounting measurements of the balance equation sums, or other existing methods, for example, the method based on the statistical analysis of the ID values observed earlier.

ID and NM with which accounting measurements were made in MBIP or in PI shall be assessed in accordance with the procedure given in Appendix No. 2 to this Safety Guide.

26. The analysis of the results of PI for detection of anomalies in the accounting and monitoring of NM, transformed and subject to accounting measurements in MBP shall be based on the comparison of the ID module value obtained when solving the balance equation for each of the NM with values NM masses stipulated by the item 69 of the Basic Rules.

An example of the ID analysis following PI of NM in MBA for detection of anomaly in the accounting and control NM and threshold NM quantities of the main considered nomenclature used when taking decision on availability or absence of anomaly in the accounting and control of NM are presented in Appendix No. 3 to this Safety Guide.

The method based on determination and analysis of the cumulative (accumulated) amount of ID for several MBA shall be used for verifying the assumptions on potential availability of anomaly in the accounting and monitoring of NM in the form of systematic losses of NM for several MBP. An example of application of this method is given in Appendix No 4 to this Safety Guide.

27. The recommended diagram of NM accounting algorithm in PI taking at MBA of the organizations not having continuous generation, and analysis of its results is presented in Appendix No. 5 to this Safety Guide.

Appendix No. 1
to the safety guide in the use of atomic energy "Recommendations for accounting nuclear materials in their physical inventory taking in the material balance areas and analysis of its results" approved by the Order of the Federal Environmental, Industrial and Nuclear Supervision Service No. \_\_\_
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RECOMMENDATIONS
FOR DETERMINING THE SCOPE OF RANDOM SAMPLING OF INVENTORY ITEMS OF NUCLEAR MATERIALS FOR CONFIRMATORY MEASUREMENTS

The II sampling scope is given by two quantities: the threshold of nuclear material quantity in mass units (G) and probability of detecting a shortage/excess of the threshold of nuclear material quantity in the unit (P). These quantities are determined based on item 70 and Appendix 8 of the Basic Rules.

The sampling scope (n) shall be calculated using the formula:

n = [N (1 - (1 - P)1/[G/x])]+

where []+ - round-off to the nearest greater integer;

N - number II in the stratum;

G/x is the rated number of II having unacceptable mass deviation of NM, at least one of them shall be subject to detection with the given probability;

x - mean mass of this NM in one II of this stratum;

G - threshold quantity of NM for detection of shortage or excess in confirmatory measurements:

3 kg - Plutonium, Uranium-233 for NM of categories 1, 2 and 3;

8 kg - Uranium-235 for NM of categories 1, 2 and 3;

70 kg - Uranium-235 for low enriched uranium (hereinafter LEU) (category 4).

In case the NM mass in the MBA is below the above-mentioned value the threshold quantity shall be equal to 30% of this NM mass in the MBA.

For other nuclear materials the threshold quantity shall be 5% of the documented available quantity of this nuclear material in the MBA at the time of physical inventory taking.

The detection probability of shortage or excess quantity of NM (G) in the confirmatory measurements (P) shall be determined based on the application scope of ACM to NM.

Table 1

Probability of detection of shortage or surplus of the threshold NM quantity

|  |  |
| --- | --- |
| Scope of ACM application to the NM | Detection probability at least |
| For categories 1, 2, 3 | For category 4 |
| Only seals for II | 0.5 | 0.3 |
| Only NM surveillance system <1>  | 0.5 | 0.3 |
| Seals and one ACM of other type | 0.25 | 0.09 |
| Seals and simultaneously (n-1) different ACMs | (0.5)n | (0.3)n |

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<1> The surveillance system shall include:

automated technical systems, devices (displays for control of NM movement, access of the personnel to the rooms, door and manhole opening control sensors, emergency alarm devices);

engineering systems and devices for television or photographic surveillance with recording of occurring events.

Example of inventory item sample volume calculation

Let's assume that there are three NM strata in MBA and each strata contains 1000 inventory items. The first and second strata are represented by the same II in the form of lumps containing highly-enriched uranium metal (hereinafter HEU) in aluminum cladding. Inventory items in the form of similar lumps containing low enriched uranium (hereinafter LEU) metal shall be segregated in the third stratum. Uranium-235 isotope 1000 g each is present in each II containing HEU and LEU. Let II of all the strata in this MBIP were not used and accounting measurements were not made. Moreover II of all the strata in the given MBIP were in sealed tubes, but only second and third strata II were under video surveillance from the time of the previous PI of NM. Integrity verification of II and ACM state confirmed that there was no unauthorized access to II and the verification results were documented. Based on this and in accordance with the table 1 the probability of detection of shortage (excess) of the threshold quantity of NM for the first stratum is taken as equal to 0.5, and for the second and third strata in the assumption that NM of these strata were still under video surveillance is taken as equal to 0.25.

Ratio G/x for the first and second strata is 8000 / 1000 = 8, and for the third strata is 70000 / 1000 = 70.

Substituting the available input data in the expression for determining the sample size for the first strata, we get:

n1 = 1000 [1 - (1 - 0.5)1000/8000] = 1000 [1 - (0.5)1/8] = 1000 · 0.0830 = 83.0.

For the second stratum:

n2 = 1000 [1 - (1 - 0.25)1000/8000] = 1000 [1 - (0.75)1/8] = 1000 · 0.0353 = 35.3, but by rounding off n2 to the nearest higher integer, we get n2 = 36.0.

For the third stratum:

n3 = 1000 [1 - (1 - 0.25)1000/70000] = 1000 [1 - (0.75)1/70] = 1000 · 0.0041 = 4.1, but by rounding off n3 to the nearest higher integer, we get n3 = 5.0.

Thus, shall be measured in total:

83 + 36 + 5 = 124 II.

Appendix No. 2
to the safety guide in the use of atomic energy "Recommendations for accounting nuclear materials in their physical inventory taking in the material balance areas and analysis of its results" approved by the Order of the Federal Environmental, Industrial and Nuclear Supervision Service No. \_\_\_
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ESTIMATION OF
STATISTICAL SIGNIFICANCE OF INVENTORY DIFFERENCE AND ITS STANDARD ERROR

The expression determining ID for each j-th NM contained in each p-th product and subject to record and control may be presented in the form of sums of mass mji with signs sign(mji):

, (1)

where mji - i-th mass of j-th NM in the components of the balance equation.

n -  number of i-th mass of j-th NM in the components of the balance equation.

The sign sign(mji) in the equation shall imply the following: when the mass is related to the balance component of AQ or DEC - minus sign.

In this case the weight mji in each p-th product of weight Мp is determined based on the results of measurements of the weight of product, concentration Сj (mass fraction) of NM in the product of mass Мp in accordance with the expression:

mji = Мp · Сj. (2)

For example, mass of isotope mU235 in each product containing it p is determined by calculations following measurements of the product weight Мp, mass fraction of uranium СU in the product, mass fraction of EU235 isotope U235 in uranium

mU235 = Мp · СU · ЕU235.

Error in determining the mass of isotope U235 in this case shall be composed of the relative measurement errors of the product weight Мp, mass fraction of uranium СU in the product, mass fraction of isotope U235 in uranium ЕU235:

,

where ,  and  are relative measurement errors which are composed of their relative random and systematic components:





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Besides, if  is taken as multiplicative measurement error (error changing together with the change of values of the quantity subject to measurements), assuming that each of n weights of NM included in the NM balance equation is subject to the measurements, the method of measurement error transfer of each of these n weight of NM is used considering the random and systematic components of the errors and potential correlations of the measurement errors of NM.

The standard error deviation of the inventory difference  in the mass units is determined as the root of inventory difference dispersion: .

When the measurements of all the masses included in the expression (1) have been executed only in sole scales (for example, during operation in MBA with thorium metal), dispersion  is determined by the expression:

. (3)

In this case the sole source of uncertainty of measurements is the scales, in the formula (3) characterized by random component of measurement accuracy  and not excluded by the systematic component of measurement accuracy  in relative units. In addition the characteristics of the device errors and measurement procedures (hereinafter MP) may differ. For example, if MP requires n-times repetition of measurements, the random component of measurement accuracy for this MP shall be root of n times less the corresponding device error.

If the number of sources of uncertainties is more than one and equal to K, then  is determined by the sum:

, (4)

where ;

.

The amount is taken for all the sources of uncertainties (errors) of MP and measuring instruments (or other determinations) of the product volume (weight) (for example several level detectors and scales), concentration of NM in the product (several MP of measurements), mass fraction of isotope U235 in uranium, if required.

Contribution coefficient in  from random accuracy component of each device for measurement of any characteristics of NM shall be determined by the sum of squares of only those weights, which were subject to measurements by this device or for this MP.

The systematic component of accuracy of the same device (MP) not excluded  is determined not by the sum of squares of weights, but by the square of the sum of the same weight with their signs.

Example of the assessment inventory difference and its accuracy

1. Accepted task conditions

Three containers with net weight of product with NM in each of them 16 kg each, measured concentration of U - 95% and mass fraction U235, equal to 40%. During MBIP the product in these containers was transformed and subject to accounting measurements in the current PI taking period. Besides it was established that the net weight of the product with NM with measured concentration of U equal to 98% and mass fraction of U235 equal to 40% in each contains constitutes 15%.

During MBIP another 20 containers were received at MBA. The net weight of the product with NM in each container on an average is 18.5 kg, measured concentration of U is 98%, and the mass fraction of U235 is equal to 65%.

All the products received at the MBA were reprocessed before the end of MBIP and 8 containers of processed products with net weight with NM in each container is 65 kg, measured concentration of U is 67.6% and mass fraction of U235 equal to 67% were sent to another organization.

The wastes generated in using the products both in the MBA before the start of MBIP ad received in the MBIP at MBA were sent from the MBA in 2 containers for further processing. The net weight of the product with NM in each container is 25 kg, measured concentration of U is 20%, and the mass fraction of U235 is equal to 1%.

Accounting measurement of NM were performed in MBA in the products received, reproccessed and dispatched from the MBA.

It is required to find ID and  for U, U235 considering that the measurements had three sources of uncertainty (weights, procedure for determination of U in the product and device for measurements of the mass fractions of U235 in uranium), recalibration of the scales and laboratory methods were not performed, chemical analysis was performed for each container, and the multiplicative mathematical of measurement accuracy was used in determining the weight and concentrations of NM.

2. Calculation ID

ID is determined in accordance with the balance equation (1).

Data for determining the balance equation components for U and U235 may be obtained based on data on the product nett weight, on the measured mass fraction of U in the product, on mass fraction of U235 in U and the expression (2) for calculation of mass U, U235.

Based on the above specified condition on availability of only three containers (n = 3) in the MBA at the start of PI taking, in which following accounting measurements in each of them product with NM of nett weight Mp = 15 kg, measured mass fraction U in the product equal to 98% and mass fraction of U235 in U equal to 40% is present, the actual quantity of U (hereinafter - AQU) and U235 (hereinafter - AQU235) in MBA may be calculated in accordance with the expressions mji = Mp · Cj and  respectively.

Thus:

AQU = naqmU = 3 (15 · 0.98) = 44.1 kg;

AQU235 = naqmU235 = 3 (15 · 0.98 · 0.4) = 17.64 kg.

The quantity of U and U235, which was in MBA at the start of MBIP (hereinafter - IQU and IQU235 respectively), is determined by the availability of three containers (niq = 3) with net weight of product with NM in each of them Mp = 16 kg. The measured mass fraction of U in the product is equal to 95%, and the mass fraction of U235 in U is equal to 40%. Then, in accordance with the specified:

IQU = niqmU = 3 (16 · 0,95) = 45.6 kg;

IQU235 = niqmU235 = 3 (16 · 0.95 · 0.4) = 18.24 kg.

Increase of the quantity of U and U235 in MBA and MBP (hereinafter - INCU and INCU235 respectively) is determined by the receipt of 20 containers (ninc = 20) with net weight of product with NM in each of them Mp = 18.5 kg. In this case, the measured mass fraction of U in the product is equal to 98%, and the mass fraction of U235 in U is equal to 65%. Then, in accordance with the specified:

INCU = nincmU = 20 (18.5 · 0.98) = 362.6 kg;

УВU235= nincmU235 = 20 (18.5 · 0.98 · 0.65) = 235.69 kg.

Decrease of the quantity of U and U235 in MBA in MBIP (hereinafter - DECU and DECU235 respectively) is determined by shipment of 8 containers (ndec1 = 8) with net weight of product with NM in each of the them Mp = 65 kg and х two containers (ndec2 = 2) with wastes of net weight in each of them Mp = 25 kg. In this case, the measured mass fraction of U in the product is equal to 20%, and the mass fraction of U235 in U is equal to 1%. Then, in accordance with the specified:

DECU = ndec1mU + ndec2mU = 8 (65 · 0.676) + 2 (25 · 0.2) = 361.52 kg;

DECU235 = ndc1mU235 + ndc2mU235 = 8 (65 · 0.676 · 0.67) + 2 (25 · 0.2 · 0.01) = 235.6184 kg.

Thus, the values of all the components of the balance equation have been determined and ID value may be calculated.

IDU = AQU - (IQU+ INCU - DECU) = 44.1 - (45.6 + 362.6 - 361.52) = -2.58 kg;

IDU235 = AQU235 - (IQU235 + INCU235 - DECU235) = 17.64 - (18.24 + 235.69 - 235.6184) = -0.6716 kg.

3. Determination of the standard deviation value of ID

Since the measurements of NM were performed using three different sources of errors, the calculation of the standard deviation value of ID (standard error) for U and U235 should be made using the expression (4) and values of NM weights obtained based on the statistical processing of the results of measurements for each component of the equation.

Let the error components of the results of measurements made of the NM for the lots of NM for which the accounting balance is made have the value given in the table 1.

Note. The error components of the results of measurements made of NM of all the lots of NM which in the MBA or in performing PI were subject to accounting measurements shall be subject to accounting in each component of the balance.

Determination of the dispersion values  using the expression (4) assumes the calculation of its random or systematic components.

Besides for simplifying the calculations it is reasonable that these components for each of the components of the balance equation (1) with subsequent simple addition of the found values in determination of random component and summation considering the sign of the component in the balance equation in the event of determination of the non-excluded systematic component.

Table 1

Accuracy values of the results of performed measurements of NM

|  |  |
| --- | --- |
| Relative error components of the NM measurement result | Stage of NM presence in MBA where the accounting measurements were performed. |
| Accounting measurements in the previous MBP | Receipt of NM in MBIP | Dispatch to MBIP | Current inventory taking |
| Product | Wastes |
| Systematic weighing error componentbase_1_285082_32799 | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 |
| Random weighing error componentbase_1_285082_32800 | 0.0015 | 0.0015 | 0.0015 | 0.0015 | 0.0015 |
| Systematic component for determining mass fraction of Ubase_1_285082_32801 | 0.002 | 0.005 | 0.03 | 0.05 | 0.002 |
| Random component for determining mass fraction of Ubase_1_285082_32802 | 0.004 | 0.01 | 0.01 | 0.008 | 0.004 |
| Systematic error component for determining mass fraction of U235 in Ubase_1_285082_32803 | 0.002 | 0.005 | 0.03 | 0.05 | 0.002 |
| Random error component for determining mass fraction of U235in Ubase_1_285082_32804 | 0.004 | 0.01 | 0.01 | 0.008 | 0.004 |

3.1 Random components  of the balance equation

Thus the random components of the dispersions of the results of measurements AQU and AQU235 in accordance with (4) and considering that mU and mU235 in all the three containers are the same, they can be determined as follows. <1>

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<1> Hereinafter, when the summable masses are the same, addition is replaced by multiplication.

For U:

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For U235:

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Similarly, the random components of dispersions of the measurement results of all the remaining balance equation component may be determined.

For U:

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For U235:

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For U:

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For U235:

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For U:

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For U235:

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Total quantity of random component of dispersion of the measurement results of mass U shall have the following value:

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Total quantity of random component of dispersion of the measurement results of mass U235 shall have the following value:

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3.2 Systematic component  of the balance equation components

Systematic components of dispersions of the results of measurements of NM mass by components of the balance equation may be determined as follows.

Systematic component of the dispersion results of measurements of mass of U in the AQ component:

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Systematic component of the dispersion results of measurements of mass of U235 in the AQ component:



Systematic component of the dispersion results of measurements of mass of U in the IQ component:



Systematic component of the dispersion results of measurements of mass of U235 in the IQ component:



Systematic component of the dispersion results of measurements of mass of U in the INC component:



Systematic component of the dispersion results of measurements of mass of U235 in the INC component:



Systematic component of the dispersion results of measurements of mass of U in the DEC component:





Systematic component of the dispersion results of measurements of mass of U235 in the DEC component:





The integral value of the systematic component of dispersion of the measurement results of mass U shall be determined in accordance with the expression:



The integral value of the systematic component of dispersion of the measurement results of mass U 235shall be determined in accordance with the expression:



In accordance with the expression (4) dispersion of IR may be found by adding its random and systematic components.

For U:

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For U235:

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Based on the obtained values , the values of mean square deviations (errors) of ID in accordance with the expression  shall be equal to:

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The obtained values of ID and  together with other values determined in the item 69 of the Basic Rules are used in the analysis of the results of Pl for identifying the potential anomalies in the NM record and control.

Appendix No. 3
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EXAMPLE
OF THE ANALYSIS OF INVENTORY DIFFERENCE OF THE PHYSICAL INVENTORY OF NUCLEAR MATERIALS IN THE MATERIAL BALANCE AREA FOR DETECTING THE ANOMALY IN ACCOUNTING AND CONTROL OF NUCLEAR MATERIALS

The conditions of the tasks considered in Appendix 2 of this Safety Guide have been accepted by the condition for performing analysis, in accordance thereof the basic input data shall be the following:

PI of NM was made in the MBA of the commercial nuclear installation for processing HEU-LEU containing category 1 NM.

the in-reprocessing and reprocessed products contain such NM as U and U235;

All NM coming in and going out and located in the MBA in the derived products at the MBA were subject to accounting measurements in MBA or during PI taking;

the following values of the ID modules for U and ,  were obtained in balance accounting following PI of NM;

the standard deviation values of ID respectively are equal to , .

In compliance with the item 69 of the Basic Rules determining the values of NM mass, which must be compared with ID of NM mass in the analysis of the results of PI of NM in MBA of the commercial nuclear installation it has been defined that the conclusion on detection of anomaly in the accounting and monitoring of NM may be made on establishment of the fact of exceedance of the minimum value (threshold - P) by the obtained value of ID module from the following aggregate of values of NM mass:

thrice the standard deviation (standard error) of ID determination for U and for ;

2% of the quantity of U and U235 which were subject to accounting measurements in this MBIP;

values of U235 mass for this MBA - 8 kg

Thrice standard deviation of ID determination for U shall have the following value , and for .

The amount of NM transformed and subject to accounting measurements for the given MBA may be determined either as the amount of NM which was spent from IQ available at the start of MBIP, plus the amount of NM which was spent from INC, received for MBIP, i.e. IQпр + INCпр, or as the amount of NM which was transformed for MBIP and remained in the MBA at the time of current inventory taking AQпр, plust the amount of NM DECпр, which was transformed and dispatched from the MBA for MBIP i.e. AQпр + DECпр.

Based on the results of resolution of the task of Appendix No. 3 of this Safety Guide AQUпр = 44.1 kg, AQU235пр = 17.64 kg, УМUпр = 361.52 kg, DECU235пр = 235.6184 kg. Based on the specified values of AQпр and DECпр we get the following values:

2% (AQUпр + DECUпр) = 0.02 (44.1 + 361.52) = 8.1 kg;

2% (AQU235пр + DECU235пр) = 0.02 (17.64 + 235.6184) = 5.06 kg.

Analysis of the aggregate of NM mass values determined above for comparison with the values of the ID module shows that the minimum values for U and for U235 shall the values of treble standard error of determining ID .

The comparison  with  shows that , a, hence anomaly in the accounting and monitoring of U is not observed.

The comparison  with  shows that , a, hence there is no anomaly in the accounting and monitoring of U235 .

The rules for determining the threshold values used during decision making on the presence or absence of anomalies in the accounting and monitoring of NM of the main considered nomenclature with which or in PI the accounting measurements were made are presented in the table.

Threshold amounts of NM of the main considered nomenclature used in taking decision on presence or absence of anomaly in the accounting and monitoring of NM

|  |  |
| --- | --- |
| Nuclear material | Threshold quantity P for nuclear installations |
| commercial | research |
| Pu, U233 in MBA with NM of categories 3 and 4 | base_1_285082_32850 | base_1_285082_32851 |
| U, Th in MBA with NM of any categories |
| U235 in products with mass fraction of U235 in U no more than natural in MBA with NM of any categories |
| NM in irradiated products |
| Pu, U233 in MBA, classified as MBA with category 1 and 2 NM | base_1_285082_32852 | base_1_285082_32853 |
| Pu, U233, HEU, LEU in MBA classified as MBA with category 1 and 2 NM | base_1_285082_32854 | base_1_285082_32855 |
| Pu, U233, HEU, LEU in uranium-plutonium solution in MBA classified as MBA with category 1 and 2 NM | base_1_285082_32856 | base_1_285082_32857 |
| Pu, U233, HEU, LEU in MBA classified as MBA with category 3 NM | base_1_285082_32858 | base_1_285082_32859 |
| Pu, U233, HEU, LEU in MBA classified as MBA with category 4 NM | base_1_285082_32860 | base_1_285082_32861 |
| Uranium and plutonium solutions in MBA of a radiochemical plant with any category NM  | base_1_285082_32862 | base_1_285082_32863 |

Appendix No. 4
to the safety guide in the use of atomic energy "Recommendations for accounting nuclear materials in their physical inventory taking in the material balance areas and analysis of its results" approved by the Order of the Federal Environmental, Industrial and Nuclear Supervision Service No. \_\_\_
dated \_\_\_\_\_\_\_\_\_\_, 20\_\_

EXAMPLE
OF APPLYING DETERMINATION AND ANALYSIS METHOD OF CUMULATIVE AMOUNT OF INVENTORY DIFFERENCE

The deterministic components in the time series may notably illustratively and effectively highlighted using the cumulative chart method (CUSUM method).

The basic principles of using control charts of cumulative sums (hereinafter CUSUM-charts), methods of their construction and basic rules of taking decisions is stipulated by GOST R ISO 7870-4-2013.

The implementation of the method in case of consideration of the time change of the value of NM ID is as follows. The values of ID of NM obtained as a result of a whole range of scheduled PI taking at MBA are regularly added. Then the obtained ID amount from the start of surveillance to the relevant moment of time is entered on the chart (i = 1, m; m - number of the last MBIP).

The cumulative amount remains constant in time until the individual differences of IDi from i are randomly dispersed under the impact of only . If systematic losses (or procurements) of small quantities of NM take place, they act on the cumulative sum CUSUMm and cause it deviation from the constant value to one or other direction.

On adequate choice of the scale in the image CUSUMm even minor displacements within the limits  may be recognized through several points. The control charts for such cumulative amount of ID is reasonable to build so that the quantity on the Y-axis and time segment between the two successive measurements of ID (i.e. MBIP) had the same scale. In such choice the random fluctuations manifest that the minor displacements CUSUMm within the limits  shall give the line under the angle 45° to the horizontal.

If for each MBIP the losses were , then for example, for six MBIP the losses shall be  and by investigating not the ID but the cumulative (inclined) sum of ID the losses (displacement) can be identified drawing on the fact that the contribution to CUSUM from displacement increases proportional to the number of MBIP, and the contribution from the sum of values of ID of different signs for many MBIP reduces or in any case does not grow as fast wherefore the CUSUM method is based and that is shown below in the example.

The basic rule of taking decisions consists in building the V-masks on the CUSUM--chart and determination of significant changes on exit of the CUSUM curve points outside the V-mask line. There are three different forms of masks, they are identical by the building principle and action. complete V-mask, truncated V-mask and parallel mask The most commonly used among them is the truncated V-mask.

The schematic representation of the truncated V-mask or stencil of V-mask is given in the fig.1. The are called intervals of solutions and are denoted by H, and the lines BD, CE are called resolution lines.

Figure (not given)

Fig. 1. Stencil of truncated V-mask:

H = AB = AC =  - intervals of decisions; 2H = DF = FE = ;

d = 10 - number of sampling intervals;

CE and BD - resolution lines

The V-mask stencil which can be made from transparent plastic, thick paper or film shall be used for convenience of work at places with the CUSUM-chart. In practice for drawing the stencil from the axis AF passing parallel to the horizontal axis CUSUM-map H= АБ = AC =  perpendicular to AF is marked off. At a distance d = 10 of the sampling intervals left to the point from the point A, FD = FE =  is marked off perpendicular to the axis AF . The values  and  may be found based on the calculated values of the standard error  of the investigated random value and scale multiplier. The stencil shall be used by placing the target point A on any plotted point on the control chart. The last plotted point on the chart shall be selected, but it may be a point in any previous interval. If any of the preceding points shall be outside the inclined resolution lines BD and CE (or their continuations), then it is a signal about the significant deviation of the process from the target value. If the entire CUSUM curve is between the half-rays, then there no significant movement. The nature of the graph line is verified using V-shaped control mask at each point.

Let us consider the following as an example.

The values of ID of NM and CUSUM(ID) given in the table 1 have been obtained for verifying the assumptions on possible anomaly in the accounting and control of NM in the form of systematic loss of NM following monthly scheduled PI in MBA with category 1 NM.

Table 1

Values of ID of NM and CUSUM(ID) in units 

|  |  |  |
| --- | --- | --- |
| Month of the year, on the first date thereof PI is taken | ID-inventory difference in units base_1_285082_32879 | CUSUM(ID) - cumulative sum of inverntory differences in units base_1_285082_32880 |
| December (not shown in the schedules) | -0.54751 | -0.54751 |
| January | -2.06548 | -2.61299 |
| February | 0.405371 | -2.20762 |
| March | 0.034378 | -2.17324 |
| April | -0.3147 | -2.48794 |
| May | 0.784457 | -1.70349 |
| June | -1.3731 | -3.07659 |
| July | -0.66195 | -3.73854 |
| August | -1.23375 | -4.97229 |
| September | -2.01923 | -6.99152 |
| October | -2.22695 | -9.21847 |
| November | -2.22695 | -9.56342 |
| December | 0.179201 | -9.38422 |

The change schedules of the values ID and CUSUM (ID) in accordance with the data of table No. 1 are given in the fig.1 and fig. 2 respectively.

The stencil of truncated V-shaped verifying mass in the form of equilateral trapezium with height d = 10 sampling intervals and bases equal to  and  respectively. Each sampling interval in this case corresponds to MBIP.

Example of superposing V-mask on CUSUM(ID) graph is given in the fig.3.

Fig. 1. ID value curve by months of the year

(not performed)

Fig. 2. CUSUM(ID) value curve by months of the year

(not performed)

Fig. 3. Example of superimposition of V-masks on CUSUM(ID) curve

(not performed)

Mask registration of V-mask with curve points allows identify the critical points which indicated at the start of occurrence of a significant shift of the quantity ID. As it is seen, on mask registration of V-mask with the point 10 the CUSUM5 point falls beyond the mask raster. This indicated the occurrence of a significant shift for this parameter, requirement of performing investigation and taking the relevant measures

The CUSUM graph analysis using V-mask in some cases may be supplemented by the identification of 4 or more successive points, monotone decreasing values of CUSUM(ID). But the target value of ID shall be given in this case.

Appendix No. 5
to the safety guide in the use of atomic energy "Recommendations for accounting nuclear materials in their physical inventory taking in the material balance areas and analysis of its results" approved by the Order of the Federal Environmental, Industrial and Nuclear Supervision Service No. \_\_\_
dated \_\_\_\_\_\_\_\_\_\_, 20\_\_

RECOMMENDED DIAGRAM
OF THE NM ACCOUNTING BALANCE ALGORITHM IN PI TAKING AT MBA OF THE ORGANIZATIONS NOT HAVING CONTINUOUS PRODUCTION AND ANALYSIS OF ITS RESULTS

|  |
| --- |
| Comparison of the positions of NM II PIL with the actual quantity (N) of NM II |
|  |  |  |
| No | IDII = NPIL - NPIL = 0 | Yes |
|  |  |  |
|  | Verification of ACM confirming the measurements with verification of the attributive indicators of II, masses and concentrations of NM, elements, isotope in II.Determination of the values of ID and sigmaID for each NM, element, isotope in accordance with the expressions: ID = AQ - DQ, sigmaID = √sigma2 (m) |  |
|  |  |  |
| No | Availability of accounting measurements of NM in MBIP during PI taking | Yes |
|  |  |  |
| Determination of the divergence values of the results of accounting and confirmatory measurements of NM in the sampling Deltami = (mSI ) i - mПИ)idetermination of the belonging of the quantity Deltami to the interval +/- 2.58sigmai |  | Comparison of the obtained values of ID module with the threshold values Pi according to item 69 of NP-030-12 |
|  |  |  |
| No | -2.58sigmai <=Deltami <= +2.58sigmai | Yes |
|  |  |  |
| No | ID < min(Pi) | Yes |
|  |  |  |
| Confirmation of anomaly |  |  |
|  | Accounting measurements of NM |  |
|  |  | Accepted value of AQ |