Methodology and software development for nuclear material characterization using weighing scales

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Abstract

Weighing scales are the main measurement systems used in nuclear facilities for nuclear material first level controls. In addition, nuclear material characterization in processing facilities is usually performed combining weighing and analytical techniques on a sample taken from the product (UF_6, uranium and/or plutonium oxides...).

This paper describes the methodology and software implemented at IRSN for nuclear material physical inventory taking in its own facilities and in-field inspections using weighing scales. The modalities of calibration, control and use of each scale are defined according to the type of item to be measured, the application (gross mass, net mass, true mass and conventional mass) and the operating conditions (laboratory inventory taking, in-field inspection). Measurement uncertainties are estimated by considering the following influencing factors : the material itself, the measurement system, the applied method, the environmental conditions and the operator.

Results obtained with different kinds of nuclear materials (noble material, technological wastes), scales and operating conditions (laboratory, in-field) are considered.

1 INTRODUCTION

In collaboration with the Mediterranean technology center of metrology (CT2M), the Nuclear material metrology laboratory (L2MN) of the Institut de radioprotection et de sureté nucléaire (IRSN) has developed a methodology for weighing the true and conventional mass of an object (gross mass) and the mass of nuclear material in a container (net mass) for masses up to 300 kg. Such methodology is applicable within the laboratory, as part of the nuclear material annual inventory, and during inspections as part of national control. It guarantees the correct use of the scales, the weighing result and the associated uncertainty. A spreadsheet in Excel format is used to control scales and temperature probes, and to process and format the collected data.

2 WEIGHING METHODOLOGY

2.1 PRELIMINARY OPERATIONS

Several operations must be performed by the user before implementing the weighing protocol. The scale, which is subject to legal metrology, is verified annually by an accredited body. The user has then to check that the last verification was done less than 12 months ago and that the conformity sticker affixed to the scale is green. The scale must be turned on for, at least, 30 minutes before starting a calibration in order to achieve optimal stabilization of the weighing instrument. In addition, additional time may be required to warm up the scale if there is a difference in temperature between the weighing location and the place where the weights were previously stored.

The horizontality of the scale must be verified and adjusted if needed. Moreover, the platform must be clean. Once those checks performed and the balance is stable, the temperature probe can be switched on and data acquisition can start.

The first operation consists in carrying out the calibration (manual or automatic) of the balance in order to get as close as possible to the conditions of use of the balance. Balances equipped with an internal calibration system that is automatically activated by temperature variations can guarantee these conditions without the need for an operator.

Then, the balance can be controlled according to the procedure described in paragraph 2.3. If the verification is not compliant and the weighing cannot be performed on another instrument or postponed to a later date (after the instrument's ability to function properly has been verified), the uncertainty will be downgraded to consider the deviation.

2.2 WEIGHING PROTOCOL

For each weighing, the protocol consists in taring the scale first, then placing the object to be weighed, waiting for the I_i indication to stabilize, reading or transferring the value, removing the object and finally making sure that the scale indicator returns to 0 (+/- 2 digits). If it is not the case, such information will be processed and will allow to anticipate a possible malfunction or instability of the equipment.

After each series of weighing operations, two actions must be carried out in order to finalize the operation. The user needs first to stop the acquisition of temperature data and read the minimum and maximum temperatures, then to carry out the verification of the scale according to the verification procedure described in the following paragraph.

A non-automatic weighing instrument is sensitive to many influencing factors. Therefore, if there is any doubt about the impact of any of these influencing factors, it is strongly recommended to increase control frequency to limit the risk of invalidating the results.

2.3 SCALE FUNCTIONAL CHECK

The purpose of these controls is to maintain confidence in the proper functioning of the scales and to guarantee the weighing result and its associated uncertainty.

2.3.1 WEIGHTS USED TO CONTROL SCALES

The weights used for checking the scales are, when it is possible, different from the weights used for their calibration and characterization. Their nominal values are selected in order to cover the operating range of the scales. The traceability to the international system of units of the masses is given to a calibration laboratory accredited by COFRAC or equivalent. The standards can only be used if the last calibration is less than 12 months old.

2.3.2 CONDITIONS FOR CARRYING OUT THE CONTROLS

The scales are checked every day of use before and after each weighing series. A weighing series is defined as a period of use of the scale, without interruption of more than 4 hours. Consequently, any interruption of weighing for more than 4 hours requires an end-of-series control (before stopping weighing) and a start-of-series control (when weighing is restarted).

2.3.3 CONTROL PROTOCOL

The control protocol used to test each scale consists, for the user, in taring the scale first, then placing the first test weight on the scale, and reading or transferring the displayed value in the corresponding file. Such operations have to be repeated for all the weights defined for the scale, before being able to validate the conformity test (see § 2.3.4).

N.B.: Check weights are defined for each scale according to its use and identified within the software to guide the operator.

2.3.4 USE OF RESULTS

The scale control data are automatically transferred to an Excel file, which allows the recording of all control results and the processing of the data.

The evaluation of the test results consists in comparing the error of indication of the scale with the MPE (Maximum Permissible Error).

2.3.5 ACTION TO BE TAKEN IN CASE OF NON-COMPLIANT TESTING

In case of non-compliant testing, the user must repeat the control protocol (tare + weighing). If the control is non-compliant again, a calibration must be performed as well as the control operations. If such control is non-compliant again, the non-conformity must be noted.

N.B. : If controls are not compliant and operations can neither be postponed nor carried out on another scale, the weighing can be carried out under "degraded" conditions, considered in the result uncertainty.

If the end-of-series control is not compliant, the observed drift must be considered in the weighing uncertainty of all weighing results performed since the last compliant check. Such scale must be declared "out of service" and may no longer be used under normal conditions of use until its ability to function correctly has been verified.

3 USE OF DATA

Weighing must allow determining the true and conventional gross mass of the object being weighed (mass of the container and contents), but also the true and conventional net mass of nuclear material when used for nuclear material physical follows-up and accountability. This can be performed from a declared value of the container mass (tare) or from the weighing of an equivalent container.

Cases related to conventional mass determination are not described in this document. The equations detailed below apply to balances calibrated in conventional mass.

3.1 DETERMINATION OF THE TRUE GROSS MASS OF AN OBJECT TO BE WEIGHED AND THE ASSOCIATED UNCERTAINTY

3.1.1 ESTABLISHING THE MODEL

In this first case, the result is obtained from a single weighing, to which a correction for air buoyancy (C) is made. When the errors of indication of a weighing instrument are determined using mass standards in accordance with OIML recommendation R 111 [1], the mass (M) of the weighed object is given by the following approximate equation, the second order terms being neglected :

$$M = x + C \text{ [2]}$$

With $C = a\left(\frac{1}{r} - \frac{1}{r_0}\right)x$ [2]

Hence $M = x + a\left(\frac{1}{r} - \frac{1}{r_0}\right)x$

With :

- x : result of the weighing of the object in kg ;
- a : density of the ambient air at the time of weighing, expressed in kg/m^3 ;
- r : density of the body weighed, expressed in kg/m^3 ;
- r_0 : conventional density equal to 8000 kg.m^{-3}.

The density of the weighed object not being directly accessible (apparent density), it is deduced from the volume of the object ($V_{container}$) and the mass of the container (M). M can be approximated to x in order to simplify the equation :

$$r = \frac{M}{V_{container}} \sim \frac{x}{V_{container}}$$

And $M = x + ax\left(\frac{V_{container}}{x} - \frac{1}{r_0}\right) = x + aV_{container} - \frac{ax}{r_0}$

3.1.2 *ESTIMATION OF THE UNCERTAINTY OF THE WEIGHING RESULT* $\boldsymbol{u}(\boldsymbol{M})$

The uncertainty calculation associated with the mass $\boldsymbol{u(M)}$ is performed according to the GUM methodology [3]. In accordance with this standard, the uncertainty parameters being independent, the combined standard uncertainty is calculated according to the following equation:

$$u(M)^2 = \left(\frac{\partial M}{\partial x}\right)^2 u(x)^2 + \left(\frac{\partial M}{\partial a}\right)^2 * u(a)^2 + \left(\frac{\partial M}{\partial V_{container}}\right)^2 u(V_{container})^2 + \left(\frac{\partial M}{\partial r_0}\right)^2 u(r_0)^2$$

$$u(M)^2 = \left(1 - \frac{a}{r_0}\right)^2 u(x)^2 + \left(V_{container} - \frac{x}{r_0}\right)^2 u(a)^2 + a^2 * u(V_{container})^2 + \left(\frac{ax}{r_0^2}\right)^2 u(r_0)^2$$

Since the uncertainty on the conventional density $u(r_0)$ is negligible (the standards used for the calibration of the balance are very close to the value of 8000 kg/m^3), the equation can be simplified as follows :

$$u(M)^2 = \left(1 - \frac{a}{r_0}\right)^2 u(x)^2 + \left(V_{container} - \frac{x}{r_0}\right)^2 u(a)^2 + a^2 u(V_{container})^2$$

The uncertainty budget is given in Table 1 here after.

Table 1: uncertainty budget of the gross mass weighing results

Standard uncertainty	Component	Sensitivity Coefficient C		C x u
		Factor	unit	unit
Weighing Result u(x) with $u(x)^2 = u_f^2 + u_j^2 + u_{rc}^2 + u_{r0}^2 + u_T^2 + u_{exc}^2$	Precision (u_f)	$\left(1 - \frac{a}{r_0}\right)$	No unit	Grams
	No-load Resolution (u_{r0})			
	On-load Resolution (u_{rc})			
	Trueness (u_j)			
	Temperature effect (u_T)			
	Off-centre (u_{exc})			
Air density u(a)	Range of possible densities	$V_{container} - \frac{x}{r_0}$	m^3: x must be set in kg to calculate C	C*u in kg to convert to grams before combining
Volume of the weighed objet $u(V_{container})$	Uncertainty on the determined volume of the container	a	kg/m^3	C*u in kg to convert to grams before combining

3.1.2.1 <u>Estimation of the weighing result uncertainty $\boldsymbol{u(x)}$</u>

The uncertainty of the weighing result incorporates all the influencing factors related to the weighing as defined in the table above.

The weighing result x can be written as follows :

$x = i + C_j + C_f + C_{r0} + C_{rc} + C_T + C_{exc}$

with :

- i, the indication given by the scale ;
- C, the set of corrections applied to the weighing result :
  - C_j trueness correction ;
  - C_f precision correction ;
  - C_T temperature effect correction ;
  - C_{r0} / C_{rc} resolution corrections (no-load and on-load) ;
  - C_{exc} eccentricity correction.

In this case, no correction for these factors is applied. Since these factors are independent, in accordance with GUM [3], the combined standard uncertainty is written as follows :

$$u(x) = \sqrt{u_f^2 + u_j^2 + u_{rc}^2 + u_{r0}^2 + u_T^2 + u_{exc}^2}$$

3.1.2.1.1 Estimation of the precision standard uncertainty u_f

During its annual periodic control, the precision of the scale was evaluated by comparing the amplitude of the values from the precision test to the scale's MPE (Maximum Permissible Error).

Considering that :

- Weighing results follow a normal distribution ;
- During use, the precision may change (in particular due to weighing conditions, influence quantities which are difficult to control), but remains under control via the monitoring in the form of a control chart ;
- The range of values obtained remains lower than the MPE of the scale. The MPE is an encompassing value of the range of possible values, equivalent to +/- 3 S (i.e. 6 S) which represents 99.7% of the possible values ;

An estimate of the standard deviation S can therefore be determined from the MPE of the scale :

MPE = 6 x S , which lead to S = MPE / 6 for the corresponding load.

Therefore, the fidelity uncertainty is associated with a normal distribution of range equal to MPE_x :

$$u_f = \frac{MPE_x}{6}$$

With MPE_x, the MPE of the scale at the considered load.

3.1.2.1.2 Estimation of the resolution at no load and under load standard uncertainty u_{r0} et u_{rc}

The standard uncertainty associated with the resolution depends on the value of the scale interval at no load (d0) and at load (d).

The uncertainty associated with the resolution of the scale is obtained by a type B evaluation, which follows a uniform distribution of possible values corresponding to the resolution d0 and d for each load considered:

$$u_{r0} = \frac{d_0}{2\sqrt{3}} \text{ and } u_{rc} = \frac{d}{2\sqrt{3}} \quad [4]$$

3.1.2.1.3 Estimation of the trueness standard uncertainty u_j

During its annual periodic control, the trueness of the scale was evaluated by comparing the indication error (E_x, x being the load) to the scale's MPE.

In addition, each weighing series is monitored by checking that the indication error (Ex) is less than the MPE of the scale.

We can therefore consider that the trueness error is controlled and limited by +/- MPE of the scale at the considered load.

Consequently, the uncertainty associated with the trueness of the scale follows a uniform distribution of possible values corresponding to 2 MPEx :

$$u_j = \frac{2\ MPE_x}{2\sqrt{3}} = \frac{MPE_x}{\sqrt{3}}$$

With MPE_x, the MPE of the scale at the considered load.

3.1.2.1.4 Estimation of the standard uncertainty linked to temperature variation during the weighing series u_T

The parameters which intervene in this uncertainty component are the following :

- C (°C^{-1}): the coefficient of variation of the slope of the scale as a function of temperature provided by the manufacturer of the instrument (sensitivity coefficient) ;
- DT (°C): the temperature variation during the series of weighings.

The standard uncertainty due to the effect of temperature on the scale is given by :

$$u_T = \frac{C\ DT\ x}{\sqrt{3}}\ [4]$$

With x the weighed load.

3.1.2.1.5 Estimation of the standard uncertainty linked to the eccentricity of the load during weighing $\boldsymbol{u_{exc}}$

During its annual periodic control, the indication error linked to eccentricity tests (E_{exc}) was compared to the MPE of the scale.

The standard uncertainty linked to the eccentricity of the load is estimated assuming that the probability to place the object to weigh at the centre of the scale pan is higher than placing it at the edge of the scale pan, and the eccentricity error is proportional to the load weighed. As described in the EURAMET cg-18 document [5], the eccentricity uncertainty is given by the following expression, considering a triangular distribution of possible values equal to 2 MPEx :

$$u_{exc} = \frac{2\ MPE_x\ x}{2\sqrt{6}\ \ x_{test}} = \frac{MPE_x\ x}{\sqrt{6}\ \ x_{test}}$$

With :

- MPEx, the MPE of the scale at the considered load ;
- x, the weighed load ;
- x_{test} the load at which the eccentricity test was performed.

3.1.2.2 <u>Determination of the air density a and the associated uncertainty $\boldsymbol{u(a)}$</u>

According to data coming from the COFRAC document LAB GTA 95 [4], the air density a and its associated uncertainty u(a) are estimated at (1,214 ± 0,082) kg/m^3.

3.1.2.3 <u>Determination of the container volume Vcontainer and the associated uncertainty ($V_{container}$)</u>

The volume of the container is determined :

- Either from the type of container: a list of containers regularly used, as well as the corresponding volumes associated has been established ;
- Or from dimensions of the weighed object.

An envelope uncertainty of 10% was arbitrarily taken on this volume in the uncertainty calculation : u($V_{container\ \%}$) = 10% so u($V_{container)}$ = 0,1 x $V_{container}$

3.2 DETERMINATION OF THE NET (TRUE) MASS OF NUCLEAR MATERIAL AND THE ASSOCIATED UNCERTAINTY

3.2.1 ESTABLISHING THE MODEL

In this first case, the mass of nuclear material M is calculated from :

- The gross weight x_{gross} (performed by L2MN) ;
- The tare value x_{tare} (data provided by the operator or tare weighed by L2MN) ;
- The mass of air included in the container x_{air} (estimated from the characteristics of the container and the mass of nuclear material weighed).

Total mass (x_{gross}) = tare mass (x_{tare}) + air mas ($_{xair}$) + NM mass (M)

From the total mass (x_{gross}) and the mass of the container (x_{tare}), the following equation can be deduced :

$$M = (x_{gross} - x_{tare} - x_{air}) + C$$

With

- $C = a\ \left(\frac{1}{r} - \frac{1}{r_0}\right) x$ [2] ;

- x the difference ($x_{gross} - x_{tare} - x_{air}$) in kg ;
- r = ρ_{MN} the nuclear material density in kg.m^{-3} ;
- r_0 : conventional density of 8 000 kg.m^{-3}.

That is $M = \left(x_{gross} - x_{tare} - x_{air}\right) \left(1 + a\left(\frac{1}{\rho_{NM}} - \frac{1}{r_0}\right)\right)$;

$x_{air} = a\,V_{air} = a\,(V_{container} - V_{NM}) = a\left(V_{container} - \frac{M}{\rho_{NM}}\right)$

with

- a, the air density (kg/m^3) ;
- $V_{container}$, the internal volume of the container (m^3) ;
- V_{NM}, the volume of nuclear material in the container (m^3) ;
- ρ_{NM}, the density of the nuclear material in the container (kg/m^3).

That is $M = \left(x_{gross} - x_{tare} - a\left(V_{container} - \frac{M}{\rho_{NM}}\right)\right)\left(1 + a\left(\frac{1}{\rho_{NM}} - \frac{1}{r_0}\right)\right)$.

Therefore $M = \dfrac{(x_{gross} - x_{tare} - a\,V_{container})\left(1 + a\left(\frac{1}{\rho_{NM}} - \frac{1}{r_0}\right)\right)}{1 - \frac{a}{\rho_{NM}}\left(1 + a\left(\frac{1}{\rho_{NM}} - \frac{1}{r_0}\right)\right)}$

In order to simplify the equation, A and B coefficients are defined as follows :

- $A = \left(X_{gross} - X_{tare} - a\,V_{container}\right)$;
- $B = 1 + a\left(\frac{1}{\rho_{NM}} - \frac{1}{r_0}\right)$.

3.2.2 ESTIMATION OF THE UNCERTAINTY OF THE WEIGHING RESULT $\boldsymbol{u(M)}$

The calculation of the uncertainty associated with the mass is done according to the GUM methodology [3]. In accordance with this standard, uncertainty factors being independent, the uncertainty associated with M is calculated according to the following equation :

$$u(M)^2 = \left(\frac{\partial M}{\partial x_{gross}}\right)^2 u(x_{gross})^2 + \left(\frac{\partial M}{\partial x_{tare}}\right)^2 u(x_{tare}) + \left(\frac{\partial M}{\partial a}\right)^2 u(a)^2 + \left(\frac{\partial M}{\partial V_{container}}\right)^2 u(V_{container})^2 + \left(\frac{\partial M}{\partial \rho_{NM}}\right)^2 * u(\rho_{NM})^2 + \left(\frac{\partial M}{\partial r_0}\right)^2 u(r_0)^2$$

$$u(M)^2 = \left(\frac{B}{1 - \frac{a}{\rho_{NM}} \times B}\right)^2 u(x_{gross})^2 + \left(\frac{-B}{1 - \frac{a}{\rho_{NM}} \times B}\right)^2 u(x_{tare})^2 + \left(\frac{V_{container}\,B\left(\frac{aB}{\rho_{NM}} - 1\right) + A\left(\frac{B^2}{\rho_{NM}} + \frac{1}{\rho_{NM}} - \frac{1}{r_0}\right)}{\left(1 - \frac{a}{\rho_{NM}}B\right)^2}\right)^2 u(a)^2 + \left(\frac{-a \times B}{1 - \frac{a}{\rho_{NM}} \times B}\right)^2 u(V_{container})^2 + \left(\frac{\frac{A\,a}{\rho_{NM}{}^2}\,(B^2 - 1)}{\left(1 - \frac{a}{\rho_{NM}}B\right)^2}\right)^2 u(\rho_{NM})^2$$

N.B. : the assumption that the uncertainty on the conventional density of the standards $u(r_0)$ is negligible (standards used for the calibration of the balance are very close to the value of 8000 kg/m^3) was made.

Table 2 : uncertainty budget of the net mass weighing result

Standard uncertainty	Component	Sensitivity Coefficient C		C x U
		Factor	Unit	Unit
Gross weight result $u(x_{gross})$ With $u(x)^2 = u_f^2 + u_j^2 + u_{rc}^2 + u_{r0}^2 + u_T^2 + u_{exc}^2$	Precision (u_f)	$\frac{B}{1-\frac{a}{\rho_{NM}}B}$	No unit	Grams
	No-load Resolution (u_{r0})			
	On-load Resolution (u_{rc})			
	Trueness (u_j)			
	Temperature effect (u_T)			
	Off centre load (u_{exc})			
Tare weighing result $u(x_{tare})$	Information given by the operator or tare weighing by L2MN	$\frac{B}{1-\frac{a}{\rho_{NM}}B}$	No unit	Grams
Air density u(a)	Range of possible densities	$\frac{V_{container}\, B\left(\frac{aB}{\rho_{NM}}-1\right)+\ A\left(\frac{B^2}{\rho_{NM}}+\frac{1}{\rho_{NM}}-\frac{1}{r_0}\right)}{\left(1-\frac{a}{\rho_{NM}}B\right)^2}$	m^3 : x_{tare} and x_{gross} in kg to calculate A	C*u in kg to convert to grams before combining
Volume of the weighed objet $u(V_{container})$	Uncertainty on the determined volume of the container	$\frac{-\,aB}{1-\frac{a}{\rho_{NM}}B}$	kg / m^3	C*u in kg to convert to grams before combining
Nuclear material density $u(\rho_{NM})$	Range of possible densities	$\frac{\frac{A\,a}{\rho_{NM}{}^2}\,(B^2-\,1)}{\left(1-\frac{a}{\rho_{NM}}B\right)^2}$	m^3 : x_{tare} and x_{brute} in kg to calculate A	C * u in kg to convert to grams before combining

3.2.2.1 <u>Estimation of the uncertainty of the gross weighing result $u(x_{gross})$</u>

The uncertainty of the tare value is determined in the same way as it was determined for the weighing result $u(x)$ described in § 3.1.2.1.

3.2.2.2 <u>Estimation of the uncertainty of the tare value x(tare)</u>

Two cases are considered :

1. The tare value is provided with an associated uncertainty by an operator. This value is entered by the inspector in the calculation file so that it can be considered. If no uncertainty is associated, the inspector can choose to integrate an "envelope" uncertainty of its choice.
2. The tare value is determined by the inspector from the weighing of n containers of the same type. The average of the weighings is considered in the determination of the tare: $x_{tare} = \frac{\sum_i x_i}{n}$, each container being weighed only once.

The weighing of these containers is carried out on the same weighing instrument as for the weighing of the gross mass. The result of the weighing x can be written as follows :

$x = i + C_j + C_f + C_{r0} + C_{rc} + C_T + C_{exc} + C_{DM}$

With :

- i the indication given by the scale ;
- C, all the corrections applied to the weighing result :
  - C_j trueness correction ;
  - C_f precision correction ;
  - C_T correction related to the effect of temperature ;
  - C_{r0} / C_{rc} resolution corrections (empty and loaded) ;
  - C_{exc} correction related to the effects of eccentricity ;
  - C_{DM} : correction related to the variation of mass of a container of the same type.

In this case, no correction of these factors is applied. Since these factors are independent, in accordance with GUM [3], the combined standard uncertainty is written as follows :

$$u(x) = \sqrt{u_f^2 + u_j^2 + u_{rc}^2 + u_{r0}^2 + u_T^2 + u_{exc}^2 + u_{DM}^2}$$

The combined standard uncertainty associated with this weighing consists of:

- The same influence factors as for the weighing of a "gross" mass described in §3.2.2.1 ;
- An uncertainty related to the variability of the mass between several containers of the same type (u_{DM}). This uncertainty factor takes into account the fact that 2 containers of the same type do not have exactly the same mass.

In order to determine the variability of the containers of the same type, it is essential to be able to weigh several containers allowing to obtain a representativeness of all the containers of this type. For this, it is necessary to have :

- n ≥ 2 containers of the same type ;
- Ideally, n ≥ 5 containers in order to have a better representativeness of this variability ;
- In the case where only one container is available, 2 solutions are possible :
    - a 10% envelope uncertainty is taken into account ;
    - the inspector has data from the operator (in this case, documented proof will be provided).

N.B. : the greater the number of containers weighed, the more representative the average value will be.

The uncertainty on the variability of the u_{DM} containers is estimated from :

- the standard deviation S obtained on the sample of containers weighed (of population n) ;
- corrected by the Student's t factor (with a two-sided probability of 95%, i.e. a one-sided probability of 97.5% and a degree of freedom ν equal to n-1).

$$u_{DM} = \frac{1}{2} \times t_{0.975}\ [\upsilon = n - 1)\ \times S$$

3.2.2.3 <u>Determination of the air density a and the associated uncertainty $u(a)$</u>

The uncertainty associated with the air density a $u(a)$ is calculated in the same way as in § 3.1.2.2.

3.2.2.4 <u>Determination of the volume of the weighed object $V_{container}$ and associated uncertainty $u(V_{container})$</u>

The volume of the container is determined :

- Either from the type of containers,(a list of containers regularly used, and the corresponding volumes associated has been established and can be selected within the software by the operator) ;
- Or from the taking of dimensions of the weighed object.

A standard envelope uncertainty of 10% at k=1 was taken arbitrarily on this volume in the uncertainty calculation : $u_{container\ \%}$ = 10% so $u_{container}$ = 0,1 x $V_{container}$

3.2.2.5 <u>Determination of the density of nuclear material ρ_{MN} and the associated uncertainty $u(\rho MN)$</u>

Two main types of nuclear material can be weighed :

- Waste whose density has been estimated to be between 100 and 19000 kg/m^3 ;
- Noble material whose density has been estimated between 2000 and 20000 kg/m^3.

These ranges of possible values allow to consider the diversity of the weighed materials and forms.

In order to generalize the calculation, the following data are considered :

- Average density : 10 000 kg/m^3 ;
- The associated uncertainty takes into account the possible amplitude of the density values in the form of a uniform distribution of possible values :

$$u(\rho\mathrm{MN}) = \frac{20\,000 - 100}{2\sqrt{3}} = \frac{19\,900}{2\sqrt{3}} = 5745\ \mathrm{kg/m^3}$$

4 SOFTWARE

The application, in Excel spreadsheet format, supports the riding of the scale and the temperature probe by USB ports of a PC. It guides the user by taking back the weighing methodology in the form of check boxes. It also takes back the calculations of the gross and net mass in real and conventional mass as well as the associated uncertainties and allows the user to modify some parameters that are essential for the proper operation of the device.

When the scale is selected, and depending on the use : either a weighing for nuclear material physical inventory taking, or for an inspection, the selection of the weights necessary for the control of the correct operation of the scale is carried out automatically, the user only has to follow the protocol imposed by the code. When a verification is performed, the graphs in the form of control charts are automatically updated and the user is informed about the conformity of the check.

5 CONCLUSION

The implementation of the weighing methodology established, both for the weighing in the scope of inventory control within the laboratory and the weighing in the scope of inspection within the framework of the national control, guarantees the good functioning of the balance, the weighing result and its associated uncertainty. The software in Excel format developed by the nuclear material metrology laboratory allows the user to control the scale and the temperature probes and guides the user through the methodology set up in form of check boxes corresponding to each step of a weighing. The next step will consist in qualifying this new measuring device.

RÉFÉRENCES

[1] OIML R111 recommendation (edition 2004) « Weights of classes E1, E2, F1, F2, M1, M1-2, M2, M2-3, M3 » Part 1: Metrological and technical requirements and Part 2: Test Report Format.

[2] COFRAC 2089 guide « Exigences spécifiques relatives à l'étalonnage d'instruments de pesage à fonctionnement non-automatique » - Revision 00 - Octobre 2000.

[3] GUM (JCGM 100) « Evaluation of measurement data - Guide to the expression of uncertainty in measurement ».

[4] COFRAC LAB GTA 95 guide « Etalonnage des Instruments de Pesage à Fonctionnement Non-Automatique ».

[5] EURAMET_cg-18 « Guidelines on the Calibration of Non-Automatic Weighing Instruments » Version 3.0 (03/2011).