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NEW DATA ANALYSIS APPROACH APPLIED FOR MEASUREMENTS OF OCCUPATIONAL ^{131}I INTAKES THROUGH INHALATION

M.A. SAIZU

"Horia Hulubei" National Institute for Physics and Nuclear Engineering – IFIN-HH,
30 Reactorului Street, P.O.Box MG-6, 077125 Magurele, Ilfov, Romania
E-mail: saizu_ang@yahoo.com

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Abstract. The new approach to the assessment of internal doses from monitoring data presented in EURADOS Report 2013-01 [1] offers valuable guidance on harmonizing evaluations recommending a structured process defined by means of a series of flow charts. It was implemented in the Whole Body Monitoring Laboratory (WBML) of Horia Hulubei National Institute of Physics and Nuclear Engineering (IFIN-HH), Magurele, Romania for the interpretation of data obtained by *in vivo* thyroid routine and special monitoring, in order to evaluate internal contamination with ^{131}I. Results of this implementation are presented.

Keywords: thyroid monitoring, I-131, intake, committed dose.

1. INTRODUCTION

Thyroid measurements of ^{131}I contamination and dose evaluation were conducted routinely for workers in nuclear medicine units and at IFIN-HH facilities involved in the production of radiopharmaceuticals, which were used for diagnosis and radiotherapy of thyroid diseases [2, 3]. In case of an abnormal radiation event, special monitoring was performed to quantify the associated committed effective dose. Considering the main chemical characteristic of the ^{131}I, namely, its volatility, a real risk of internal contamination of the workers through inhalation had to be considered. Thyroid monitoring to evaluate iodine thyroid retention was performed by gamma spectrometry, using a spectrometer based on a NaI(Tl) scintillation detector. The WBM Laboratory updated the methodology applied for intake estimation according to a new data analysis approach recommended by EURADOS Report 2013-01 for single and multiple intakes, through inhalation, for both routine and special monitoring. The data used for its implementation were archived data. In order to implement the routine individual monitoring program, one worker from the target group involved in ^{131}I radiopharmaceutical regular operation was measured for two months at time

intervals of 7 days. During this monitoring period, another worker was internal contaminated with ^{131}I through inhalation as a result of a local incident in the workplace and had to be measured. The measurement data for both workers were sufficient to permit the optimum application of the new evaluation method. In each step of the method, the quality of data was controlled in order to obtain the best estimate of the intake and of the committed doses.

2. MATERIALS AND METHODS

The system for *in vivo* monitoring used in WBML for the measurement of the retained activity in thyroid after inhalation of ^{131}I vapor, which may occur during the process of preparing and handling ^{131}I radiopharmaceuticals, is a gamma spectrometer equipped with a lead shielded and collimated NaI(Tl) scintillation detector of 40 mm diameter and 50 mm thickness. Its efficiency calibration was performed with an ORTEC Plexiglas thyroid phantom, IAEA/ANSI type [4], simulating the standard adult thyroid anatomical volume [5], filled with certified radioactive solution of known ^{131}I activity. The values calculated for the efficiency and for the Detection Limit were 9 E-03 counts per second/gammas per second and 34 Bq, respectively, at the ^{131}I main energy line of 364 keV, for a 10 cm distance between the detector Aluminum housing and the front surface of the thyroid.

The associated electronics of the detector for analog signal processing consists of ORTEC NIM modules (High Voltage Power Supply Model 556, Spectroscopy Amplifier model 570 and Dual Multichannel Buffer, ASPEC-927). Spectra acquisition was performed using the dedicated spectroscopy software ScintiVision 32 [6] also supplied by ORTEC.

In vivo thyroid measurements for routine monitoring were performed at time intervals of 7 days. Special monitoring measurements required for the worker who received a single accidental intake were performed at different times after the intake. The IMBA [7] software was used for the calculation of the retention fractions $m(t_i)$ after intake of 1 Bq of ^{131}I, necessary for intake evaluation and committed effective dose assessment. The following assumptions were made for ^{131}I: chemical form – vapour, regional deposition: class SR-1, absorption: Type F, particle transport model, GI tract model, bioassay and biokinetic models: ICRP Publication 78 defaults [8].

For analysis of routine monitoring data, according to ICRP 78, multiple ^{131}I intakes were considered as acute inhalations at the middle of the monitoring interval of T days. Considering M as the measured quantity and $m(T/2)$ as the predicted value of the measured quantity for a unit intake assumed to occur at the mid-point of the monitoring interval ($T/2$), the intake is given by Eq. (1) [8]:

$$I = (M - P) / m(T/2), \tag{1}$$

where the numerator takes account of the fact that the measured quantity can be influenced by contributions, P, from preceding intakes. In this case, these contributions have to be subtracted from the measured quantity for a correct estimation of the intake.

The structured method proposed in the reference [1] was applied for intake and dose evaluation following the appropriate flow charts, which consist of a series of stages with different steps.

The process of data evaluation is initiated if the monitoring value M is greater than a value of M_c. M_c is a Critical Monitoring quantity, defined as the amount of activity retained at the end of a monitoring period that corresponds to an intake which, if it was repeated for all monitoring periods during the accounting year, would result in a value of committed effective dose of 0.1 mSv in a year. It is given by Eq. (2) [1]:

$$M_C = \frac{0.1\text{mSv} \cdot m(T/2)}{e(50)} \frac{T}{365}. \tag{2}$$

For correct decisions on the occurrence of a new intake, the method supposes that the calculation of the overall uncertainty for each monitoring data is based on a log-normal distribution and geometric standard deviation SF (Scattering Factor), according to the formula given by Eq. (3):

$$\text{SF} = \exp\left[\sqrt{(\ln \text{SF}_\text{A})^2 + (\ln \text{SF}_\text{B})^2}\right], \tag{3}$$

where $\text{SF}_\text{A} = \exp[\sigma_\text{A} / M]$ is the scattering factor for the uncertainties of type A, due to counting statistics, and SF_B is the scattering factor for the uncertainties of type B with many non-statistical components[9].

The significance of monitoring data value is judged by checking one of two scenarios:

1. $M > P \cdot \text{SF}^2$; if true, this indicates the presence of a new significant intake and triggers the determination of the net measurement value by subtracting the contribution of the previous intakes from the measurement value.
2. $P/\text{SF}^2 < M < P \cdot \text{SF}^2$; if true, this indicates the absence of a significant intake.

The best estimate of intake, in the case of special monitoring, was calculated by applying the maximum likelihood method assuming a log-normal distribution with a given SF for the probability distribution of measurements. Its mathematical expression is shown in Eq. (4) [1]:

$$\ln(I) = \frac{\sum_{i=1}^{n} \frac{\ln(I_i)}{[\ln(\mathrm{SF}_i)]^2}}{\sum_{i=1}^{n} \frac{1}{[\ln(\mathrm{SF}_i)]^2}}, \quad (4)$$

where $I_i = M_i / m(t_i)$ represents the intake calculated from the i^{th} measurement value.

In addition, for comparison, the intake was also calculated, applying the unweighted least squares method assuming a normal distribution of the uncertainty on the data [10].

3. RESULTS AND DISCUSSION

Applying the structured approach to the interpretation of the measurement data for routine monitoring shown in Table 1 (monitoring interval of 7 days), appropriate flow charts were obtained for our process of evaluation of intakes leading to doses less than 1 mSv.

Table 1

Data for intake evaluation – routine monitoring

Day of monitoring	M-Measured Activity [Bq]	Monitoring intervals [days]	M_C [Bq]
7	300	7	19
14	*150*	7/*14*	19/*27*
21	200	7	19
28	*100*	7/*14*	19/*27*
35	1300	7	19
42	*1000*	7/*14*	19/*27*
49	500	7	19
56	*1300*	7/*14*	19/*27*
63	650	7	19
70	*1500*	7/*14*	19/*27*

According to Stage 1, presented in Fig. 1, all measurement data were used for evaluation, because they exceeded the values of the Critical Monitoring quantity calculated according to Eq. (2).

From the 10 monitoring values, only 6 were found to have been generated by new intakes, the others representing contributions of previous intakes only. The data analysis followed the steps of Stage 2 (Fig. 2), applying the criteria for statistical significance of the monitoring value *M*.

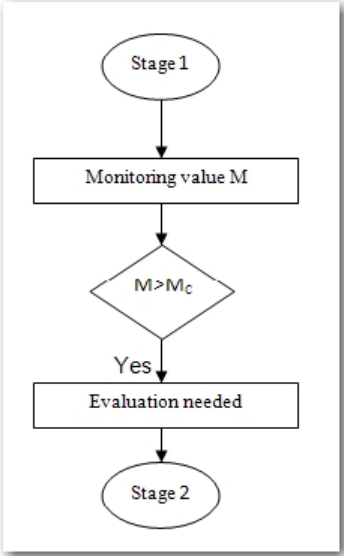

Fig. 1 – Block diagram of Stage 1.

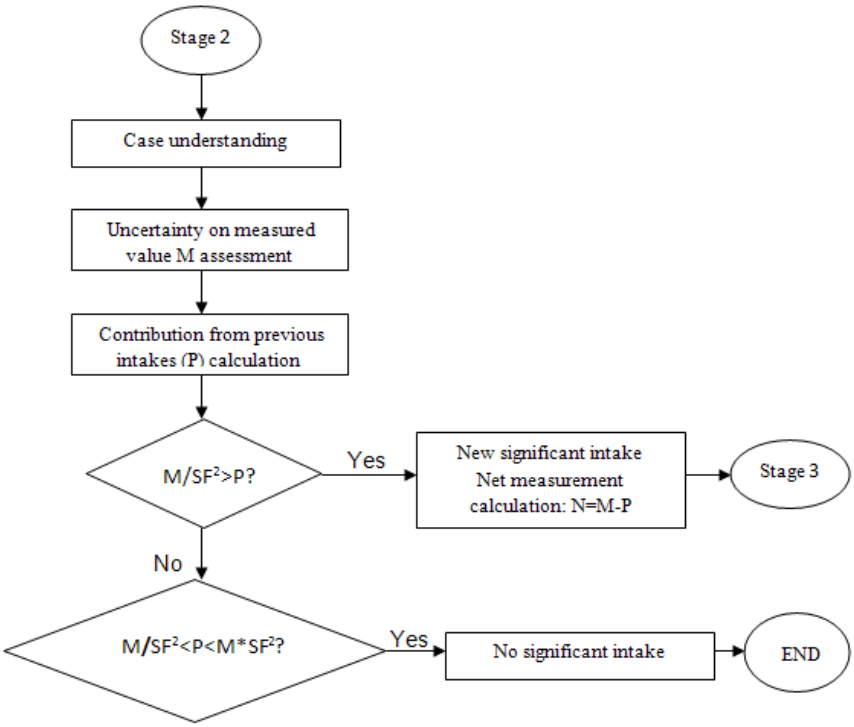

Fig. 2 – Block diagram of Stage 2.

For the type A uncertainty, a value of 10% was assumed, resulting in a value of 1.11 for SF_A.

For the type B component of the scattering factor, SF_B, a value of 1.15 was assumed for *in vivo* measurements of radionuclides emitting high photon energy radiation [1].

Following Stage 3 (Fig. 3), the multiple intakes shown in Table 2 were determined based on the net values of ^{131}I activity as indicated in Eq. (1).

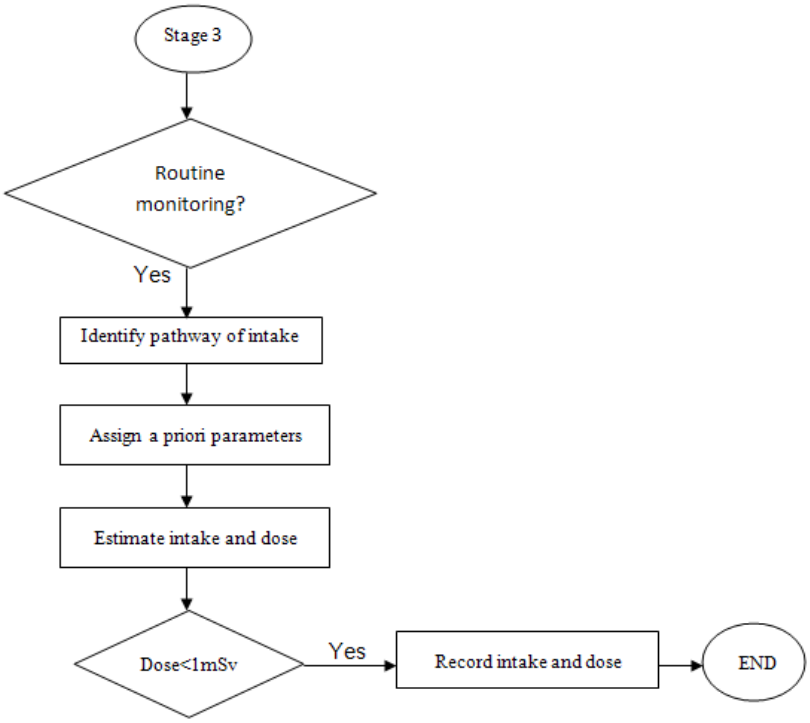

Fig. 3 – Dose assessment for Routine Monitoring.

Table 2

Intake results – 7 days interval

Day of intake	Intake [Bq]
4	1 600
17	700
31	6 500
38	1 900
52	5 400
66	6 000
Total	**22 100**

The contributions of the intakes to the successive measurements are presented in Table 3, where *x* means that the measurement data are associated with a new intake. These values are quite significant, requiring special attention to be given to their evaluation.

Table 3

Contribution of the intakes on the successive measurements (P quantity)

Measurement/ Intake [Bq]	1	2	3	4	5	6	7	8	9	10
1	X	150	77	40	21	11	6	3	2	0
2		–	X	60	30	16	9	5	3	0
3		–	–	–	X	615	320	165	85	45
4		–	–	–	–	X	175	90	45	25
5		–	–	–	–	–	–	X	511	265
6		–	–	–	–	–	–	–	–	X

A total ^{131}I intake of 22 100 Bq and an associated committed effective dose of approximately 0.50 mSv [11] were obtained for the monitoring interval of 7 days.

For comparison, using part of the same series of data, namely alternate values, emphasized in Table 1, the same quantities were determined using a monitoring interval of 14 days. In this case, all the 5 monitoring values had generated new intakes, resulting in similar values to those estimated for the 7 day monitoring interval, namely, a total ^{131}I intake of 24 000 Bq and a committed effective dose of 0.5 mSv. These results, presented in Table 4, had a significant impact on monitoring planning, on the selection of methods and the annual frequencies of monitoring.

Table 4

Intake results – 14 day interval

Day of intake	Intake [Bq]
7	1 100
21	500
35	7 000
49	7 000
63	8 400
Total	**24 000**

For the special monitoring case of internal contamination with ^{131}I, three measurements were performed, the monitoring data being presented in Table 5. The flow chart applied in our case for special monitoring is shown in Fig. 4.

Table 5

Data for intake evaluation – Special Monitoring

Day of monitoring	Measured Activity [Bq]
2	10 400
5	7 700
8	6 500

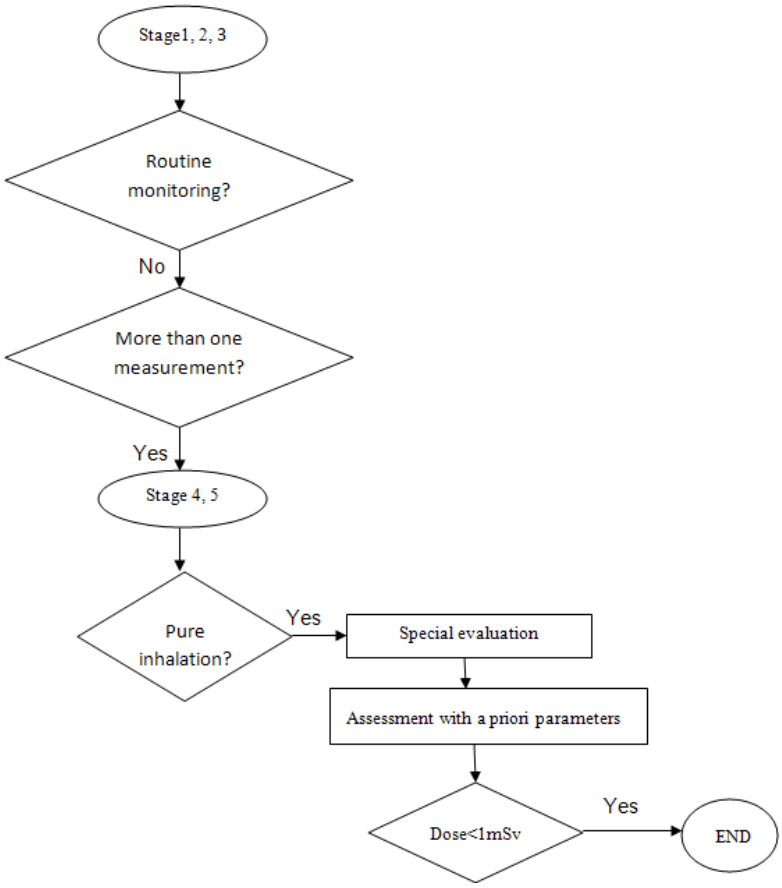

Fig. 4 – Dose assessment for Special Monitoring.

The intake, assuming the log-normal and the normal distribution for the overall uncertainty, was calculated as approximately 47 800 Bq and 47 200 Bq, respectively. The small difference between them demonstrates that the model used for the predicted values of the measured quantities for 1 Bq intake fits the measurement data very well. In this case, the assumed distribution has only a minor influence on the intake value.

The associated doses were calculated as 98.9E-05 Sv and 98.3E-05 Sv, respectively.

4. CONCLUSIONS

The structured method for the evaluation of ^{131}I intakes through inhalation and associated doses was applied at WBML to monitoring data resulting from thyroid routine and special monitoring. The method is valuable because it applies qualitative and quantitative criteria for dose assessment, proposing appropriate procedures for each level of risk to occupational exposure, with risk classified according to three categories: no risk, low risk and high risk for dose ranges of 0.1–1 mSv, 1–6 mSv and greater than 6 mSv, respectively [12]. The statistical criteria applied in all stages of the method are, undoubtedly, a new approach to dose assessment that allows the reliability of the measurement data to be checked. If the special monitoring case described here can be considered to be at the limit of the "no risk" category, the analysis of the routine monitoring data obtained during 2 months of measurements can be allocated to the "low risk" category, taking into account the other intakes that occurred up to the end of the year, in similar work conditions. The insignificant difference between the values of total intakes estimated for routine monitoring assuming 7 and 14 day measurement intervals confirms the suggestion made in the EURADOS Report [1] for routine monitoring programme planning, namely, to consider a maximum 15 days measurement period in the case of ^{131}I intake, in order to obtain reliable results. The un-weighted least squares method, considered as a special case of the maximum likelihood method, can be used for intake assessment in the case of acute intake, provided that the measurement data are predicted very well by the model for inhalation of ^{131}I.

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