Proposed Guideline for dose assessment after exposure to I-131 in an accidental situation

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Abstract. The events in which individuals may become internally contaminated with I-131 cover a wide range of possible situations, ranging from an accidental exposure in a medical, industrial or research environment that involves only a few people to an accident at a nuclear power plant or a radiological terrorist event, with dozens of potentially contaminated individuals. Dose evaluations of these individuals may include the analysis of bioassays: such as the measurement of thyroid, urine and/or nasal samples. These measurements may support medical decisions, which may be based on the projected thyroid dose and/or the effective dose. The purpose of dose assessment in these situations is to provide objective information that contributes to make decisions about follow-up actions after an incident, to comply with legal regulations and to improve conditions in the workplace. In this work, it is proposed a nine-step guideline for the assessment of exposure to I-131 after real or suspected abnormal events or in the case of a positive result during triage or routine monitoring. This methodology allows giving recommendations on the type, number and time at which measurements should be made. This guideline provides an effective handling of I-131 accidental exposures, contributing in the support for decision-making on follow-up actions (e.g. thyroid blockade with KI), as well as it allows verifying compliance with the legal regulations.

KEYWORDS: I-131 accidental exposure, thyroid dose, dose assessment

1 INTRODUCTION

The events in which individuals may become internally contaminated with I-131 cover a wide range of possible situations. On the one hand, an accident at a nuclear power plant or a radiological terrorist event involving the dispersion of this radionuclide with dozens of potentially contaminated individuals. To handle this type of larger events, the estimate of the potential dose can be calculated through specialized software. On the other hand, the event can be an accidental exposure in a medical, industrial or research environment that involves only a few people. In this case, dose evaluations of these individuals include the analysis of bioassays, such as the measurement of the thyroid gland, nasal samples and/or urine. These measurements can support medical decisions based on the projected thyroid dose and/or the effective dose [1].

Currently different recommendations or evaluations exist at the international level to guide the actions and dose assessment after exposure to I-131 in an accidental situation. In this work, the last recommendations from IAEA, ICRP, NCRP, REAC/TS, EURADOS, ISO, and WHO were compiled and analyzed to produce a harmonized guideline based on new trends on internal dosimetry to support regulatory bodies and final users.

2 INTERNATIONAL RECOMMENDATIONS FOR IODINE PROPHYLAXIS

As internal contamination with radioactive iodine does not cause by itself early clinical signs and symptoms, three important quantities must be evaluated during an internal exposure situation involving I-131:
1. AD $(\Delta)_{THY}$: RBE-weighted averaged absorbed dose in thyroid for evaluating deterministic effects, calculated using a 30-day commitment period.
2. H_{THY}: Thyroid equivalent dose to assess the probability of occurrence of stochastic effects in the thyroid.
3. E: Effective dose to evaluate the detriment related to occurrence of stochastic effects.

IAEA provides a generic criteria [2] for doses received due to an acute intake of 2 Gy of $AD(30d)_{THY}$, to avoid or to minimize severe deterministic effects in thyroid (hypothyroidism), and 50 mSv of H_{THY} in the first 7 days, as indicative to thyroid blockade with KI [3]. These generic criteria are estimated to

a reference person. Due to the strong evidence of an age-dependent risk induced by radioactive iodine the administration of stable iodine may be recommended at significantly lower levels of projected dose to recognize the higher sensitivity of children and the unborn [4]. Table 1 shows a specific guide that recommends the treatment of radioactive iodine intake considering the projected thyroid dose, with different guidance according to the risk group [5]. In this work, the reference levels of projected dose recommended by FDA were taken as a basis to develop the reference levels of intake of I-131, which are the intake values for which iodine prophylaxis is recommended.

Table 1. Reference levels of intervention and recommended doses of KI for different risk groups by WHO and FDA [5, 6].

Group	Reference Levels: Projected dose to thyroid (mGy)		KI Mass (mg)	
	WHO	FDA	WHO	FDA
Adult>40	5000	5000	130	130
Adults 18 - 40 y	100	100	130	130
Pregnancy or lactation	10	50	130	130
Age 12 - 18 y	10	50	130	130
Age 7 - 12 y	10	50	130	65
Age 3 - 7 y	10	50	65	65
Age 0.5 - 3 y	10	50	32	32
Age <0.5 y	10	50	16	16

In particular, the administration of stable iodine is recommended previous the release of this radionuclide into the environment (in case of a nuclear accident) or as soon as possible after the intake. In some countries, it is suggested the intake of KI several hours before the start of the release of I-131 into the environment up to 12 hours after the intake of this radionuclide when intervention levels are exceeded [5]. In relation to adverse effects, thyroid blocking can lead to a reduction in metabolic activity and eventually, a compensatory increase in the volume of the gland. In general, these effects are not observed in normal individuals after administration of KI for a period not exceeding two weeks [3]. The reference levels of intake of I-131 for which iodine prophylaxis is recommended were estimated, and are depicted in table 2 as Reference Levels of Intervention (RLIs) for each age group, as well as the dose coefficients to estimate the effective dose and the projected dose to thyroid from a known intake of I-131 [7].

Table 2. Reference Levels of Intervention (RLIs) and Dose coefficients for acute intake of I-131.

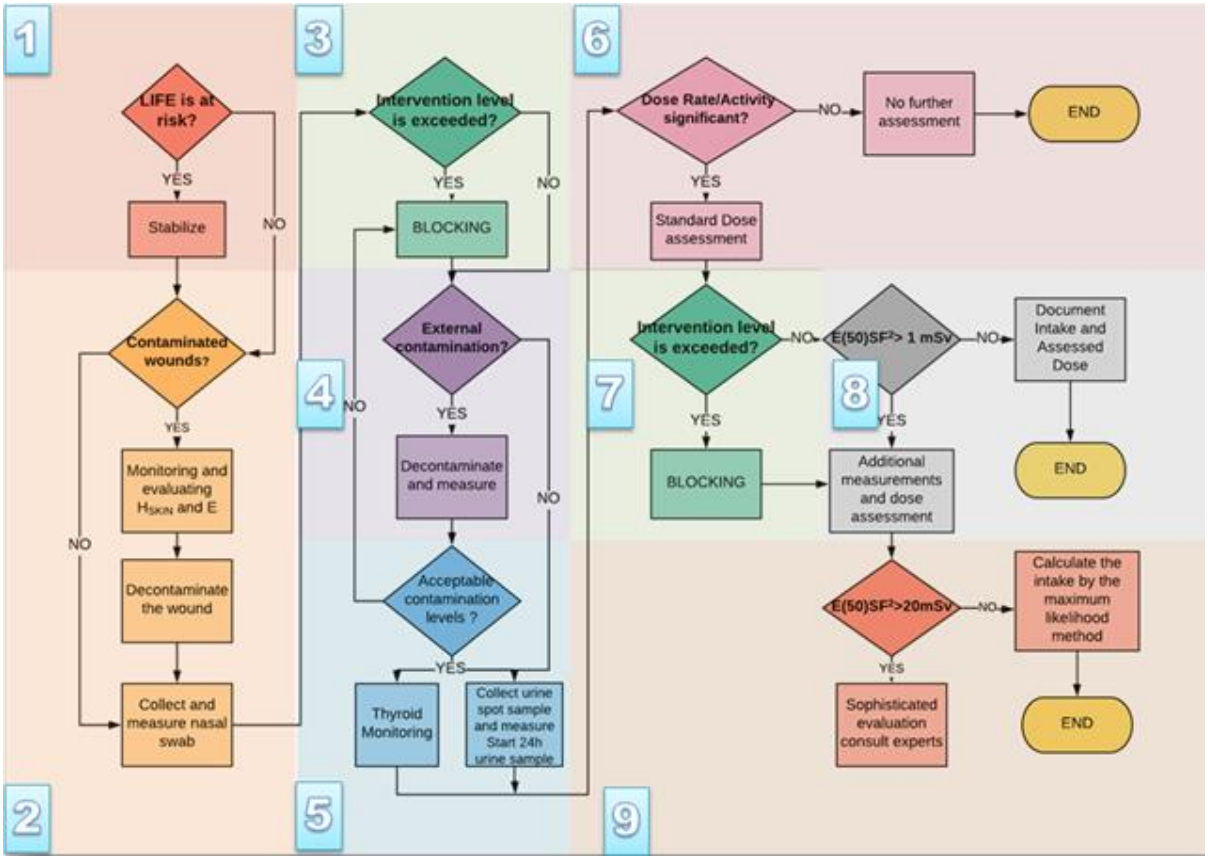
Group	RLI (Bq)	$h_{THY}(\tau)$ (Sv/Bq)[(a)]	$e(\tau)$ (Sv/Bq) [(a)]
Adult>40	1.30E+07	3.90E-07	2.00E-08
Adults 18 - 40 y	2.60E+05	3.90E-07	2.00E-08
Pregnancy or lactation	1.30E+05	3.90E-07	2.00E-08
Age 12 - 18 y	8.10E+04	6.20E-07	3.10E-08
Age 7 - 12 y	5.30E+04	9.50E-07	4.80E-08
Age 3 - 7 y	2.60E+04	1.90E-06	9.40E-08
Age 0.5 - 3 y	1.60E+04	3.20E-06	1.60E-07
Age <0.5 y	1.50E+04	3.30E-06	1.70E-07

[(a)] Where τ is the time period in years over which the dose is calculated, i.e. 50 y for adults and from intake to age 70 y for infants and children.

3 PROPOSED GUIDELINE FOR DOSE ASSESSMENT AFTER EXPOSURE TO I-131

After real or suspected abnormal events or in the case of a positive result during triage or routine monitoring a dose assessment is needed. A nine-step guide for the assessment of exposure to I-131 is proposed (Fig.1). At each level a question is made and the actions to be taken depend on the answer.

Figure 1: Nine-step guideline for the assessment of exposure to I-131



Step 1. Is life at risk? Yes, stabilize. Monitoring of vital signs and the control of hemorrhages, if they occur, are a priority over considerations of exposure and/or external or internal contamination. Clinical signs and symptoms can be used to estimate a radiation dose to a patient. This includes time to emesis and a decline in the lymphocyte count post-irradiation [8].

Step 2. Are there contaminated wounds? YES, monitoring and evaluating H_{SKIN} and E. Once all the lesions have been stabilized, radiological triage should be performed. When open wounds are present, they should be treated on a case-by-case basis. Monitoring of local activity around the site of the wound should be implemented, and if it is appropriate, the object that caused the wound, dressings, compresses and excised tissue to assess the equivalent dose in the area of the injured skin [9].
If all the measurements on the individual or the object that caused the wound are above the detection limit, the estimated risk of exposure is significant [9]. If the measurements are above 100 Bq cm^{-2} decontamination or showering is advised but if the measurements are above 1000 Bq cm^{-2} or 0.2 µSv h^{-1} iodine prophylaxis is recommended (Table 3).

As the person is decontaminated, skin dose can be assessed. In order to do this, the activity spread over the skin, the contaminated skin area, and the contamination duration (t) should be considered. In the case of skin surface contamination, the skin dose H_p (0.07) µSv, is calculated using the expression 1 defined in ISO 15382 [10]:

$$H_p(0.07) = A_{F,0} \times I_C \times \lambda^{-1} \times (1 - e^{-\lambda t}) \quad (1)$$

Where

$A_{f,0}$ is the activity per unit area at the beginning of the contamination, in Bq cm^{-2};
I_C is the localized skin dose rate factor (1.4 µSv cm^2 h^{-1} $Bq^{-1}$for I-131);
λ is the decay constant, in hours;

t is the duration of skin contamination, in hours.

If the wound is measured within the first 3 hours after exposure, it can be assumed that the measurement corresponds to 27% of the intake and the coefficients register in table 2, can be used to estimate H_{THY} and E. NCRP 156 [11] describes a more precise model for workers, and the following coefficients can be used assuming that I-131 is weakly retained in wounds: $h_{THY}(50) = 4.24 \times 10^{-7}$ Sv Bq^{-1} and $e(50) = 2.13 \times 10^{-8}$ Sv Bq^{-1}.

Table 3: Recommended actions based on the measurement levels of contaminated wound or skin [7, 12]

Bq cm^{-2} (nCi cm^{-2}) [dpm cm^{-2}]	µSv h^{-1} (µrem h^{-1}) in low background area	Actions
<100 (<2.7) [<6,000]	Not detectable	*No actions* •Assure people that there is no significant health risk and inform them where to get additional information. •Allow release
>100 (>2.7) [>6,000]	Not detectable	*Intervention optional* •Decontaminate or advise to shower and wash clothing. •Assure them that there is no significant health risk and inform them where to get additional information. •Slow release
>1,000 (>27) [>60,000]	0.2 - 0.3 (20 – 30)	*Intervention advisable* •Prevent inadvertent ingestion and inhalation, limit spread of contamination and decontaminate. •**Give stable iodine prophylaxis if radioiodine is involved.** •Consider registry for long term medical follow-up. •Perform comprehensive psychological counselling (in particular for pregnant women).
>10,000 (>270) [>600,000]	2-3 (200 – 300)	*Intervention required* •Prevent inadvertent ingestion and inhalation, limit spread of contamination and decontaminate. •**Give stable iodine prophylaxis if radioiodine is involved.** •Perform medical examination and indicated treatment •Registry for long term medical follow - up •Perform comprehensive psychological counselling (in particular for pregnant women).

Step 2.1 Decontaminate the wound: Local decontamination with plenty of warm water and neutral soap.

Step 2.2 Collect and measure nasal swabs: Once the wounds have been evaluated or in the absence of it, proceed to collect the nasal swabs. A general estimation can be done assuming that the average activity measured on the nasal swabs represents the 5% of the intake [8]. Table 4 shows and the nasal swabs measurements values corresponding to the RLIs, calculated in Bq and dpm for each group.
A negative test (nasal or oral swabs) does not rule out the possibility of internal contamination.

Step 3. Is intervention level exceeded? YES, iodine prophylaxis. Iodine prophylaxis is recommended if the measurements are performed within 10 hours after intake (See Table 1). If the answer is no, go to step 4.

Step 4. Is there external contamination? YES, decontamination and assessment of H_{skin}. The removal of all clothing will generally eliminate approximately 90% of external contamination [13]. If

contamination persists, a shower may be required. If the water and soap do not eliminate all contamination, there is a possibility that the contamination is internal. Assessment of H_{skin} is performed as shown on step 2. In case of negative results, internal contamination cannot be excluded.

Step 5. Are contamination levels acceptable? YES, Urine samples and direct thyroid measurements.

Table 4: Nasal swabs measurements values corresponding to the RLIs.

Groups	RLI (Bq)	Nasal Swabs Measurement (Bq)	Nasal Swabs Measurement (dpm)
Adults>40	1.30E+07	6.50E+05	3.90E+07
Adults18 -40 y	2.60E+05	1.30E+04	7.80E+05
Pregnancy or lactation	1.30E+05	6.50E+03	3.90E+05
Age 12 - 18 y	8.10E+04	4.05E+03	2.43E+05
Age 7 - 12 y	5.30E+04	2.65E+03	1.59E+05
Age 3 - 7 y	2.60E+04	1.30E+03	7.80E+04
Age 0.5 - 3 y	1.60E+04	8.00E+02	4.80E+04
Age <0.5 y	1.50E+04	7.50E+02	4.50E+04

Step 5.1 Urine samples: Urine bioassay is one of the most commonly used methods for assessing the intake of I-131. 24 hour samples are preferred as biokinetic models, used for interpretation of the data, are based on daily excretion rates. However, during an emergency that involves a large number of individuals, spot samples are more convenient. The measurements from spot samples can be normalized by using volume levels to reflect daily excretion, as shown in table 5. Usually, the first sample is collected as soon as possible after the exposure and additional samples will be required during the following days, which may be spot or 24 hours. Sequential samples are necessary for the assessment of the intake and would be used in the future to follow up the efficacy of the treatment.

Table 5: Reference values for 24 h urine volume [14]

Age	Excretion (ml d^{-1})	
	Male	Female
Age <0.5 y	300	300
Age 0.5 - 3 y	400	400
Age 3 - 7 y	500	500
Age 7 - 12 y	700	700
Age 12 - 18 y	1200	1200
Adult	1600	1200

Step 5.2 *In vivo* thyroid measurements: It is the most accurate bioassay to assess internal contamination with I-131. These measurements should be made until 20 days after the intake as further measurements may not have a proper sensitivity. First, a triage of the internal contamination should be performed positioning the detector as close to the neck as possible. If a properly calibrated spectrometric instrument is available, the value of activity retained in the thyroid can be obtained directly at the time of measurement. Recommendations about correction factors and considerations about the calibration of these instruments to measure the different age groups can be found in the CAThyMARA report: "Technical guidelines for radioiodine in thyroid monitoring" [15].

If it is not possible to perform the measurement on a child, the dose should be calculated from the measurements of an adult that accompanied at the moment the intake occurred. The intake can be

inferred from the intake of this adult, taking into account the relationship between the respiratory volume between the adult and the child.

Step 6. Is the dose rate/activity on the thyroid significant? YES, Standard dose assessment

Step 6.1 Dose rate assessment: If the thyroid measurement is performed with a monitor in dose rate, the value of the dose rate measured on the thyroid can be compared with the predetermined operational intervention level (OIL) for thyroid monitoring provided by the IAEA [16]. The default value for OIL for thyroid monitoring is 0.5 μSv h^{-1} above the background and is applicable for gamma dose rate meters that meet the following criteria:

- An effective window area <15 cm^2.
- A response greater than 0.1 μSv h^{-1} per kBq of I-131 in thyroid.
- If the measurement is made within 10 hours after intake.
- If the background environmental dose is less than 0.25 μSv h^{-1}.

IAEA [16] indicates that if the dose rate is less than 0.5 μSv h^{-1}, no action is necessary. But if the dose rate is greater than 0.5 μSv h^{-1}, stable iodine should be taken and a medical examination should be performed.

Step 6.2 Thyroid activity assessment: If a positive value of I-131 activity is obtained on the thyroid, considering the person age and the estimated time between the intake and the measurement *t*, and the dose coefficient per unit of activity measured in the thyroid corresponding to $z_{I-131}^{Thy(30\,d)}(t,\ age)$, the committed dose absorbed in 30 days in the thyroid can be assessed using this expression:

$$D_{I-131}^{Thy(30\,d)} = M(t) \times z_{I-131}^{Thy(30\,d)}(t,\ age) \tag{2}$$

The coefficients $z_{I-131}^{Thy(30\,d)}(t,\ age)$ can be found in the CAThyMARA report [15]. During a nuclear emergency, the intake of I-131 may be accompanied by other short life iodines I-132, I-133, I-134, I-135, and Te-132. In this case, the dose in the thyroid gland can be adjusted with the use of correction coefficients, which are available also in the CAThyMARA report [15].

Step 7. Is intervention level exceeded? YES, iodine prophylaxis. Proceed to thyroid block with KI if it has not already been administrated and if the measurement has been performed within 10 hours after intake. Next go to step 8. If intervention level is not exceeded go directly to step 8.

Step 8. Is estimated dose above 1 mSv? YES, perform additional thyroid and urine measurements and estimate the dose. The number of measurements and the time range, in which they should be performed, depends on the potential effective dose, as shown in Table 6:

Table 6: Number of measurements and time range, depending on the potential effective dose [9,17].

Radio-nuclide	Bioassay	Monitoring Required Data					
		E < 1mSv		1mSv < E < 6mSv		E > 6mSv	
		Number	Range (days)	Number	Range (days)	Number	Range (days)
I-131	Thyroid	1	-	2	7	4	14
	Urine	-	-	2	7	4	14

If the dose is less than 1 mSv, document the dose and the intake. If it is above 1 mSv, go to step 9.

Step 9. Is estimated dose more than 20 mSv? YES, sophisticated evaluation (consult experts). To determine if the dose limit for workers is potentially exceeded, each measurement (M) should be compared with the values in Table 7.

If M <A* it can be affirmed, with a high level of confidence, that E(50) is below the annual dose limit of 20 mSv.
If A* <M <B*, E(50) could be below or above the annual dose limit of 20 mSv.
If M> B* it can be affirmed, with a high level of confidence, that E(50) is above the annual dose limit of 20 mSv.

If the dose does not exceed 20 mSv, the intake should be estimated using with the Maximum Likelihood Method [17].

Table 7: Iodine -131 range of thyroid activities (Bq) for a dose reference level of 20 mSv [18].

Time after intake in days	Thyroid activity (Bq) for a dose reference level of 20 mSv	
	A*: Minimum Value	B*: Maximum value
1	2.27E5	2.29E5
2	2.27E5	2.27E5
5	1.72E5	1.72E5
10	1.07E5	1.07E5
20	4.20E4	4.21E4
50	2.58E3	2.59E3
100	2.52E1	2.53E1
180	1.53E-2	1.54E-2

Even though the committed effective dose in this point could be greater than 20 mSv, the absorbed dose committed to 30 days in the thyroid is already calculated in step 6 (expression 2), which is the pertinent measure of risk in this case because is more restrictive than the effective dose [7]. What is done in this step is to give more precision to the calculation of the committed effective dose with a greater number of measurements. Then, if the committed effective dose is still greater than 20 mSv, it is necessary to use advanced methods to specify it, and therefore it is recommended that an expert perform these calculations. Nevertheless, at this point an estimate of the committed absorbed dose to thyroid has already been given and it has been evaluated whether it is necessary or not to take a protective measure (thyroid blocking).

4 CONCLUSIONS

In this work, it was proposed a nine-step guideline for the assessment of exposure to I-131 after real or suspected abnormal events or in the case of a positive result during triage or routine monitoring. This methodology allows giving recommendations on the type, number and time at which measurements should be made, highlighting when the urgent protective action of the thyroid block should be taken. Therefore, this guide provides an effective handling of I-131 accidental exposures in a practical way. It gives support for decision-making on follow-up actions for regulators and final users, as well as it allows verifying compliance with the legal regulations. Finally, this guidance attempt to assist internal dosimetry laboratories, health physicists and medical staff to deal with internal exposure to I-131 in Argentina, and could be used in countries without specific criteria or guides for the assessment of these situations.

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