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Child and adult thyroid monitoring after a reactor accident (CAThyMARA): Technical recommendations and remaining gaps

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A B S T R A C T

Following a severe nuclear reactor accident large amounts of radioactive iodine are released in the atmosphere. Health consequences estimation for the affected population is based on the dose assessment which can be derived from *in vivo* measurements. Since the uptake of radioactive iodine increases the thyroid cancer risk of children it is of particular interest to dispose of technical recommendations on thyroid monitoring, particularly for children.

This paper summarizes recommendations that have been issued by a group of European radiation protection specialists during the CAThyMARA project. It covers technical aspects such as the choice of instruments, the calibration process, the measurement preparedness, the dose assessment and communication issues. This paper also discusses remaining gaps and serves as an introduction to other papers of this special issue.

1. Introduction

Following a nuclear accident, like the Chernobyl or Fukushima Daiichi accident, large amounts of radionuclides are released in the atmosphere. In the early stage of the accident direct irradiation by the passing radioactive cloud and direct inhalation of radionuclides affect the population and workers, in latter stages consumption of contaminated foods is a potential hazard as well as irradiation due to ground deposition.

Estimation of the early or late radiation-induced health consequences for the affected population is based on the dose assessment which can be obtained by different ways. Schematically, dose maps can be calculated and continuously refined as more information is available on the content of the release; dose can also be based on local environment monitoring; finally the dose can be assessed from individual monitoring.

Individual monitoring of the internal exposure can be carried out by measurements of the excreta or by direct *in vivo* measurements, which consists in measuring the radiation emitted by the body, or specific organs (ICRU, 2003); from the measurements the committed effective

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dose or organ doses can be deduced (Breustedt et al., 2018; Davesne et al., 2018). The ICRP set-up a task group to draw lessons from the Fukushima Daiichi accident and acknowledged that ICRP does not recommend individual monitoring of the public in case of emergency exposure (González et al., 2013). However it also acknowledged that individual monitoring might "have been insufficient" and that they provide "*invaluable data*" and "*reassurance*" to the affected population. In (Li et al., 2016) it is stated that "*population monitoring is an essential element of the response to a radiological and nuclear emergency*". Furthermore, in Japan, thyroid doses predicted from dispersion modelling were found to overestimate doses deduced from individual monitoring (Kim et al., 2016); in the contaminated territories of Russia it was also shown that large discrepancies can be found between thyroid doses assessed from direct measurements and assessed from models (Stepanenko et al., 2004).

In practice, all of the radionuclides released in a nuclear accident cannot be detected by *in vivo* measurements: some are released in relatively small amount and others are short-lived. The Fukushima Daiichi and Chernobyl experience have shown that in most cases only ^{134,137}Cs and ^{131}I are measured (Kurihara et al., 2014; Stepanenko et al., 1996) even if other radionuclides such as ^{132}I, ^{133}I, ^{132}Te have been detected in early measurements (Balonov et al., 2003; Lopez et al., 2016).

Iodine-131 is of particular interest since it is one of the major releases, since its half-life is relatively long as compared with other radioactive iodine isotopes and since radioactive iodine might increase the risk of thyroid cancer in adults (Cardis and Hatch, 2011). The health hazard of radioactive iodine is particularly crucial for children since, contrary to adults, exposure in childhood is associated with an increased risk of developing thyroid cancer (Cardis et al., 2005; Cardis and Hatch, 2011). Following the Fukushima Daiichi accident the UNSCEAR recalled that "*It is particularly important to consider the absorbed doses to the thyroid of infants from intakes of radioiodine because of the radiosensitivity of their thyroids.*" (UNSCEAR, 2013).

Assessment of the thyroid dose in children by *in vivo* measurements raises metrological problems, mainly because the calibration of *in vivo* measurement system is usually carried with an adult thyroid phantom. Consequently the retained activity deduced from measurements does not account for the thyroid size of the children that varies between a few cubic centimeters around 5 years and 20 cm^3 for adults. During the Fukushima Daiichi accident thyroid measurement campaigns have been carried out for children, despite efforts being made to take into account age dependent calibration factors, child specific calibration phantoms would have reduced the uncertainties of measurement and thus of dose assessment (Kim et al., 2012).

Other issues concerning emergency assessment of internal contaminations are of importance: how to deal with short lived radio-isotopes, how to assess doses from measurements taking into the age, what is the state of preparedness of European countries, how to take into account measurements carried out by citizens, how to communicate results properly? As highlighted in (González et al., 2013; Li et al., 2016) there are many disperse documents dealing with these issues but there is a clear lack of standardization and practical guidelines.

The CAThyMARA project addressed some of the issues introduced above. The first section of this article presents the topics covered during the CAThyMARA project and introduces the other articles of this special issue. The second section presents the most relevant points of the "*Technical guidelines for radioiodine in thyroid monitoring*" issued during the project. The last section discusses remaining gaps.

2. Outline and outcomes of the CAThyMARA project

Having in mind the need for preparedness of children thyroid measurements and some of the issues explained above a project was submitted to the European Commission within the framework of the OPERRA (OPERRA, 2018) project. This project gathered 41 radiation measurement and dosimetry specialists from 13 Institutes, most of the members of the project were already involved in common projects within the EURADOS network (Lopez et al., 2011). The CAThyMARA project (Child and Adult Thyroid Monitoring After Reactor accident) was selected by the OPERRA board and received funding for 18 months, the project started on December 2015.

2.1. Topics covered

The CAThyMARA project focused on the following topics.

1. Review the international recommendations regarding emergency measurements of the public, focusing on internal exposure, thyroid measurements and the children case.
2. Study the state of preparedness of European countries regarding the same points than in (1) and study how the state of preparedness complies with international recommendations.

These two topics are covered in (Monteiro Gil et al., 2019).

3. Assess the degree of performance of adult and children thyroid measurements with spectroscopic and non-spectroscopic devices.

For that purpose two intercomparisons of measurements with thyroid phantoms were carried out. After the closure of the intercomparison participating teams were given the activity of the phantom to help in future harmonization of measurements practice. This topic is covered in (Lebacq et al., 2019) for spectroscopic devices and in (Isaksson et al., 2019) for non-spectroscopic devices.

4. Study the factors affecting the calibration coefficients of thyroid measurements by means of Monte-Carlo calculations.

For that purpose human voxel models were considered and factors such as the counting distance, thyroid volume and time since intake were studied. This topic is covered in (Gómez-Ros et al., 2019).

5. Provide free and exhaustive compendium of conversion coefficient to interpret the thyroid measurements in term of committed effective dose and thyroid dose.

The compendium is exhaustive in that sense that it takes into account: measurement time since intake, different ages (including the foetus case), several radioactive iodine isotopes, correction factors for short-lived radioactive iodine isotopes that cannot be measured and finally the case of iodine-prophylaxis. Only the inhalation case has been treated, due first to the limited time of the project. Then, because we started from the hypothesis that in a potential future reactor accident food and drink ban would be efficiently implemented. The methods and results related with the compendium of dose coefficient are covered in (Berkovskyy et al., 2019) while the case of iodine prophylaxis is covered in (Broggio et al., 2019).

6. How to guarantee reliable measurements of thyroid internal exposure when the measurements are carried out by the citizens themselves and what could radiation protection bodies do to support such measurements?

This topic is covered in (Fojtík et al., 2019).

7. Identify needs of citizens regarding internal contamination assessment after a nuclear accident.

For that purpose we took into account the Fukushima Daiichi and Chernobyl experience and views expressed by an independent European network of civil society organizations: Nuclear Transparency

Watch. Methods and identified needs are covered in (Baudé, 2019).

2.2. Outcomes of the CAThyMARA project

The results of the CAThyMARA project consist of seven reports covering the items (1) to (7) and on two guidelines.

The first guidelines "*Guidelines for development of monitoring strategies and derivation of reference levels*" are rather oriented to decision makers so that a general organisation can be established to face with a nuclear emergency situation. The guidelines focus on monitoring of ^{131}I but have been extended to cover monitoring of external contamination and other types of internal contamination. The issues covered in (7) and related with communicating the results to the public have been included in these guidelines. These guidelines are not presented in this special issue but can be downloaded elsewhere (CAThyMARA, 2018).

The second guidelines "*Technical guidelines for radioiodine in thyroid monitoring*" are rather oriented to measurement specialists or specialists in charge of dose assessment. Details on their content and their connections with other articles of this special issue are given in section 2.

2.3. Rationale for another public dissemination

The results of the CAThyMARA project have been made publically available on the ResearchGate platform (CAThyMARA, 2018). However, we believed that another public dissemination of the results was necessary for the following reasons.

The results obtained during the project were internally reviewed but not peer-reviewed by external anonymous reviewers. Having anonymous peer-reviewing for the articles presented in this issue makes the results more reliable.

The reports made publically available might lack of concision (may be at the exception of the guidelines), since more than 600 pages were produced. This special issue is the occasion to present more concisely the main outcomes and to help the readers who consult publically available reports.

The results about the interpretation of thyroid measurement after iodine prophylaxis were not in their final form by the official termination of the project.

Publishing results in a journal offer a supplementary guarantee for the long term accessibility of the results.

3. Technical guidelines for radioactive iodine in thyroid monitoring with focus on the most important items

3.1. Monitoring equipment

(a) Spectrometric instruments are preferred over non-spectrometric instruments, because they make it possible to identify gamma-emitting radionuclides.
(b) Detectors with small crystal size such as cadmium zinc telluride (CZT) or caesium iodide (CsI) should be considered for thyroid monitoring of very young children. Indeed typical NaI detectors do not allow setting up the detector in contact with the neck (Fig. 1).
(c) Shielding and collimation of the detector are recommended but not essential.
(d) As revealed by the intercomparison exercise and shown elsewhere (Dantas et al., 2007; Scuffham et al., 2016) gamma-camera of hospital can be used for thyroid monitoring provided that the collimators are removed.
(e) Portable non-spectrometric instruments (radiometers, dosimeters, count-rate meters), properly calibrated, can be used for thyroid monitoring, as revealed by the intercomparison exercise.

Table 1
Recommended age-dependent thyroid volume (cm^3).

1 year	*5 years*	*10 years*	*15 years*	*Adult (Male)*
1.7	*3.2*	*7.5*	*11.4*	*19.05*

3.2. Calibration and detection limits

(a) The background must be subtracted to calibration and subjects' measurements.

For non-spectrometric instruments the background should be measured on another body part of the subject (e.g. the thigh, forearm or shoulder). For spectroscopic device the background is measured in the absence of the subject.

(b) Detectors should be calibrated with age-specific bi-lobed thyroid phantoms with volumes as recommended by ICRP (ICRP, 2002), as given in Table 1.

Examples of such phantoms have been developed by SCK•CEN (Karachalias, 2013) and IRSN (Beaumont et al., 2017). The phantoms of SCK•CEN are described in this special issue.

(c) Spectrometric instruments may be calibrated with either ^{131}I or ^{133}Ba sources.

It is recommended to calibrate non-spectrometric instruments with ^{131}I sources. If this is not possible then a mock source, as described in the paper of Isaksson et al., should be used.

(d) Neck to detector distances must be the same for calibration measurements and subject measurements. Measurements at contact of the neck are recommended.
(e) If age specific calibration factors are not available two solutions are possible.

To perform measurement at distances of at least 20 cm and apply the adult calibration, provided the detection limit of the measurement is adequate. As shown in the paper by Gómez-Ros et al. this method stands on the fact that the counting efficiency decrease as power law with distance. At 20 cm the counting efficiency difference between adult and children could be disregarded. This method is not recommended for non-spectroscopic device.

To use default correction factors as shown in Fig. 2. If the calibration factors is *F* (Bq/Instrument reading) then *F* times the value provided by the Figure gives the calibration factor for a given thyroid volume (i.e. for a specific age). These default values have been obtained

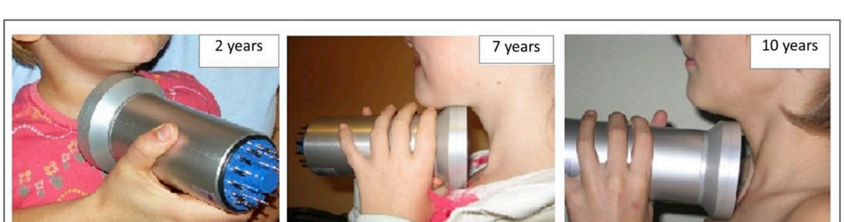

Fig. 1. For young children measurements in contact with the neck are not always possible with standard spectrometer, here a NaI detector with an entrance window of 8.5 cm diameter.

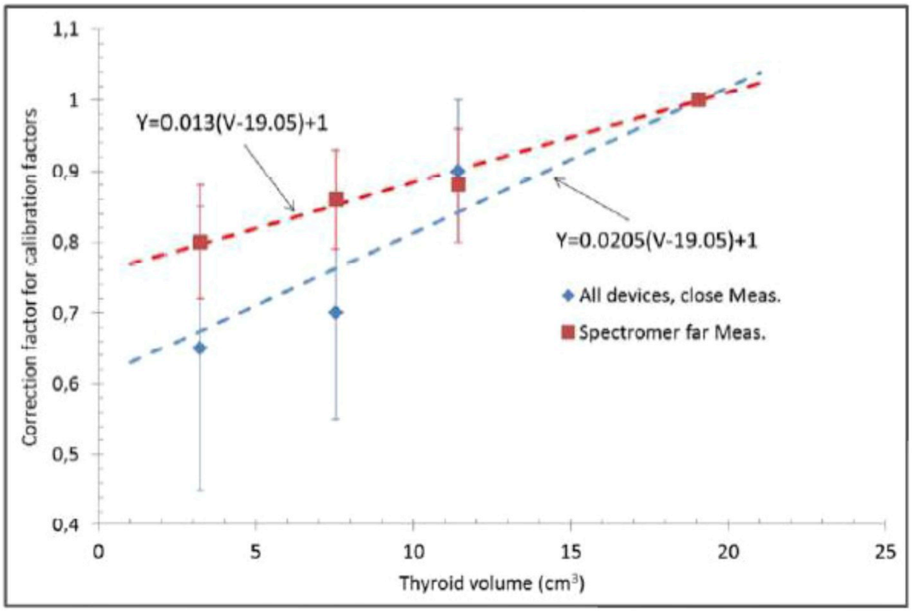

Fig. 2. Multiplicative correction factor to be applied to the adult calibration factor as a function of thyroid volume.

taking into account eight published studies and measurements carried out at CIEMAT and IRSN (the references about literature data are given in the Technical Guidelines).

(f) For the purpose of harmonization detection limits in lines with international standards should be used. Explicit formulas are given in the Technical Guidelines.

3.3. Measurement preparation and practice

(a) Planning and preparation is essential: stock of instruments and other equipment (environment monitors, replacing clothes, information boards, etc) must be available. Monitoring center guarantying low background should be identified in advance.
(b) Monitoring instruments should be properly calibrated, validated and periodically checked.
(c) Internal contamination monitoring should be carried out only after external contamination measurements have been performed and adequate decontamination actions carried out.
(d) All instruments (including any chair used for spectrometric measurements on people) should be protected against contamination by covering with a removable thin plastic film.
(e) Measurements of ^{131}I should ideally be performed between 24 h and 20 days after intake; later measurements may not have adequate sensitivity.

As shown in the article by Gómez-Ros et al., before 24 h other organs contribute to the counts in spectroscopic device and thus the calibration factor is inadequate. Furthermore, as shown by the article of Berkovskyy et al., the dose per unit measurements conversion factor are relatively independent of the intake time if measurements are carried out around 24 h.

(f) It is also recommended to select a representative sample of the population (both workers and members of the public) and monitor them as soon as possible with germanium detectors.

Doing so, it should be possible to identify short-lived radionuclides and the dose contribution of these radionuclides could be taken into account for subjects measured later.

3.4. Measurement of very young children

For measurements of children under 5 years old the following supplementary recommendations can be given (this specific age is given as an order of magnitude).

(a) Reliable calibration factors should be obtained by:
  - using phantoms with small thyroid volumes (around 2 cm^3) or,
  - estimating the calibration factor by a linear extrapolation of calibration data for other age categories or,
  - using correction factors calculated from Fig. 2.

(b) It is recommended that parents stay with the child to ensure that the child is content and keeps the correct position. For non-spectrometric measurements, the counting time is low and thus this issue may be of minor concern.
(c) Devoted small size spectrometric detectors could be considered (see 2.1 (b)). Non-spectrometric instruments generally have smaller size and can thus be placed in close contact.
(d) Spectrometric instruments with larger entrance windows can be used for very young children with neck-to-detector distances of 10–15 cm.

In this case, a conic collimator is recommended to reduce the contributions from other organs or from the parents.

(e) If the measurement of a very young child is not possible, then a dose should be calculated from a measurement of a surrogate person who stayed with the child at the time of intake.

The child's intake can be inferred from the surrogate person's intake by taking into account the breathing volume ratio between adult and child.

3.5. Measurement uncertainties and measurement bias

Even for emergency monitoring, it is recommended to establish an uncertainty budget associated with the measurements made, so that information can be provided on the general level of uncertainty and bias in the results of iodine in thyroid measurements. Typical orders of magnitude are provided in the Technical Guidelines.

3.6. Results management

(a) Before measurement, all persons must be registered, receiving a unique registration code in order that their identification is clear and unequivocal.
(b) Personal and contact information of the measured person should be collected in a database guarantying data protection and confidentiality.

The location of the person when the radionuclide release occurred and the subsequent locations before monitoring should also be recorded. Information about administration of stable iodine should be recorded, including the administration time. Locations informations could then be used to assess more precisely the intake pattern as evidenced in (Kurihara et al., 2017).

(c) All measurement results should be recorded on survey reports and linked to the monitored subject via the unique registration code. Templates for these reports should be prepared in advance.
(d) People who have been monitored should receive a report of their own results.

The reporting form should contain, as a minimum, their unique code, personal information, the description of the actions carried out (external contamination monitoring, decontamination, internal contamination monitoring), the measurement results and the entity that performed the measurement.

(e) Easy-to-understand information should be provided to explain the meaning of the results in terms of risk to health.

Teams of appropriate people should be present to provide reassurance to all those who have been monitored, to answer questions, and to explain the procedures of any follow-up programme (see 2.9).

(f) The national authorities should receive periodically information

This information is for example the number of people monitored, the number of people with or without detectable contamination, the number of people directed to medical assessment, etc. Such information should be anonymized.

3.7. Thyroid measurements made by members of public

As highlighted in the paper by Fojtík et al. and in the paper by Montero Gil et al. and elsewhere it is clearly expected that following a nuclear emergency citizens or group of citizens (Normile, 2011; Brown et al., 2016) or local authorities (Nomura et al., 2017) will carry out their own measurements. As revealed by the paper of Monteiro Gil et al. technical authorities are well aware of this trend but not yet prepared to support citizens for this kind of actions or prepared to take advantage of such measurements.

This section of the technical guidelines gives recommendations that are intended for radiation protection experts and decision makers who intend to support members of the public in performing their own measurements. These recommendations can be used to set up a training or education programme. They may also be useful when recommending reliable measurement instruments to citizens or groups of citizens.

Since all the details are given in (Fojtík et al., 2019) we do not give more information here.

3.8. Dose assessment from measurements

The thyroid measurements are intended to assess the thyroid dose or the committed effective dose. Conversion coefficients have been tabulated exhaustively. Methods, results and limitations are given in (Berkovskyy et al., 2019). The Technical Guidelines include ready to use tables.

3.9. Communication issues

As highlighted by Baudé in this issue and elsewhere (González et al., 2013; Tateno and Yokoyama, 2013; Shimura et al., 2014) honest, appropriate and instructive communication with the monitored subjects is essential. A section of the Strategic Guidelines is devoted to this issue. Since this aspect of the measurements process is sometimes neglected we would like to recall here essential points.

(a) Making clear the objectives of internal contamination assessment and the use of data.

Before performing internal contamination assessment, the objectives of the assessment should be made clear to the person. The organisation performing the assessment should make clear what outcomes the person can expect, but also what use will be made of the data collected. The limitations of the measurements and outcomes should also be stated.

(b) Interpretation of internal contamination assessment is as important as the assessment itself.

Receiving results of internal contamination measurements without interpretation and without the possibility to discuss them with a knowledgeable person entailed frustration and distress of people receiving the results, but also misinterpretation and degradation of trust towards the institutions providing the results.

(c) The need for 2-way person-to-person communication.

This can be made in face to face communication after the internal contamination assessment or collectively, at a later time, in small discussion groups of 20–30 people. A debriefing should also include discussion about the next steps in the process: how to identify and reduce the main sources of internal contamination, how to identify and access to complementary health examinations.

(d) The need to build a visibility of the situation in a contaminated area or of a group of people.

Internal contamination assessment should not only shed light on personal (or family) situations, but should also help to build collective assessment of the situation of a given area or a given group or population.

4. Remaining gaps

Some gaps identified prior to the project were filled-in or partially filled-in. At least recommendations have been given and they should be now implemented, with adequate modifications to cope with peculiar situations, to improve emergency preparedness.

However some work is still needed to fill-in some gaps and we would like to discuss some of them briefly.

Measurement of very young children is still a challenge (less than 5 years old or around). Suitable spectrometric detectors of limited size are needed to carry out measurements in contact with the neck since detectors used for adults are not really suitable. Such detectors are certainly available but they should be tested and integrated in the emergency equipment. Similarly, whole body counting systems are not suitable for very young children. Systems similar to the babyscan (Hayano et al., 2014) should be acquired or developed by monitoring teams.

The assessment of the thyroid dose due to short-lived radionuclides is a long standing challenge. Only a very few studies give results about thyroid dose due to inhalation of short-lived radioactive iodine isotopes other than ^{131}I. In studies made with residents of the Fukushima prefecture (Shinkarev et al., 2015), estimated that the inhalation contribution of short-lived radioactive iodine isotopes to the thyroid might be as great as 30–40%. In (Balonov et al., 2003) retrospective processing of early measurements of evacuees of the Chernobyl area showed that 30% of thyroid dose came from short-lived radioactive iodine isotopes. In (Mück et al., 2002), considering a zone 30 km around the Chernobyl nuclear power plant, and taking into account all radionuclides in the release it was shown that ^{131}I represented 40% of the inhalation dose (not the thyroid dose, the committed effective dose). Taking into account the short-lived radioactive iodine isotopes is important to estimate the doses due to inhalation or ingestion a few days after the intake; however the case of long-term exposure in contaminated territories is different since in that case only long lived radioisotopes, mainly ^{137}Cs, will contribute to the ingestion doses or to the gamma irradiation (Gavrilin et al., 2004; Thornberg et al., 2005; Balonov et al., 2007; UNSCEAR, 2008).

To take into account the thyroid dose due to the inhalation of short-lived radioactive iodine isotopes during the emergency phase a practical solution, detailed in the article by Berkovskyy et al., has been provided. It consists in applying a multiplicative factor to the thyroid dose, as deduced from measurement of iodine-131. This correction factors takes into account the time since reactor shut-down and is deduced from the core inventory of a Light Water Reactor. Since this method is based on a peculiar source term it is not strictly valid for all accident scenarios but at least provides orders of magnitude of the thyroid dose contribution from the short-lived radioactive iodine isotopes. That is why early measurement of a sub-sample of the population should be carried out with Germanium detectors so that short-lived radioactive iodine isotopes can be identified and quantified. Furthermore, in a process of refinement of measured doses all information coming from the atmospheric dispersion modelling and environmental measurements should be consider to take into account the contributions of short-lived radioactive iodine and radioactive telluriums isotopes.

Refinement of the dose assessment might also imply to better assess the thyroid weight of measured subjects. Indeed, the age-dependent thyroid weights defined by ICRP are only averaged values that do not necessarily apply to specific subject. In (Skryabin et al., 2010) the standard deviation of thyroid weights for a given age was found significant for children living in Belarus. In (Likhtarov et al., 2013) the thyroid dose assessment for children living in Ukraine was refined thanks to individual ultrasound evaluation of thyroid weight, and significant differences with ICRP recommended weights. The sources of uncertainties affecting thyroid dose assessment are further discussed in (Berkovskyy et al., 2019).

As revealed by the survey perform during the project, iodine-in-thyroid monitoring capacity varies widely in different European countries, ranging from a few tens to several thousand people who could be monitored during one day. Numbers of trained staff in different EU countries also vary widely, from a few to over 100. Whatever the exact capacities the most important question is to know if they are adapted to the number of people that should be monitored in case of a reactor accident. In 2014, in a report prepared for the Energy Directorate-General of the European Commission (ENCO, 2014), it was stated: *"These national capabilities for whole body and thyroid monitoring appear to be considerable; however, a careful and systematic assessment (if it does not already exist) should be made of their adequacy in relation to the scenarios assumed/adopted for the purposes of emergency planning and the anticipated public demand for personal monitoring that may ensue following any nuclear accident, if only for reassurance."* In this report the maximum number of daily thyroid measurements per day in nuclearized European countries was reported to be around 500 while it was around 2500 in the CAThyMARA survey (Monteiro Gil et al., 2019). In a report issued by the German Commission on Radiological Protection (Strahlenschutzkommission, 2017) it is estimated that between 1 000 and 200 000 members of the public would require monitoring in case of a nuclear power plant accident. In the French guidance for nuclear emergency response (SGDSN, 2014) the same number of people is mentioned.

Even if the order of magnitude of public member that should be monitored is assessed in these French and German documents it is our opinion than some questions should be addressed in a more systematic way. Whatever the means in each country we do not exactly know if they would be sufficient to monitor hundreds or tens of hundreds of people in a reasonable time, either in the emergency or post accidental phase. Since the measurement campaign could last several weeks not only the question of device availability is of concern but also of human means. A concerted and documented evaluation of the number of people to monitor in case of emergency should be carried out at the national or European level, eventually taking into account several accident scenarios (limited or massive release, in more or less populated area, with or without efficient evacuation) so that more precise orders of magnitude of the potentially affected population could be obtained. Then it could be seen if the available physical and human means are adequate.

Either or not the means at disposal are sufficient, either or not European collaboration would work properly in case of emergency it can be anticipated that the public demand for monitoring would finally exceed the human means at disposal by radiation protection authorities. In that sense it might be good to support citizens' associations that want to get involved in the measurement process. Not only it would increase the means at disposal but also increase the number of available data. This of course would not be limited to internal exposure monitoring but also to environmental monitoring or external exposure monitoring. For this cooperation between citizens and professional to work efficiently it should be prepared and anticipated. Professional bodies would also need to prepare public-database so that measurements carried out with different instruments can be stored and correctly interpreted. This cooperation between citizens and technical bodies is in line with the recommendations given in the SHAMISEN project (SHAMISEN, 2018).

Finally, many often the general guidelines about emergency preparedness and management end with statements requiring medical actions or follow-up above a given threshold. However, there is no general consensus on the value of this threshold. The TMT handbook (Rojas-Palma et al., 2009) considers the committed effective dose. In the adult case, above 200 mSv medical assessment is required and decorporation should be considered. For doses above 1–20 mSv (a range is given so that resources can be adapted to the situation) a long-term follow up is required so that diagnostic can reduce morbidity or mortality. The IAEA defines generic criteria triggering actions for prevention of deterministic and stochastic effects (IAEA, 2015). The criteria related to deterministic effects include absorbed doses to different organs and committed over different time period. Regarding stochastic effects, above an effective dose of 100 mSv (received during 1 month) long term medical follow up is advised. In another document (IAEA, 2018) the IAEA has derived intake values above which decorporation should be undertaken; these values are deduced from generic criteria expressed in terms of risk of developing severe deterministic effects or risk of developing radiation induced cancer. The NCRP has defined the Clinical Decision Guide (CDG), an operational quantity above which decorporation and clinical follow-up is required (NCRP, 2008). The CDG takes into account stochastic and deterministic risks and is thus based on the committed effective dose and RBE-weigthed doses to the lungs and red-marrow. For most of radionuclides the dose that defines the CDG is in fact a committed effective dose of 250 mSv (for adults). The case of iodine-131 is treated differently and the CDG is then defined considering a thyroid dose of 100 mGy (for adults less than 40 years-old). Finally the IARC has given specific recommendations on thyroid monitoring after a nuclear accident (IARC, 2018). It recommends offering a long-term thyroid monitoring program for higher risk individuals (i.e. those exposed in utero, during childhood or adolescence) and that received a thyroid dose between 100 and 500 mGy.

More essentially we are not aware of technical guidelines defining medical actions or health surveillance when one is facing with relatively low doses. Who are the trained health specialists who will give relevant advices? What recommendations will they follow? What kind of exam will be prescribed? At which frequency? Who will pay for these exams? Above which dose threshold is it relevant to induce anxiety by medical exams aiming at detecting cancer? How the benefit/risk ratio of such exams can be defined? These questions have been mentioned in the SHAMISEN project and to some extend in (IARC, 2018). Among the SHAMISEN recommendations one can retain, among others, that (i) health surveillance should be propose but not imposed, (ii) health screening should be based on appropriate justification and design, (iii) economic and psychological assistance is part of the support that population should receive.

5. Conclusion

As recalled in the introduction many general guidelines on emergency preparedness and management are available, but they are quite general, not always available for free, not always covering all the technical topics from measurements to dose assessment. Having in mind preparedness for a reactor accident affecting a large number of people we decided to focus on radioactive iodine monitoring. It is indeed important to consider the case of radioactive iodine since it accounts for a large amount of the potential release and since it can induces thyroid cancer, especially when children are affected. Having in mind that technical solutions are possible to improve the thyroid monitoring of children we focused on this aspect and have shown that reliable measurements are possible provided proper calibration is performed.

There are many sources of uncertainties affecting dose assessment, such as the time of intake, the chemical form of contaminants, and the intrinsic variability of individuals. However, it is not a reason for not improving the reliability of measurements if it is possible. In case of emergency, if the public was aware that more precise measurements of children could have been conducted, it would be difficult to justify that the technical solutions have not been adopted.

The outcomes of the CAThyMARA project are not only recommendations but also data that can be used directly (conversion coefficients for dose assessment) or methods that can be implemented (phantom description or interpretation of measurements after iodine prophylaxis). There is certainly room for improvement or clarification; provided the recommendations are implemented they will certainly be improved by practitioners.

We have also highlighted in this article that there are remaining issues and that measurement is not all that matters: proper communication of the results to the public is essential as well as a clear definition of health actions that should follow.

The recommendations and results issued in the CAThyMARA projects are endorsed by the authors of this article but are not official positions endorsed by the institutes they belong to.

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Appendix A. Supplementary data

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