IAEA
International Atomic Energy Agency
Atoms for Peace and Development

ASSESSMENT OF OCCUPATIONAL EXPOSURE DUE TO INTERNAL RADIATION SOURCES

UNIT 12

ASSESSMENT OF INTERNAL EXPOSURE FOLLOWING ACCIDENTS OR INCIDENTS

LECTURE CONTENT

- INTRODUCTION
- POST EVENT INFORMATION REQUIREMENTS
- POST EVENT MONITORING
- FOLLOW-UP MONITORING
- DEVELOPMENTS ON EMERGENCY DOSIMETRY

INTERNAL EXPOSURE FOLLOWING ACCIDENTS OR INCIDENTS

- **INTERNAL EXPOSURE FOLLOWING ACCIDENTS OR INCIDENTS**
  - ✓ The objective of this unit is to provide an overview of principles and methods for accidental intake of radionuclides.
  - ✓ The unit addresses use of direct and indirect methods for intake assessment.
  - ✓ At the completion of this unit, the student should understand the steps should be taken, principles to be applied, dosimetric methods to be used, and precautions to be exercised following a radiation accident involving intake of radionuclides.

Introduction

ACCIDENT

"Any unintended event, including operating errors, equipment failures or other mishaps, the consequences or potential consequences of which are not negligible from the point of view of protection or safety."

IAEA Safety Glossary

INTERNAL EXPOSURE FOLLOWING ACCIDENTS OR INCIDENTS

IAEA

- **IAEA ACCIDENT RESPONSE EXPERIENCE**

Under the 1986 *Convention on Assistance in the Case of a Nuclear Accident or Radiological Emergency*, the IAEA:

- ✓ makes available appropriate resources for emergency response,
- ✓ promptly transmits requests for assistance to other States or international organizations which may possess necessary resources, and
- ✓ may co-ordinate assistance at the international level

INTERNAL EXPOSURE FOLLOWING ACCIDENTS OR INCIDENTS

IAEA

- **Radiation emergency exposures** may occur
  - ✓ during the operation of a planned situation
  - ✓ from a malevolent act
  - ✓ from any other unexpected event

  requiring urgent action to prevent or reduce unwanted health effects.

- One priority is **to quickly identify internal exposures and to quantify the doses received by the exposed people**:
  - ✓ nuclear site workers
  - ✓ Emergency workers (including first responders)
  - ✓ population

IAEA

- **IAEA ACCIDENT RESPONSE EXPERIENCE**
  - ✓ Chernobyl and Fukushima were the most serious accidents in Agency history
  - ✓ IAEA has been involved in investigation of a number of other accidents involving.
    - loss of control or misuse of radioactive sources,
    - errors in medical treatment, or
    - accidental exposure in irradiation facilities.

INTERNAL EXPOSURE FOLLOWING ACCIDENTS OR INCIDENTS

- **Several situations contribute to accidents**

1 Operational error or equipment failure when transferring large sources;

2 Interlock failure on high dose rate equipment;

3 Radiography sources left unshielded;

4 Equipment failure or operational errors in nuclear facilities.

5 Medical misuse of sources; and

6 Criticalities

INTERNAL EXPOSURE FOLLOWING ACCIDENTS OR INCIDENTS

- **Accidents with ”clinical consequences”***

Activity	Persons affected
✓ Nuclear fuel cycle	245
✓ Industrial uses of radiation	94
✓ Medical uses of radiation	18
✓ Tertiary education and accelerators	19
✓ Other	344
Total	720

* From 2000 UNSCEAR Report (1975 through 1994)

Post Event Information Requirements

INTERNAL EXPOSURE FOLLOWING ACCIDENTS OR INCIDENTS

- There will be situations involving the use of radioactive material in which the operational controls break down

- Accidents or incidents may result in releases of radioactive materials into the working environment with the potential for high doses to the workforce

INTERNAL EXPOSURE FOLLOWING ACCIDENTS OR INCIDENTS

- **INTERNAL DOSIMETRY FOLLOWING ACCIDENTS OR INCIDENTS**

  ✓ First challenge: **to establish an efficient individual monitoring program**
    - according to the intake scenario and the source term,
    - with appropriate in vivo and/or in vitro bioassay techniques for a large number of individuals
    - For a rapid interpretation of monitoring data for dose assessment.

  ✓ Initial main concern: **quick identification of people at highest risk (Triage)**
  Second phase: **more reliable dose investigation for the identified individuals with highest exposure**.

Transfer the dosimetric data to decision makers to support **actions**
- to reduce the risk of stochastic effects, based on **EFFECTIVE DOSE (Sv)**
- **to avoid or minimize tissue reactions,** based on **ABSORBED DOSE(Gy)**

INTERNAL EXPOSURE FOLLOWING ACCIDENTS OR INCIDENTS

IAEA

- **ACCIDENTS – Medical treatment first**
  - ✓ After an accident, the radiological consequences may be complicated by trauma or other health effects incurred by workers
  - ✓ Treatment of injuries, especially those that are potentially life threatening, generally takes priority over radiological operations
  - ✓ Post-accident exposure assessment should be conducted when the situation has been brought under control.

INTERNAL EXPOSURE FOLLOWING ACCIDENTS OR INCIDENTS

- **POST-ACCIDENT – Gather key information**
  - ✓ When exposure assessment starts, get as much information as possible
  - ✓ Example - information is needed on;
    - Time and nature of the incident
    - Radionuclides involved
    - Timing of bioassay samples and
    - Measurements of body activity

INTERNAL EXPOSURE FOLLOWING ACCIDENTS OR INCIDENTS

IAEA

- **POST-ACCIDENT – Gather key information**

  ✓ **Information is necessary for;**

  - Exposure assessment
  - Medical assessment, to guide medical treatment of the victim (which may include chelation therapy or wound excision)
  - Accident reconstruction
  - Long term medical follow-up of victims

IAEA

- **POST-ACCIDENT - information gathering**
  - ✓ Accidents or incidents can result in high committed effective doses (≥ dose limits)
  - ✓ Individual and material specific data are normally needed for exposure assessment
  - ✓ Necessary data include information on;
    - Chemical and physical forms of the radionuclide(s)
    - Particle size (AMAD)
    - Airborne concentrations

INTERNAL EXPOSURE FOLLOWING ACCIDENTS OR INCIDENTS

IAEA

- **POST-ACCIDENT - information gathering**

✓ Necessary data also includes information on;

- Surface contamination levels
- Retention characteristics in the individual affected
- Nose blows, face wipes and other skin contamination levels and
- External dosimetry results

INTERNAL EXPOSURE FOLLOWING ACCIDENTS OR INCIDENTS

- **POST-ACCIDENT - information gathering**
  - ✓ Data may seem inconsistent or contradictory, particularly if the intake period is uncertain
  - ✓ Adequate dose assessments can be made only after;
    - Considering all of the data
    - Resolving the sources of inconsistency as far as is possible, and
    - Deciding most likely and worst scenarios for exposure and magnitude of intake

INTERNAL EXPOSURE FOLLOWING ACCIDENTS OR INCIDENTS

- **INTAKE SCENARIO: NUCLEAR ACCIDENT**

✓ **Early phase:** acute **intake through inhalation**

- Volatile elements including iodine (^{131}I, ^{132}I, ^{133}I, ^{134}I, ^{135}I),
- Caesium (^{134}Cs, ^{136}Cs, ^{137}Cs), tellurium (^{132}Te), and
- Inert gases (e.g. xenon ^{133}Xe).

- Time of intake: exposure to radioactive plume,. highest concentration of the activity in the air. Conservative approach.

- Residents and evacuees in contaminated areas: first concern is internal exposure to radioiodine and thyroid cancer risk (especially for children)

INTERNAL EXPOSURE FOLLOWING ACCIDENTS OR INCIDENTS

IAEA

- **INTAKE SCENARIO: NUCLEAR ACCIDENT**

✓ **early phase: acute intake through inhalation** (cont.)

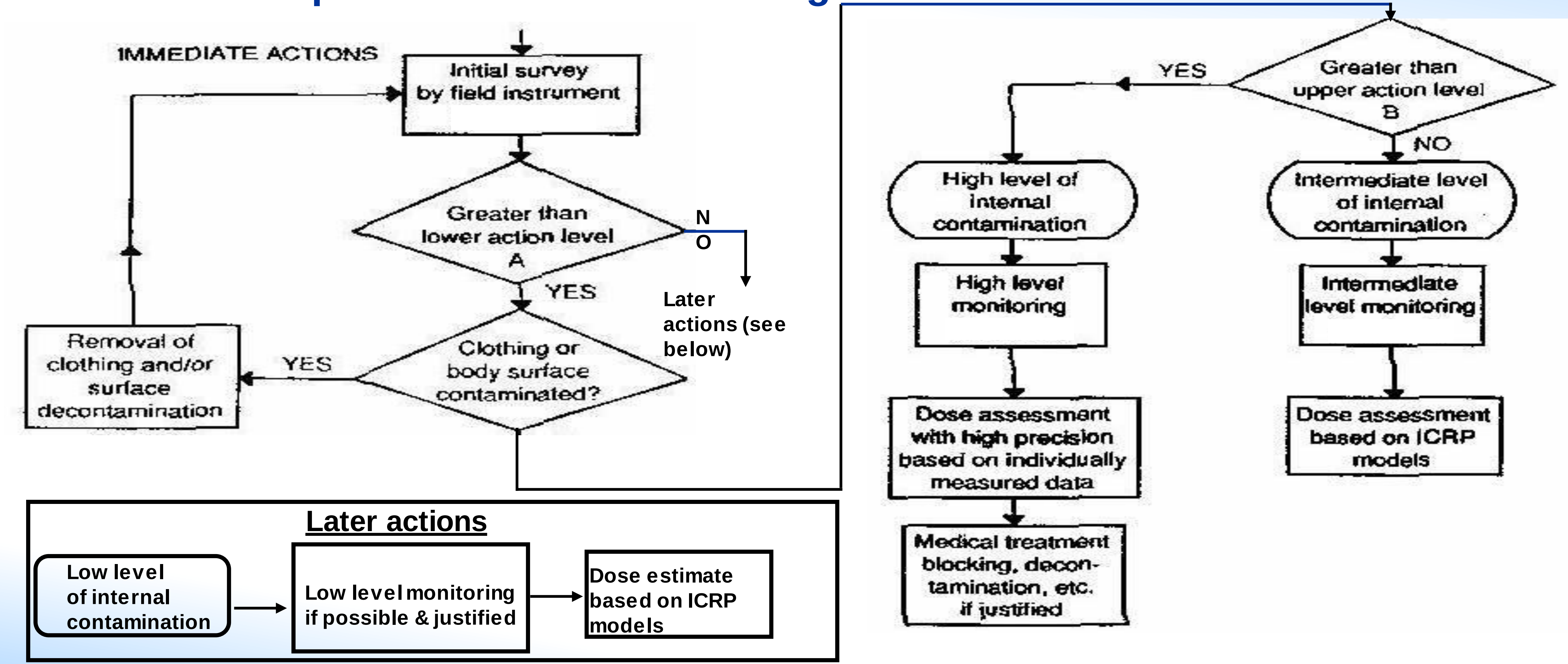
  - Major contribution of intake: **^{131}I**, $T_{1/2}$= 8.02 d,. Once incorporated into the human body, radioiodine accumulates in the thyroid.
  - Activity measurements of ^{131}I in the thyroid should be performed soon
  - Other short-lived radionuclides: ^{132}Te/^{132}I, ^{133}I,…
  - ^{134}Cs, ^{137}Cs are easily detected in total body by γ spectrometry (WBC) (longer half life)

✓ **Intermediate phase:** continuous or incidental **ingestion** may contribute to the intake through food chain (difficult to evaluate). Prompt restriction on distribution and consumption of contaminated food and drink is required.

Post Event Monitoring

INTERNAL EXPOSURE FOLLOWING ACCIDENTS OR INCIDENTS

- **Recommended procedures for monitoring**



INTERNAL EXPOSURE FOLLOWING ACCIDENTS OR INCIDENTS

IAEA

- **In-vivo monitoring** of incorporated radionuclides (internal gamma emitters)

✓ **On site measurements** (high level of background).
Field Triage for internal gamma emitters
- Mobile units of body counters (national and international support)
- Portable detectors NaI(Tl), HPGe, LaBr3 (gamma spectrometry)
- Other equipment

Objectives:1) to identify persons with highest internal exposures who require more reliable dose estimation and medical follow-up
2) reassurance individuals with no significant exposure

✓ **Whole Body Counting facilities (WBC)**
Outside emergency area, lower level of background.
in vivo monitoring individuals with highest internal exposure detected in the Triage.
- Appropriate calibration phantoms for adults and children
- Age-dependent efficiency calibration.
- Counting geometries adapted for children

IAEA

- **Mobile Direct Measurement Facilities**

INTERNAL EXPOSURE FOLLOWING ACCIDENTS OR INCIDENTS

- **Mobile Direct Measurement Facilities**

IAEA

- **In-vitro monitoring of incorporated radionuclides**
  Analysis of excreta

✓ Analyses of samples of urine and faeces should be considered to verify the intake

✓ These results may be difficult to interpret, because of;

  - Possible multiple routes of intake and
  - Imprecise about radionuclide transfer to the blood

INTERNAL EXPOSURE FOLLOWING ACCIDENTS OR INCIDENTS

IAEA

- **Analysis of excreta**

✓ Early excreta results are generally not useful for intake assessment because of the delay between intake and excretion

✓ Particularly true for faecal excretion

✓ In addition, rapid early components of urinary excretion can be difficult to interpret - not fully defined in some models

INTERNAL EXPOSURE FOLLOWING ACCIDENTS OR INCIDENTS

- **Analysis of excreta**

  - ✓ Nevertheless, all excreta should be collected following an accident or incident
  - ✓ Early detection of radioactivity in urine can be a useful indication of the material solubility and potential for effective treatment
  - ✓ Excreta analyses can be the only reliable method of assessing intakes if large amounts of external contamination interfere with direct measurements.

INTERNAL EXPOSURE FOLLOWING ACCIDENTS OR INCIDENTS

- **External contamination interference**
  - ✓ Radiological characteristics of the radionuclides determine whether direct, indirect, or both methods should be used
  - ✓ If there is external contamination with gamma emitters, direct measurements should normally be delayed until decontamination
  - ✓ This 1) prevents interference with the measurement and 2) avoids contamination of the direct measurement facility

INTERNAL EXPOSURE FOLLOWING ACCIDENTS OR INCIDENTS

- **External contamination interference**

  - ✓ If urgency of assessment precludes complete decontamination, wrap the individual in a sheet to minimize contamination of the facility
  - ✓ Such initial direct measurement results are upper limits for the body content
  - ✓ More measurements would be needed after further decontamination
  - ✓ External α or β contamination won’t normally interfere with direct measurements, unless bremsstrahlung is produced by the betas

INTERNAL EXPOSURE FOLLOWING ACCIDENTS OR INCIDENTS

- **Other concerns**

  ✓ External contamination will not interfere with indirect methods

  ✓ However, care must be taken to avoid transfer of contamination to excreta samples

  ✓ Rarely, intakes may be so high that special techniques to avoid interference with equipment response, e.g. excessive electronic dead times

INTERNAL EXPOSURE FOLLOWING ACCIDENTS OR INCIDENTS

- **Blood sampling**

  - ✓ Empahsize non-invasive procedures
  - ✓ Invasive procedures such as blood sampling are usually justified only in accident situations in which large intakes may have occurred
  - ✓ Blood sampling can provide data on the solubility and biokinetics
  - ✓ Has limited value for quantitative intake estimates because of rapid clearance of most radionuclides to other tissues

INTERNAL EXPOSURE FOLLOWING ACCIDENTS OR INCIDENTS

- **Workplace monitoring samples**
  - ✓ Workplace monitoring samples:
    - Air filters
    - Surface contamination wipes,
  - ✓ Should be analysed to determine:
    - Radionuclides involved
    - Isotopic ratios, and
    - Physicochemical characteristics

Follow-up Monitoring

INTERNAL EXPOSURE FOLLOWING ACCIDENTS OR INCIDENTS

- **Follow-up monitoring**

  - ✓ Direct and indirect follow-up measurements should be conducted at reasonable intervals for an extended period after an accident
  - ✓ These results will help in establishing the biological half-lives of radionuclides in the body tissues and their excretion rates
  - ✓ This, in turn, can help to improve the accuracy of dose assessment.

INTERNAL EXPOSURE FOLLOWING ACCIDENTS OR INCIDENTS

IAEA

- **Follow-up monitoring**

✓ Excreta samples should be collected and analyzed until a reasonable estimate can be made of the temporal pattern of excretion

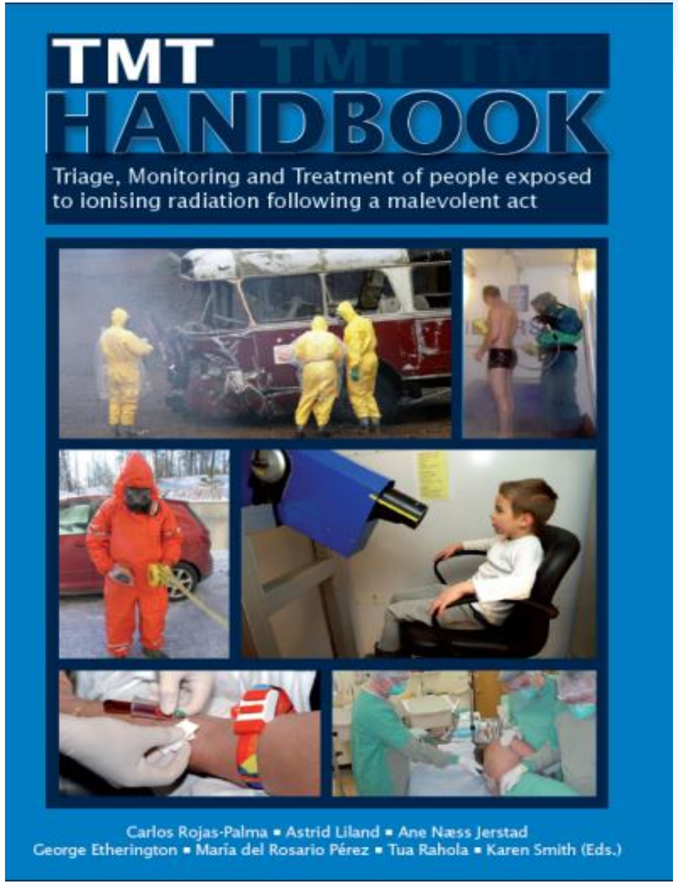
✓ If decorporation therapy, e.g. chelating agents, is used, sampling should continue to determine the effectiveness of the treatment

✓ Once excretion patterns have stabilized, individual samples collected during the day may be combined into 24-hour samples, and appropriate aliquots taken for analysis

Developments on Emergency Dosimetry

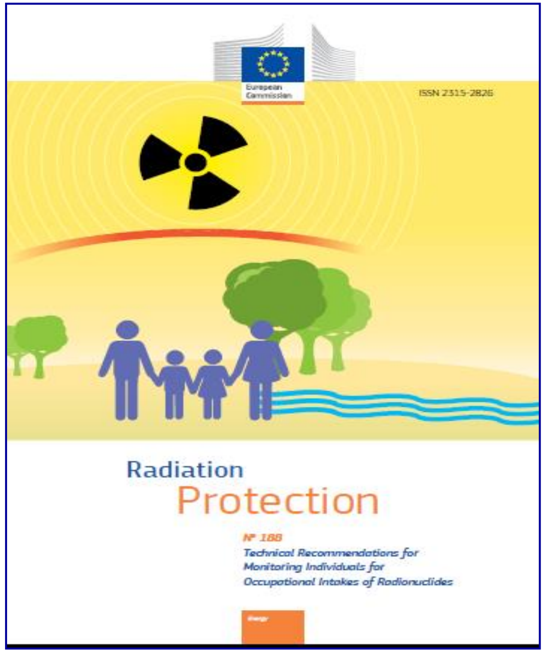
- **TMT Handbook** (Rojas-Palma, 2009) provides information and recommendations for **triage, monitoring and treatment** of people exposed to ionising radiation following a malevolent act.

http://www.tmthandbook.org/



INTERNAL EXPOSURE FOLLOWING ACCIDENTS OR INCIDENTS

- **EC RP 188 - Technical Recommendations for Monitoring Individuals for Occupational Intakes of Radionuclides**



✓ **ANNEX III - Monitoring and Internal Dosimetry for First Responders in a Major Accident at a Nuclear Facility**

- Definition of First Responders
- Reference Levels for Emergency Occupational Exposures
- Internal Contamination Monitoring for First Responders
- Assessment of the Emergency Worker Doses
- Emergency Worker Dose Records

Free available: ec.europa.eu/energy/sites/ener/files/rp_188.pdf

INTERNAL EXPOSURE FOLLOWING ACCIDENTS OR INCIDENTS

- **CATHYMARA Project** (**European Commissiom FP7/ EURATOM OPERRA 2016-2017**)
  "Child and Adult Thyroid Monitoring After Reactor Accident"
  Objective: **optimal monitoring strategies and dose assessment of post accidental ^{131}I in the thyroid of exposed individuals, particularly for children.**

  - Survey on current regulations and recommendations.
  - Intercomparison of WBC Mobile Units and portable detectors (γspectr)
  - Intercomparison for Trained responders (non spectrometric devices)
  - Monte Carlo calculations
  - Criteria for dose assessments
  - Recommendations and Dissemination of knowledge.

Technical guidelines for large scale post-accidental thyroid monitoring and dose assessments.

Reports and publications free available:

https://www.researchgate.net/project/CAThyMARA-Child-and-Adult-Thyroid-Monitoring-After-Reactor-Accident-OPERRA-Project-number-604984

INTERNAL EXPOSURE FOLLOWING ACCIDENTS OR INCIDENTS

- **SHAMISEN Project (European Commission FP7/ EURATOM OPERRA 2016-2017) Nuclear Emergency Situations. Improvement of Medical And Health Surveillance**

  - ✓ Lessons learned from experiences of exposed population due to radiation accidents (e.g. Fukushima, Chernobyl)
  - ✓ Objective: to develop recommendations for health surveillance of people involved in radiation accidents,
  - ✓ Recommendations on individual dose assessment (workers and population) Based on environmental and individual monitoring data taking into account histories of locations, food habits, indoor/outdoor stay,...of exposed individuals
  - ✓ Dose reconstruction in an intermediate to long-term time frame
  - ✓ Involvement of stakeholders and decision makers as well as scientific, medical and non-expert communities
  - ✓ Post accidental epidemiology

https://www.isglobal.org/en/-/shamisen

INTERNAL EXPOSURE FOLLOWING ACCIDENTS OR INCIDENTS

- **CONFIDENCE PROJECT (European Commission, 1st EJP-CONCERT Call (2017 – 2019))**
  Coping with uncertainty for improved modelling and decision making in nuclear emergencies

  ✓ Model improvement & proposing solutions for the operational application
  ✓ **Reduction of uncertainties in dose assessment to improve the picture of the radiological situation and come to a risk estimation**
    - environmental monitoring
    - individual dose measurements (retrospective dosimetry, internal dosimetry, biological dosimetry)
    - risk assessment.

  ✓ Improvement of radioecological models
  ✓ Countermeasures in the transition phase introducing also countermeasures for the late phase
  ✓ Social ethical and communication aspects of decision-making
  ✓ Decision making
  ✓ Education and training

Confidence
Coping with uncertainty for improved modelling and decision making in nuclear emergencies

https://www.radioprotection.org/articles/radiopro/abs/2020/02/radiopro200008s/radiopro200008s.html

REFERENCES – UNIT 12 - INTERNAL EXPOSURE FOLLOWING ACCIDENTS OR INCIDENTS

EUROPEAN COMMISSION, FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS, INTERNATIONAL ATOMIC ENERGY AGENCY, INTERNATIONAL LABOUR ORGANIZATION, OECD NUCLEAR ENERGY AGENCY, PAN AMERICAN HEALTH ORGANIZATION, UNITED NATIONS ENVIRONMENT PROGRAMME, WORLD HEALTH ORGANIZATION, Radiation Protection and Safety of Radiation Sources: International Basic Safety Standards, IAEA Safety Standards Series No. GSR Part 3, IAEA, Vienna (2014).

INTERNATIONAL ATOMIC ENERGY AGENCY, INTERNATIONAL LABOUR OFFICE, Occupational Radiation Protection, IAEA Safety Standards Series No.GSG-7, IAEA, Vienna (2018).

INTERNATIONAL ATOMIC ENERGY AGENCY, Indirect Methods for Assessing Intakes of Radionuclides Causing Occupational Exposure, Safety Guide, Safety Reports Series No. 18, ISBN 92-0-100600-4 (2000)

INTERNATIONAL ATOMIC ENERGY AGENCY, Radiation Protection and Safety in Medical Uses of Ionizing Radiation Safety Guide, Specific Safety Guide No. SSG-46 (2018)

INTERNATIONAL ATOMIC ENERGY AGENCY, The Radiological Accident in Goiânia, ISBN 92-0-129088-8 (1988).

REFERENCES – UNIT 12 - INTERNAL EXPOSURE FOLLOWING ACCIDENTS OR INCIDENTS

INTERNATIONAL ATOMIC ENERGY AGENCY, *The International Chernobyl Project: Technical Report,* ISBN 92-0-129191-4 (1991).

INTERNATIONAL ATOMIC ENERGY AGENCY, *Dosimetric and Medical Aspects of the Radiological Accident in Goiânia in 1997*, IAEA TECDOC Series No. 1009 (1998).

INTERNATIONAL ATOMIC ENERGY AGENCY, *Assessment of Doses to the Public from Ingested Radionuclides,* Safety Reports Series No. 14, ISBN 92-0-100899-6 (1999)

INTERNATIONAL ATOMIC ENERGY AGENCY, *Follow-up of Delayed Health Consequences of Acute Accidental Radiation Exposure. Lessons to be Learned from Their Medical Management*, IAEA TECDOC Series No. 1300, (2002)

INTERNATIONAL ATOMIC ENERGY AGENCY, *Rapid Monitoring of Groups of Internally Contaminated People following a Radiation Accident,* IAEA TECDOC 746 (1994).

INTERNATIONAL COMMISSION OF RADIATION UNITS AND MEASUREMENTS, *Retrospective Assessment of Exposure to Ionising Radiation*, ICRU Report 68, Journal of the ICRU Volume 2, No 2, (2002).

INTERNATIONAL COMMISSION ON RADIATION UNITS AND MEASUREMENTS, *Direct Determination of the Body Content of Radionuclides*, ICRU Report 69, Journal of the ICRU Volume 3, No 1, (2003).

UNITED NATIONS SCIENTIFIC COMMITTEE ON THE EFFECTS OF ATOMIC RADIATION, *Sources and Effects of Ionizing Radiation, Volume 1: Sources, and Volume 2: Effects,* (2000).