# The ICRP 66 Internal Radiation Exposure Control and Dose Evaluation of The Institute of Nuclear Energy Research

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**Abstract.** The Atomic Energy Council (AEC) is the regulatory body of ionization radiation protection in Taiwan. To effectively control the safety in ionization radiation, AEC brought into force the "Ionization Radiation Protection Act" on 1 February, 2003 with clear statements of the penalty for violating the Law. The Article 5 of the Act provides: In order to limit the radiation exposure from radiation sources or practices, the Competent Authority shall refer to the latest standards of the International Commission on Radiological Protection to lay down the Safety Standards for Protection against Ionizing Radiation. Thus, AEC is going to draft new safety standards of ionization radiation protection of Taiwan according to ICRP *Publication* 60. The Institute of Nuclear Energy Research (INER), the governmental institute working on ionization radiation research in Taiwan, took the responsibility of assisting AEC in establishing guidelines on the control of internal radiation exposure and responding to the regulations in the new standards as soon as possible. So, according to the recommendations of ICRP *Publications* 60, 66,67,68,69,71,78,88, and IAEA Safety Standard Series No. RS-G-1.1 and 1.2, INER undertook researches on the internal radiation exposure control and dose evaluations for INER's radiation workers as well as dose evaluations for the general public. The research accomplishments not only can be the reference of AEC when making new standards, but also can be followed by other radiation protection businesses.

## 1. Introduction

The earliest ionization radiation safety standards of Taiwan published and carried out on July 29, 1970. These standards based on the recommendations of the ICRP *Publication* 2 and ICRP *Publication* 9[1-2] published respectively in 1959 and 1966 by the International Commission on Radiological Protection (ICRP) and the IAEA safety series No.9 published in 1967 by the International Atomic Energy Agency (IAEA). Afterwards, according to the international development of ionization radiation, the regulatory body of ionization radiation protection--The Atomic Energy Council( AEC) corrected the standards based on the recommendations given in the ICRP *Publication* 26 (1977), ICRP *Publication* 30(1977), IAEA safety series No. 9[3-4] (corrected version in 1982) and the 10 CFR 20 of U. S. Federal Regulations and were published and carried out on the date of July 10, 1991.

The Administrative Procedures Law in Taiwan took effect on Jan. 1, 2001 and it made some administrative mandates of the AEC invalid because of lacking of law origins and relating to rights and obligations of people. So, AEC took measures to move the making of the Ionizing Radiation Protection Act[5] from 1998 for prevention of troubles in control operations. The Act was published on Jan. 1, 2002 and took effect on Feb. 1, 2003. Article 5 of the Act provides : In order to limit the radiation exposure from radiation sources or practices, the Competent Authority shall refer to the latest standards of the International Commission on Radiological Protection to lay down the Safety Standards for Protection against Ionizing Radiation. Based on this Article, AEC referred to the ICRP *Publication* 60 recommendations and corrected the Safety Standards for Protection Against Ionizing Radiation. The new Standards were published on January 30, 2003[6]. To prevent the modification that could bring difficulties to the facilities owners or the employers and affect the quality of radiation protection, the new Standards did not include all the ICRP *Publication* 60 spirits and recommendations; only the dose limits recommendations were adopted and the revision of the new Standards should keep going according to the ICRP *Publication* 60 spirits and the following recommendations. To comply with the new Standards earlier, INER undertook researches of the internal exposures control and dose evaluations of INER radiation workers and dose evaluations of the general public according to ICRP *Publications* 60, 66, 67, 68, 69, 71, 72, 78[7-14], IAEA Safety Series No.115, Safety Standard Series No. RS-G-1.1 and 1.2[15-17].

## 2. Development of the ICRP internal dose evaluation model

The ICRP *Publication* 2 is published in 1959. At that time, the dose evaluation model was very simple and only included two regions and two solution particles (soluble and insoluble). Assumed that 50 % of the inhaled airborne particles would deposit in the respiratory system, 25 % would be exhaled, and the rest 25 % would stay in the lung. For the soluble particles, the 25 % that stayed in the lung would be absorbed or transferred to other tissues in the body; for the insoluble particles, 12.5 % would be cleared within 24 h and the rest 12.5 % would stay in the lung with a half-life of 120 days.

The ICRP *Publication* 2 only took into consideration the dose control of one or two critical organs and used single-component exponential functions to explain the retention patterns of radioactive sources in these organs without giving consideration to circles of these materials traveling back to the system after being drained from the organ (that is, no explanation of the excretion pathways). This model was too much simplified. In 1978, the ICRP published the ICRP *Publication* 30 which introduced a more mature respiratory system and gastrointestinal tract model.

The gastrointestinal tract model of ICRP *Publication* 30 comprises four compartments : the stomach, small intestine, upper large intestine(ULI) and lower large intestine(LLI), as Fig.1. However, this structure cannot be used accurately to apply the new tissue weighting factors of the colon and the oesophagus published in ICRP *Publication* 60 : the oesophagus dose was represented by thymus dose, and the colon dose was represented by the mass weighting average of the upper large intestine(ULI) and lower large intestine(LLI)[9]. In addition, regarding the chronic intake of heavy metal through the mouth, oral tissue was an important place to stay[18-19]. So, ICRP has newly finished the revision and the new version will be published soon. The model will be called the human alimentary tract model[20].

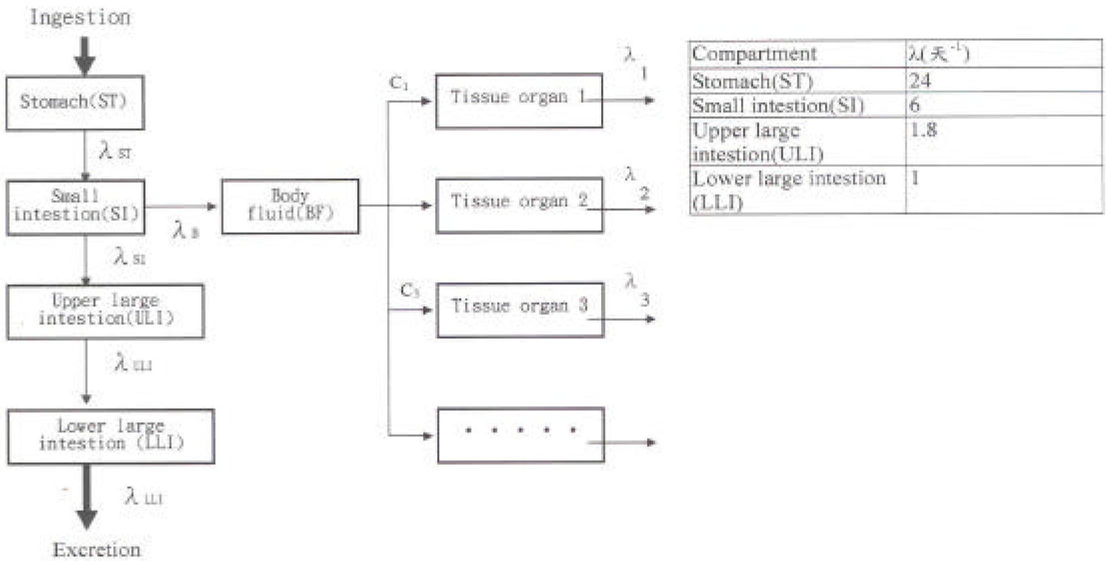
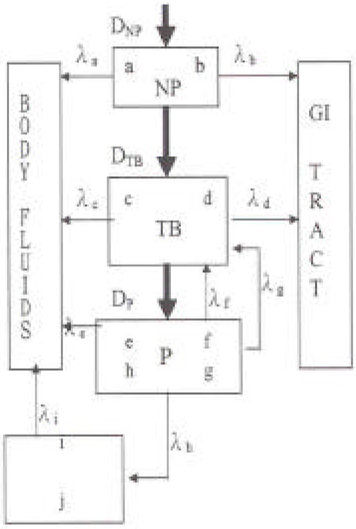



*FIG. 1. Structure of the gastrointestinal tract of the ICRP 30 model*

Further, the respiratory system of ICRP *Publication* 30 took account of the relationship of the particles deposition in the respiratory system and the inhaled aerosol. It also took account of the relationships of the clearance rate of the deposited particles and the deposition places and the chemical and physical characteristics; The clearance rates were divided into D, W and Y types according to their retention in the pulmonary region. Type D is the high solution chemical compound whose half-time of clearance was less than 10 days; Type W is the partly soluble chemical compound whose half-time of clearance was from 10 to 100 days; Type Y is insoluble chemical compound whose half-time of clearance greater than 100 days(see Fig. 2). At the same time, calculations of doses of many organs and tissues were considered, so weighting doses of tissues and organs replaced critical organs doses and the retention distribution of organs was expressed by the sum of component exponential functions to indicate the short and long retention components and models of different bio-meanings of different elements. At this time, except iodine, the cycle and excretion pathways from the organ to the system of the radionuclide had not been talked about and the metabolism of the daughter was just like that of the parent.




| Region | Compart-ment | D | | W | | Y | |
|---|---|---|---|---|---|---|---|
| | | T | F | T | F | T | F |
| NP ($D_{NP}$=0.30) | a | 0.01 | 0.5 | 0.01 | 0.1 | 0.01 | 0.01 |
| | b | 0.01 | 0.5 | 0.40 | 0.9 | 0.40 | 0.99 |
| TB ($D_{TB}$=0.08) | c | 0.01 | 0.95 | 0.01 | 0.5 | 0.01 | 0.01 |
| | d | 0.2 | 0.05 | 0.2 | 0.5 | 0.2 | 0.99 |
| P ($D_P$=0.25) | e | 0.5 | 0.8 | 50 | 0.15 | 500 | 0.05 |
| | f | -- | -- | 1.0 | 0.4 | 1.0 | 0.4 |
| | g | -- | -- | 50 | 0.4 | 500 | 0.4 |
| | h | 0.5 | 0.2 | 50 | 0.05 | 500 | 0.15 |
| | i | 0.5 | 1.0 | 50 | 1.0 | 1000 | 0.9 |
| | j | -- | -- | -- | -- | ∞ | 0.1 |

AMAD = 1 μm ; T(d)

*FIG. 2. Mathematical model used to describe clearence from the respiratory system*

Though this respiratory system was pretty mature, it did have shortcomings in many ways. The most criticized was the clearance classification of D, W and Y. It was found from many animal tests or human exposure researches of radioactive chemical compounds that the instant clearance rate in the respiratory system was different from the given rate, especially the insoluble chemical compound. For example, the clearance of $PuO_2$ in the lung was slower than the given Type Y chemical compound. The mixed radioactive chemical compounds were often seen in accident exposures. In the Chernobyl event of Russia, radionuclides were released to the environment and that was when the public exposure dose started to be cared. But, the ICRP Publication 30 model was specially suitable for referring to the male Caucasian adults' occupational exposures and could not be applied in the whole population of the world. So, the ICRP published ICRP *Publication* 66(1994) which proposed a respiratory tract model that could fully reflect contemporary physiology, tissue, anatomy, deposition and clearance of inhaled chemical compound and bio-effect, as in Fig. 3. Seeing that there was huge difference in radiosensitivity among different tissues of the respiratory tract, the dose of particular respiratory tract was calculated to improve the old method of calculating the average lung dose. Besides, the related applications got wider: not only used in evaluation of radiation workers but also in the general public. In next year, the ICRP published the ICRP *Publication* 68 (1995) which provided dose coefficients for radiation workers. Besides, the ICRP used the new respiratory tract model as the basis for the internal exposure monitoring of radionuclide intake of radiation workers and published ICRP *Publication* 78 (1998) replaced the ICRP *Publication* 54 which was based on the respiratory system given in the ICRP *Publication* 30.

Before the ICRP *Publication* 66 (1994) being published, due to the Chernobyl event of Russia, the ICRP started to pay attention to the internal dose evaluation of the general public. First in 1987, the ICRP *Publication* 56[21] giving the age-dependent dose coefficients of mouth-intake radionuclides was published for evaluations of the general public. The age-dependent dose coefficients were given sequentially in ICRP *Publications* 67, 69, 71 and 72 for reference. In 2001, the ICRP *Publication* 88 was published to provide an evaluation model for the embryo/fetus dose of radionuclide intake through the mother. For reference, Fig. 4 gives the evolution of related ICRP *Publication* used in evaluations or monitoring of radiation workers and the general public and Table I gives the differences of models and weighting factors of each ICRP *Publication* referred to when evaluating the dose of the general public.

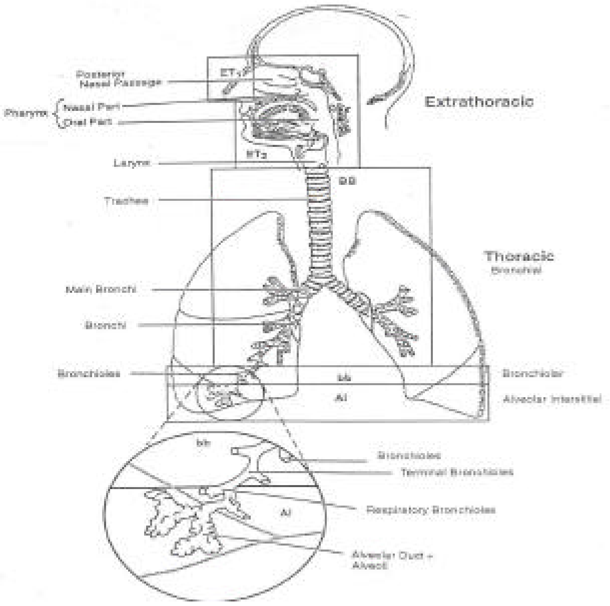



*FIG. 3. Human respiratory tract of the ICRP 66 model*

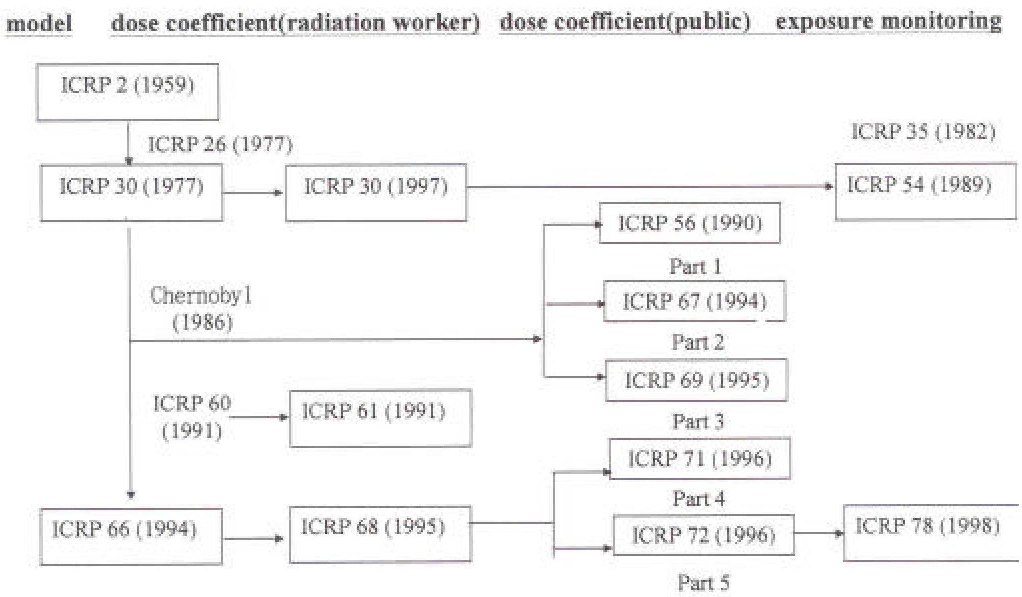



FIG 4. The evolution of related ICRP Publication used in evaluations or monitoring of radiation workers and the general public

Table I. The list of the ICRP Publications giving age-dependent dose coefficients of inhaled radionuclides of the general public

| ICRP Publications | ICRP 56[(a)] | ICRP 67[(b)] | ICRP 69[(c)] | ICRP 71[(d)] | ICRP 72 |
|---|---|---|---|---|---|
| Inhalation dose coefficient[(e)] | V | V | V | ---- | V |
| Ingestion dose coefficient[(e)] | V | ---- | ---- | V | V |
| Gastrointestinal tract model | ICRP 30 | ICRP 30 | ICRP 30 | ICRP 30 | ICRP 30 |
| Respiratory tract model | ICRP 30 | No | No | ICRP 66 | ICRP 66 |
| Tissue weighting factors | ICRP 26 | ICRP 60 | ICRP 60 | ICRP 60 | ICRP 60 |

(a)included radionuclides of H, C, Sr, Zr, Nb, Ru, I, Cs, Ce, Pu, Am and Np.
(b)included raionuclides of S, Co, Ni, Zn, Mo, Tc, Ag, Te, Ba, Pb, Po and Ra(metabolism correction model of Sr, Pu, Am and Np)
(c)included radionuclides of Fe, Sb, Se, Th.
(d)included radionuclides of (a), (b) and (c) and Ca and Cm.
(e)V means “it provides” , ---- means “ it does not provide”

## 3. Internal exposure monitoring and dose evaluation of INER

Paragraph 7.2 of Article 7 of the Ionizing Radiation Protection Act provides that: For the preceding practice of radiation protection, the facility operator shall draw up a radiation protection plan in advance, and submit it to the Competent Authority. The practice may only be implemented after approval by the Competent Authority. No practice shall be carried out without approval of the plan. According to the Act, INER modified its "Radiation Protection Plan" and the Plan was approved by AEC on Oct. 3, 2003. In the Plan, regulations about dose limits of radiation workers were totally based on the requirements of the Safety Standards for Protection Against Ionizing Radiation, as in Table II. Following the Standards, the Plan provides record level, investigation level and intervention level, as in Table III. Regarding the reference basis of workers' internal exposure, it follows the rules of Table III and is given in Table IV. This reference level was settled according to the Standards which referred to ICRP *Publications* 30 and 54. In past years, INER periodically performed routine monitoring of internal contamination such as whole body counting and bio-analysis for radiation workers every quarter, every six months, or every year. In addition, operational monitoring and special monitoring were performed for special tasks and abnormal exposures. In radiation facilities, contamination monitoring of airborne radionuclides was implemented. It showed in the historical records of monitoring results that there were almost no internal contamination of other radionuclides happening to INER radiation worker as the internal pollutions were more of tritium and just very few cases of uranium (due to the TRR project). In recent years, the TRR project has been stopped and the reactor has been torn down, so internal pollutions got fewer. For the convenience of analysis work and reduction of human and material resources, the monitoring cycle was rescheduled to be once in a year and analysis methods of total alpha and total beta in urine were developed as the tool of screening . Also the stand up NaI whole body counting system was used to screening. When the counting results were larger than the investigation level given in Table IV, measures were taken to trace and investigate personal internal contamination and evaluate the dose according to personal biological information and serial counting results. The standard procedures are given in Fig 5.

The new Safety Standards for Protection Against Ionizing Radiation which is being revised by the AEC requires that the monitoring of internal exposures and dose evaluations should adopt the recommendations and methods stated in the publications after the ICRP *Publication* 60. To respond earlier to the new Standards, a reference level was drawn up referring to the ICRP *Publications* 66 and 78 and IAEA Safety Standard Series No. RS-G-1.1and 1.2 for INER radiation workers' internal exposures, as in Table V. Compare Tables IV and V, it is concluded that the reference level responding to the new Standards (Table V) is stricter than the current Standards (Table IV), where the record and investigation level of $^{60}Co$ (whole body counting) is 3 times stricter and the rest remains 1.5 times stricter than current Standards. When the measurement value is larger than the record level, an evaluation is performed by the standard procedures given in Fig. 5 and the inhaled quantities and the dose are evaluated using the coefficient factors of the ICRP *Publication* 72 and the organ retention function of the ICRP *Publication* 78 or the LUDEP program (published by NRPB, UK).

## 4. Conclusion

INER is not only working on the establishment of the internal exposure monitoring and dose evaluation techniques corresponding to the new Safety Standards for Protection Against Ionizing Radiation, but also starting to develop related techniques of dose evaluations of the general public and the radionuclide intake of the embryo/fetus through the mother, to follow the latest standards of the International Commission on Radiological Protection. Also, This laboratory cooperates with the Isotope Application Division in INER in nuclear medicine production by use of the cyclotron, improves the human dose evaluation techniques of nuclear medicine, and at the same time, establishes the standard operation procedures corresponding to the new human respiratory tract model for dose evaluations given in the ICRP *Publication* 66 to be followed by related industries and keeps watching for the human alimentary tract model that is to be published.

Table II. Dose limit standards of INER

| Category | Dose limits |
|---|---|
| 1.Occupational exposure for radiation workers | ・The effective dose equivalent shall not exceed 100 mSv over a cycle of five consecutive years, and not exceed 50 mSv in any single year.(The ratio of deep dose equivalent to 100 mSv in a cycle of five consecutive years plus the sum of the ratios of intake of each radionuclide to twice the ALI during the five-year cycle does not exceed unity; and the sum of the ratio of deep dose equivalent to 50 mSv and the sum of the ratios of intake of each radionuclide to ALI in any single year do not exceed unity.)<br>・ A dose equivalent to the lens of the eye shall not exceed 150 mSv in one year.<br>・ A dose equivalent to skin or extremities shall not exceed 500 mSv in one year. |
| 2.16 to 18 years of age who receive education for taking practice or job training | ・ An effective dose equivalent shall not exceed 6 mSv in one year.<br>・ A dose equivalent to the lens of the eye shall not exceed 50 mSv in one year.<br>・ A dose equivalent to skin or extremeties shall not exceed 150 mSv. |
| 3.Female radiation workers who has notified pregnancy | the dose equivalent to her abdominalsurface shall not exceed 1 mSv during the remaining period of the entire pregnancy, and the intake of radionuclides into the body shall not exceed 2% of an ALI. |
| 4.The general public* | ・ An effective dose equivalent shall not exceed 1 mSv in one year.<br>・ A dose equivalent to the lens of the eye shall not exceed 15 mSv in one year.<br>・ A dose equivalent to skin shall not exceed 50 mSv in one year. |
| 5.Emergency exposure | ・ For the purpose of saving life the dose to the participants in emergency exposure does not exceed ten (10) times the dose limit in a single year of Occupational exposure for radiation workers.<br>・ Except the above, the dose to the participants in emergency exposure does not exceed two times the dose limit in a single year of Occupational exposure for radiation workers. |

* Under special situations, the operator can be free from the limit listed in Item 1for the public by providing related document and approved by the regulatory body before starting work at the condition that the highest dose within a year no more than 5 mSv and the average dose within 5 years no more than 1 mSv.

Table III. Reference level of INER

| Item | Reference level | Basis level | Note |
|---|---|---|---|
| 1. Occupational exposure dose of radiation workers | Record level | Larger than the lowest measurable value of the dosimeter | |
| | Investigation level | The dose intake at a time reaches 6 mSv (excluding emergency exposure). | If the dose intake is over 50 mSv for an exposure, the measure of special medical monitoring should be applied. |
| | Intervention level | Personal dose in a year over 15 mSv | |
| 2. Internal intaked quantities of radiation workers | Record level | Larger than the lowest measurable value | |
| | Investigation level | The radionuclide intake at a time over 5 % of the yearly limit. | |
| | Intervention level | The radionuclide intake at a time over 30 % of the yearly limit. | |
| 3. Environmental monitoring in and out of the facility | (1)The radiation monitoring items in and out of the facility include direct radiation, air concentration and environmental sampling analysis and so on, and the reference level include record level and investigation level.<br>(2) Each reference level and actions to be taken should be handled by the rules of related regulatory bodies. | | |

Note: the dose indicated in this table is the effective dose equivalent.

Table IV. The reference level of INER's current internal contamination routine monitoring

| Analyzed radionuclides | Record level | Investigation level | Intervention level |
|---|---|---|---|
| Whole body counting | | | |
| $^{60}$Co | 740 Bq* | $1.0\times10^{+4}$ Bq | $6.0\times10^{+4}$ Bq |
| $^{137}$Cs | 850 Bq* | $4.5\times10^{+4}$ Bq | $2.7\times10^{+5}$ Bq |
| Urine analysis | | | |
| G.a | $2.0\times10^{-2}$ Bq/ l | $2.0\times10^{-2}$ Bq/ l | $2.0\times10^{-2}$ Bq/ l |
| G.ß | $4.0\times10^{-2}$ Bq/ l | $4.0\times10^{-2}$ Bq/ l | $2.4\times10^{-1}$Bq/ l |
| $^{3}$H | $1.0\times10^{+2}$ Bq/ l | $8.8\times10^{+4}$ Bq/ l | $5.3\times10^{+5}$Bq/ l |
| $^{238}$U | $1.0\times10^{-3}$ Bq/ l | $1.0\times10^{-3}$ Bq/ l | $1.0\times10^{-3}$ Bq/ l |

Note: * is the acceptable lowest measurable quantity from ANSI N13.30(1989)

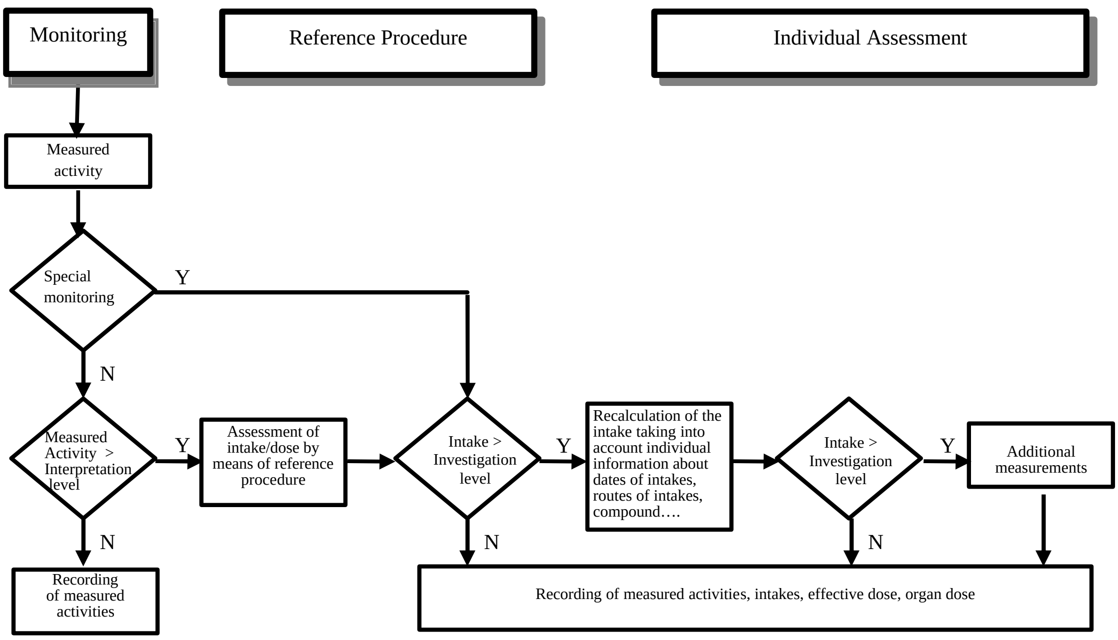



*FIG. 5. Standard procedure for the evaluation of monitoring results*

Table V. The reference level of INER's internal contamination monitoring corresponding to ICRP 66

| Analyzed radionuclides | Record level | Investigation level | Intervention level |
|---|---|---|---|
| Whole body counting | | | |
| $^{60}Co$ | 740 Bq* | $2.4\times10^{+3}$ Bq | $1.4\times10^{+4}$ Bq |
| $^{137}Cs$ | 850 Bq* | $3.6\times10^{+4}$ Bq | $2.2\times10^{+5}$ Bq |
| Urine analysis | | | |
| G.a | $2.0\times10^{-2}$ Bq/ l | $2.0\times10^{-2}$ Bq/ l | $2.0\times10^{-2}$ Bq/ l |
| G.ß | $4.0\times10^{-2}$ Bq/ l | $6.1\times10^{-2}$ Bq/ l | $3.7\times10^{-1}$ Bq/ l |
| $^{3}H$ | $1.0\times10^{+2}$ Bq/ l | $6.9\times10^{+4}$ Bq/ l | $4.1\times10^{+5}$ Bq/ l |
| $^{238}U$ | $1.0\times10^{-3}$ Bq/ l | $1.0\times10^{-3}$ Bq/ l | $4.5\times10^{-3}$ Bq/ l |

Note: * is the acceptable lowest measurable quantity from ANSI N13.30(1989)

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