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■ 論 文 ■

Current Status of Internal Dosimetry Methods and Radiological Regulations in Korea, Ukraine and European Community

Tae Young Lee* · **Jong Il Lee*** · **Vladimir Berkovski+**
*Korea Atomic Energy Research Institute
+Radiation Protection Institute, Melnikova, Ukraine

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Abstract - The paper discusses results of recent international intercomparison exercises on internal dose assessments, status of up to date internal dosimetry methods and the radiological legislation developed and implemented in Korea, European Union and Ukraine. The system of radiation protection in Korea is based on the Korean Atomic Energy Regulatory Enforcement on Safety Standards (Ministry Notice No. 2001-2). The notice is based on the recommendations in ICRP Publication 60 (1990) and IAEA Basic Safety Standards (1996). But the full implementation of the notice by the end of the year 2002 is not required because of the socio-economic situation and inexperience in internal radiation dosimetry. Regulatory framework for internal radiation dosimetry is under development toward the full implementation of the notice from January 1, 2003. The system of radiation protection in Ukraine is based on the National radiation protection regulatory code NRBU-97. The code was developed and adopted in 1998 and replaced the Regulations of Former Soviet Union. The document is based on the ICRP Publication 60, Euratom Directive 96/29 and IAEA Basic Safety Standards (1996). The transitional period of 5 years (effected till January 2003) is established for implementation of all requirements of this new regulation. The system of radiation protection in the European Community is based on the Council Directive 96/29/Euratom, adopted in 1996 and enforced from 13 May 2000. Directive 96/29/Euratom has the status of the European law.
Key words: internal dosimetry, regulation, bioassay

INTRODUCTION

Nowadays the radiological legislation and internal dosimetry methodology in most countries are in the transitional period. The implementation of ICRP Recommendations collides with non-trivial problems, mostly in the area of dosimetry of workers. Main causes of difficulties are the increased complexity of modern ICRP dosimetric models, orientation of most ICRP publications toward the prospective dosimetry and increased requirements to the reliability of assessments in individual monitoring of workers. This paper discusses results of international intercomparison exercises on internal dose assessment, current status of internal dosimetry methods and the radiological legislation of Korea, European Union and Ukraine.

PROBLEMS, DEMONSTRATED BY INTERNATIONAL INTERCOMPARISONS

Two recent international intercomparison exercises on internal dose assessments organized by IAEA[1] and the EULEP/EURADOS Action Group[2] have demonstrated large and, in many

cases, unacceptable discrepancy in the assessments among the participants. For example, in the EULEP/EURADOS exercise, the ratio between the minimum and maximum of reported results ranged from one order of magnitude for the ^{3}H and ^{137}Cs cases and up to five orders of magnitude for the ^{239}Pu cases. The IAEA study (report entitled Intercomparison and Biokinetic Model Validation of Radionuclide Intake Assessment from 1996 to 1998) involved 26 institutes from 22 countries. The 3rd European Intercomparison Exercise on Internal Dose Assessment, carried out by the EULEP/EURADOS group, involved 50 institutes from 23 countries.

In the case of continues intake of tritium through the skin a volunteer during 29 days wore wristwatch having plastic cases with luminous dials containing tritium. The average daily concentration of tritium in urine was measured for a total of 50 days starting with the first day of exposure. Since the case was an experiment, the exposure conditions were quite well known except the physical and chemical characteristics of the contaminant. Different participants of intercomparison exercise have assessed the average daily intake by the values in the range of 106 Bq ~ 20,500 Bq. The assessed maximal committed effective dose was in 77 times greater than the minimal dose.

In another case the repeated inhalation of ^{125}I in the isotope laboratory has been proposed for analysis. The most characteristic work in the laboratory was labelling different organic compounds by ^{125}I. Different phases of the work were connected with different risks of inhalation. This kind of work is repeated several times in a month but not in regular time periods. Monitoring of workers was performed on routine basis and was not connected to any working phase or event. The monitoring data for this case were artificially generated by means of ICRP models. Measurements of thyroid and urine were proposed to participants for the interpretation. Data simulate the results of the routine monitoring program with intervals 30, 60 and 90 days during the period more than 1 year. Participants have been asked to identify intake events, as well as to reconstruct their dates, levels and doses. The minimal reconstructed annual intake was 16 kBq, maximal ~ 457 kBq. The true value (assumed in the case simulation) was 68 kBq. The assessed equivalent dose to the thyroid was in the range of 3.2 ~ 53 mSv. Only 5 of all 38 participants identified 8 events of intakes with the accuracy of ±3days. Best results were found in the assessments, which used simultaneously both thyroid and urine measurements to determine the most probable time of intakes.

Experts, who have participated in intercomparioson, encountered most serious difficulties in the analysis of a real case, connected with an accidental inhalation of ^{239}Pu after explosion in a glove box. This case was well documented: the chemical compounds were known and even scanning electron microscopy and X-ray analyses of dust samples have been done. The physical diameter of plutonium containing particles was in the range 3 ~ 40 μm. The nose swab contained 5.5 kBq ^{239}Pu and the bronchial slime 1.4 kBq ^{239}Pu. Assessed total intakes were in the range 0.0011 ~ 72,000 Bq with using urine data, in the range of 30 ~ 64,000 Bq with using faeces data, and in the range 82 ~ 69000 Bq when assessors used both data sets ('best estimations'). The geometric mean of the statistical distribution of answers is 12,241 Bq, the geometric standard deviation is 4.1. Dose estimations have the same extremely high variation. 'Best estimations' of dose were in the range 0.0008 ~ 7.6 Sv, with the median value 0.2 Sv. An important peculiarity of results of the last case is the supposed AMAD of inhaled aerosols. The majority of assessors (18 of 32) have assumed the standard ICRP AMAD of 1 and 5 μm, most others used the highest, available from ICRP Publications 30/66, value of 10 μm and only three participants calculated intakes and doses with AMAD = 20 μm. Here it should be noted that the range 3 ~ 40 μm of physical diameter for uranium/plutonium particles corresponds to AMADs 10 ~ 100 m (depending on the mass density of particles). It is obvious that the observed domination of 'standard' AMAD values

is caused by the availability of retention curves and doses.

RADIOLOGICAL REGULATION IN KOREA

History

Up until the mid 1990s, Korean Atomic Energy Enforcement Rules on Basic Radiation Safety Standards was established on the basis of the recommendations in ICRP Publication 9. Since issue of ICRP 9 there have been major developments in radiation protection. New protection quantities were introduced, together with a more coherent system of radiation protection. As a result, considerations and decisions for its incorporation into the rules were made.

Current State

The system of radiation protection in Korea is based on the Korean Atomic Energy Regulatory Enforcement on Safety Standards (Ministry Notice No. 2001-2)[3]. The notice is based on the recommendations in ICRP Publication 60 (1990)[4] and IAEA Basic Safety Standards (1996)[5]. But the full implementation of the notice by the end of the year 2002 is not required because of the socio-economic situation and inexperience in internal radiation dosimetry. Regulatory framework for internal radiation dosimetry is under development toward the full implementation of the notice from January 1, 2003. In relation to the notice, the most important peculiarities are next:

- The individual monitoring for internal exposure of workers is obligatory if the annual committed effective dose potentially can be higher of 2 mSv.
- Measuring techniques are based on in vivo or in vitro methods. In case that the detection limits for the methods are too high for a meaningful assessment of intakes or doses, the monitoring is based on the analysis of air samples.
- In case with the committed effective dose exceeding 1 mSv per acute single intake, tracking measurements and investigations are required and the dose is to be re-assessed on the basis of detailed measurements.

The committed effective dose is reported to Minister of Science and Technology at the end of the calendar year. Also, the notice demands internal technical standards for monitoring procedure and its documentation, estimation methods of intake and dose, etc.

RADIOLOGICAL REGULATION IN EUROPEAN COMMUNITY

History

Until 1984 the Basic Safety Standards Directive (adopted in 1959[6] and revised in 1962[7], 1966[8], 1976[9], 1979[10], 1980[11] and in 1984[12] has been the only instrument of derived legislation based on Article 31 of the Euratom Treaty. Since then, although it remained together with the Euratom Treaty itself, the central element of the European Community radiation protection system, it has been supplemented by a number of specific legal instruments[13,14,15,16,17].

Current State

The Council Directive 96/29/Euratom[18], adopted in 1996 and enforced from 13 May 2000 has established the new legal basis for the Member States of the Euratom Treaty. The ICRP publication on which the 1996 Directive based is ICRP Publication 60 that contains the latest general recommendations issued by the ICRP to take account of the continuing development in scientific knowledge and administrative experience. This development has been evolutionary nature and it did not fundamentally change the system of protection recommended by ICRP Publication 26 on which the 1980/1984 Directive was based. In relation to internal dosimetry the most important peculiarities of new Directive are next:

- The Directive established the dual dose limits: 100 mSv in a consecutive five-year

period and the annual dose of 50 mSv;
- The Directive prescribe the special protection measures and dose limit during pregnancy and breastfeeding;
- For the estimation of effective dose and equivalent dose the Directive prescribe the respective values and relationships, but simultaneous states that the competent authorities may authorize the use of equivalent methods;
- The Directive newer refers to ALI (annual limit on intake), but only committed effective dose per unit intake (DPUI) also referred to as effective dose coefficients;
- The Directive indicates DPUI coefficients for a list of radionuclides, depending on the Type of Materials (F, M, S) and for AMADs of 1 μm and 5 μm. These values are identical to dose coefficients from recent ICRP Publications;
- In a case of ingestion if specific information is available on the gat transfer factor, the appropriate value shall be used, if not, the most restrictive value shall be used;
- In a case of inhalation the lung absorption types and gut transfer factor shall take into account the chemical form on the basis of international guidance. In general rule, if no information on the parameters, the most conservative value should be used.

Despite the fact that Member States of European Community have the common legislative basis and the long history of collaboration, the European internal dosimetry methodology is still in process of harmonisation. Recognising the importance of harmonisation, the European Commission has established a cluster of pan-European projects in this area[19]. The IDEAS project[20] is one of elements of this cluster, in which Ukraine participates.

REGULATION IN UKRAINE

History

The conceptual basis of the Ukrainian radiological legislation was developed in the Former Soviet Union (FSU) in 60th years and practically did not changed till the middle of last decade of the previous century. The FSU radiological legislation has had a complex hierarchical structure and comprised several hundreds regulatory documents, including numerous site-specific implementation guides for the internal dosimetry. Intensive investments into the FSU nuclear program in combination with the secrecy and the isolation of dosimetric researches led to developing in FSU sophisticated site-specific internal dosimetry methods, most of which still not published[21]. Due to the reasonable conservatism and the long period of exploitation the old FSU radiological legislation was characterized by the self-consistency. The introduction into many national radiological legislations an 'effective dose equivalent' (ICRP Publication 26) or of the 'effective dose' (ICRP Publication 60) have made the FSU concept of 'doses to critical organs' the main subject of inconsistency with world-wide accepted radiological concept.

Current State

After splitting of FSU the New Independent States continue to use the old radiological legislation, which should be gradually replaced by new regulatory acts. The system of radiation protection in Ukraine is based on the National radiation protection regulatory codes NRBU-97[22] (enforced in 1998), NRBU-97/D-2000 "Protection from potential exposure" [23] (enforced in 2000)[24] and NRBU/OSPU-2002 "Implementation Guide" [4] (enforced in 2002). The document NRBU-97 was developed and adopted in 1998 and replaced the FSU regulation NRB-76/87[25]. The document is based on the ICRP Publication 60[4], Euratom Directive 96/29[18] and IAEA Basic Safety Standards[5]. The transitional period of 5 years (effected till January 2003) is established for implementation of all requirements of this new regulation. Several secondary-level regulatory documents already were enforced in a framework

of transition to the new safety standard.

NRBU-97 requires the implementation in the internal dosimetry practice of the recent ICRP biokinetic and dosimetric models, including the ICRP Human Respiratory Tract Model (Publication 66)[26]. According to Ukrainian regulations the individual monitoring for internal exposure of workers is obligatory if the committed effective dose, associated with annual intake can be higher of 1 mSv. The new Ukrainian regulation demands the implementation of an on-site hierarchical internal dosimetry monitoring system, which in general case should include the check-in/check-out, routine, special, task-related (operational) and accidental monitoring programs. The site-specific implementation guides are required. An important component of Ukrainian regulatory system is the Special Safety Standard for the Chernobyl Site, which currently is under development[27]. The unique and extremely complex exposure conditions in the Unit 4 of Chernobyl NPP necessitate establishing of a reliable internal exposure monitoring system[28,29].

Prospective internal dosimetry

One of the peculiarities of NRBU-97 is a requirement to apply in the 'prospective dosimetry' assessments (technology design, planning of exposure, etc.) most restrictive dose coefficients in a case if there is a lack of information about factual conditions of exposure (e.g. AMAD, Type of Materials, etc.). In the 'prospective dosimetry' NRBU-97 permits using of assessments of either the committed effective dose or the intake or air/foodstuff concentrations. The committed effective dose should be compared with dose limits (20 mSv per year for workers), whereas other quantities should be used in the 'equation for mixture': the sum of ratios of factual values to respective Secondary Limits, like the Annual Limit on Intake (ALI) or the Permissible Concentration (PC), should be less than one. The regulation permits to use of Reference (generalised) Secondary Limits or to develop site-specific Secondary Limits.

The Reference Secondary Limits given in NRBU-97 are applicable in any unknown conditions of exposure. To ensure such applicability the Reference Secondary Limits have been calculated for the most restrictive combination of parameters of exposure (like AMAD, Material Type, duration of exposure, and the age of subject):

$$ALI = \min\left[\frac{DL_E}{e_{k,d,\tau}}\right] \qquad (1)$$

where DL_E is dose limit for respective category (members of the public or workers),
$e_{k,d,\tau}$ is committed effective dose per unit intake, calculated for reference type of material k (if applicable: Types V, F, M, S deposition classes SR-0, SR-1, SR-2; organic and non-organic compounds), AMAD d, and reference age τ (for workers τ ='Adult');

and

$$PC = \min\left[\frac{DL_E}{g_{k,d,\tau}}\right] \qquad (2)$$

where $g_{k,d,\tau}$ is committed effective dose per unit concentration in air, calculated for reference type of material k (if applicable: Material Type V, F, M, S; Deposition classes SR-0, SR-1, SR-2; organic and non-organic compounds), AMAD d, and reference age τ (for workers τ ='Adult').

New achievements in retrospective internal dosimetry

In contrast to the prospective dosimetry methodology, new retrospective dosimetry methods are in the design stage and not yet enforced in Ukrainian regulatory documents. The Ukrainian Radiation Protection Institute is performing long-term projects[30] for the development and the pilot exploitation of new retrospective methods and advanced computer codes[31,32] in this area.

NRBU/OSPU-2002 regulatory document states that for documentation of the factual internal exposure on the workplace (the retrospective dosimetry problem) the bioassay data should be

used for the identification of an exposure event and for the assessment of committed effective dose. The widely used algorithm of the bioassay data interpretation consists of two main steps:

- the reconstruction of intake and
- the calculation of dose.

On the first step the linear combination of retention (excretion) functions r(t) is being involved for data approximation and for the reconstruction of intake(s). On the second step dose coefficients 'dose per unit intake' e are being used for the dose calculation.

The Ukrainian regulation does not require the quantification of intake in terms of activity. The intake should be identified as an event (series of events) for workers or as a chronic process in a case of exposure of population and should be characterised by associated dose(s). Such new legislative approach permits to develop new robust technology for purposes of the retrospective dosimetry. Both r(t) and e are substantially depend on parameters of exposure (like time or pattern of intake, AMAD or AMTD, Type of Materials (TM), others). The most critical parameters are the AMAD or AMTD, Type of Materials (TM) and time of intake. In a typical situation these parameters are not known or poorly defined.

The aggregated functions 'dose per unit organ (body) content (excretion)'

$$\zeta(t, AMAD, TM) = \frac{e(AMAD, TM)}{r(t, AMAD, TM)} \quad (3)$$

has been proposed[33] for using in the retrospective dosimetry. The variation of ζ with changes of AMAD (and even with changes TM) on some time intervals is substantially less than variations of components of ζ (i.e. e(AMAD, TM) and r(t, AMAD, TM)). The invariance of ζ permits to select one function ζ for a whole area of stability. Figures 1 and 2 illustrate this approach. Figure 1a shows the variation of reconstructed intake with AMAD and time in a case of acute intake of ^{241}Am and the urine sample. The AMAD value has a dramatic influence on the assessment of intake even if the time of event is known. For correct estimations by means of the classical two-step procedure the information about AMAD is vitally important. Such requirement is difficult achievable in practical cases. The ζ function (Figure 1b) substantially mitigates this restriction. Moreover, if the time interval between intake and measurement is greater than 10 days the uncertainty associated with AMAD is practically negligible.

The behaviour of ζ functions for some radionuclides grants a unique advantage of an 'absolute stability area'. In the 'absolute stability area' bunches of ζ functions associated with different AMAD and Types of Materials are crossing. For example, such peculiarity of ζ functions for ^{60}Co (Figures 2a, 2b) has a big practical importance for the internal dosimetry protocol at Nuclear Power Plants[34]. Figure 2a demonstrates the variation of reconstructed intake with AMAD, Types of Materials and time in a case of lung counter data. The uncertainty associated with AMAD and Types of Materials is more than one order, as is clear from Figure 2a. Involving of the ζ function into the data interpretation (Figure 2b) gives the information about the 'absolute' stability area, located at the distance about 6 months after intake (it is marked by the ellipse on Figure 2b). The dose assessments based on measurements in this time area are practically independent from both AMAD and Types of Materials. Indicated properties of the function are extremely valuable for planning of the routine monitoring program.

As discussed earlier the ζ function is useful on the stage of scheduling of bioassay measurements as well as on the stage of dose assessments. In a framework of this approach the direct dose estimation for multiple (chronic) intakes case can be implemented. An arbitrary set of bioassay data (e.g. WBC data set) can be approximated by the linear combination

$$F(t) = \sum_i \frac{E_i}{\zeta(t - \tau_i)} \quad (4)$$

where F(t) = function of time t, which approximates the observed bioassay time trend; τ_i = time shift of the acute intake i; E_i = the effective dose, associated with the acute intake i (two last parameters are results of the approximation). The indicated equation implements the 'numerical deconvolution' in terms of ζ functions.

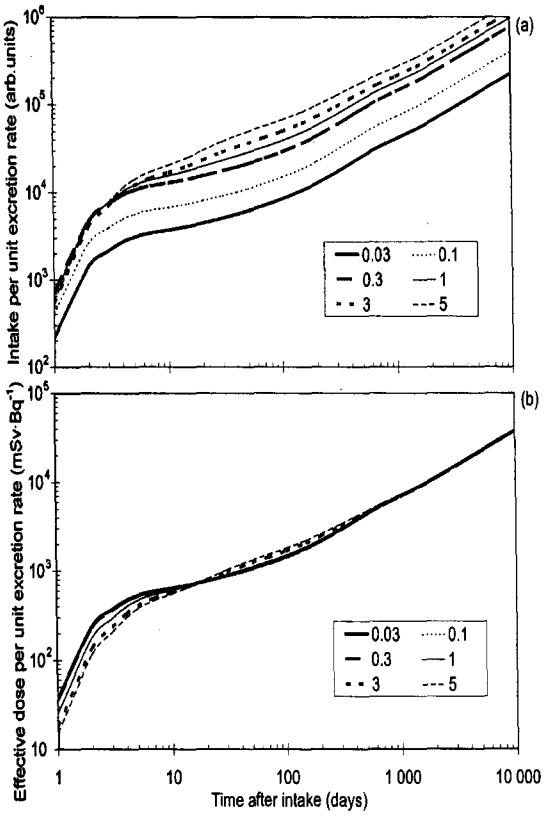

Figure 1. Curves for interpretation of urine samples (adult worker, acute intake: inhalation of ^{241}Am, Material Type M, AMADs in the range 0.035 ~ 5 μm):
[a]reconstructed intake per unit daily excretion rate;
The width of the bunch of curves: from 6th day Max/Geom. mean=3.3; Geom. mean/Min = 7.8.
[b]reconstructed committed effective dose per unit daily excretion rate.
The width of the bunch of curves: from 6th day Max(ζ) /Geom. mean(ζ)=1.11; Geom. mean(ζ)/Min(ζ) = 1.2.

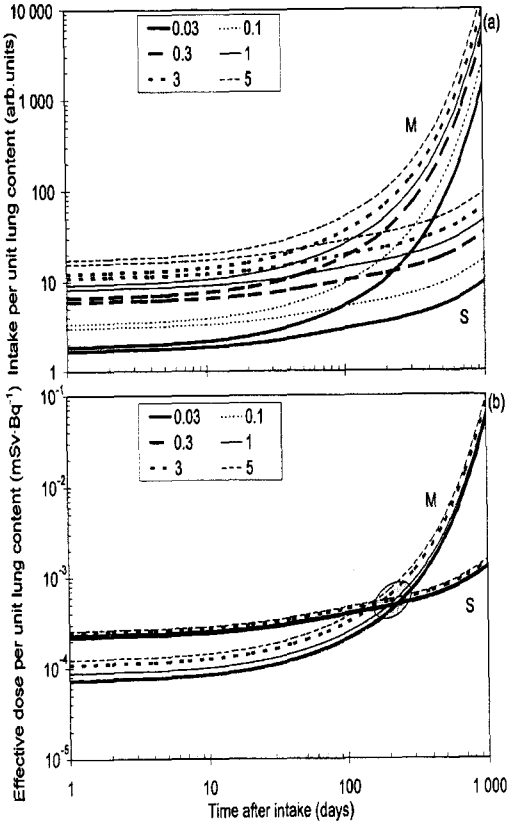

Figure 2. Curves for interpretation of lung counter data (adult worker, acute intake: inhalation of ^{60}Co, Material Type M or S, AMADs in the range 0.03 ~ 5 μm):
[a]reconstructed intake per unit lung content;
[b]reconstructed committed effective dose per unit lung content.
Lung measurements of ^{60}Co after approximately 5 ~ 7 mo. from possible intake give the values, which can be transformed to committed effective dose with the small uncertainty. In this are 'dose per unit intake' function is practically invariant not only on AMAD/AMTD, but also on Type of Materials (M or S). This area is marked on Figure 1b by the ellipse.

CONCLUSION

The results of the discussed in the paper intercomparison exercises are shocking. It appears that the current retrospective dosimetry methodology is not working as expected, and the root causes of the failure needs to be identified. In the light of these results the international harmonisation of methods of bioassay data interpretation and methods of dose assessments is at present the most critical topic in radiation protection of workers. Attention to this problem is vitally important in the view of recent implementation in most countries of more restrictive dose limits recommended by ICRP Publication 60. The non-finished state of most national radiological legislations permits their international harmonization. The incorporation into regulatory documents of new internal dosimetry methods should improve the overall reliability of internal dosimetry assessments. Task-related, special and accidental monitoring programs require sufficiently more detailed recommendations than it is currently available.

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