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Invited paper

Developments in standards and other guidance for individual monitoring

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Abstract

In recent years there has been a huge increase in the development and publication of standards, documents of relevance and other guidance for individual monitoring (IM), particularly for external radiation. An extensive list of the main documents published by the International Commission on Radiological Protection (ICRP), International Commission on Radiation Units and Measurements (ICRU), International Organisation for Standardization (ISO), International Electrotechnical Commission (IEC), CEN/CENELEC, European Council (EC) and International Atomic Energy Agency (IAEA) can be found elsewhere [Fantuzzi, E., Alves, J.G., Ambrosi, P., Janzekovic, H., Vartiainen, E., 2004. Implementation of standards for individual monitoring in Europe. Radiat. Prot. Dosim. 112 (1), 3–44; Fantuzzi, E., 2007. Standards, documents of relevance and directives in individual monitoring: is European individual monitoring in compliance with standards? Radiat. Prot. Dosim., doi:10.1093/rpd/ncl568]. In March 2007 ICRP approved a new set of fundamental recommendations that will replace ICRP Publication 60. Similarly to what has happened in the past with previous ICRP Publications 26 and 60, it is expected that this document will inspire the revision of the Basic Safety Standards of the IAEA [Safety Series 115, 1996. International Basic Safety Standards for Protection Against Ionizing Radiation and for the Safety of Radiation Sources. IAEA, Vienna] and of the European Union (EC Council Directive 96/29/EURATOM) and consequently of national legislation in the respective member states. In order to implement the radiation protection principles laid down in the BSS both the IAEA and EC have regularly published guidance documents. EC published in 1994 EUR 14852 entitled Technical recommendations for monitoring individuals occupationally exposed to external radiation that was a powerful tool for all the participants to the field of IM (radiation protection authorities, individual monitoring services and users) summarizing concepts and contributing to the improvement of quality and the reliability of results.

Particularly over the last decade, EURADOS WG2 has actively contributed to harmonization of IM in Europe, publishing reports (Bartlett, D.T. et al., 2000, van Dijk, J.W.E. et al., 2004), organizing an intercomparison in 1999. A "series" of workshops on IM to disseminate WG activity star (Bartlett, D.T. et al., 2000, van Dijk, J.W.E. et al., 2004), organizing an intercomparison in 1999. A "series" of workshops on IM to disseminate WG activity started: IM-2000 was held in Helsinki organized by STUK (Hyvönen, H., et al., 2001), IM-2005 was held in Vienna organized by ARCS, EURADOS and IAEA (Radiat. Prot. Dosim. advance access). Recent WG2 actions included the review of EUR 14852 and the preparation of a proposal to organize self-sustained intercomparisons. In September 2006, EC issued a call for a tender on the establishment of European technical recommendations. A consortium comprising GAEC and EURADOS prepared and presented a proposal. Following the evaluation procedure EC awarded a contract to the consortium: the EU-Trimer project. This paper will cover the main ICRP and ICRU quantities and requirements, standards and other guidance documents recently published or in course of development in order to achieve harmonization of practices and procedures for IM of external radiation. The main aspects of the EU-Trimer project will also be addressed.

Keywords: Individual monitoring; Standards; Technical recommendations

1. Introduction/scope

A standard is established for use as a rule or basis of comparison in measuring a quantity, a quality, a value, etc. All other texts, e.g. recommendations, reports, legislation, etc. generally called *documents of relevance* are guidance texts (Fantuzzi et al., 2004; Fantuzzi, 2007).

The purpose of individual monitoring is to perform a measurement of a quantity that will be used to estimate effective dose or the equivalent dose in an organ or a tissue. In the case of external radiation exposure, with measurements carried out with equipment worn by the exposed person, the quantity of interest is the personal dose equivalent $H_p(d)$; if the workplace

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is being monitored, then the quantities may be the ambient dose equivalent $H^*(10)$ or the directional dose equivalent $H'(0.07, \Omega)$. In the case of internal radiation exposure, the quantity of interest is the activity of a radionuclide taken into the body.

This paper will try to address standards and other guidance recently published or in course of development, in order to achieve harmonization of practices and procedures for individual monitoring (IM).

2. ICRP and ICRU quantities for IM

The International Commission on Radiological Protection (ICRP) and the International Commission on Radiation Units and Measurements (ICRU) define the main concepts and dose quantities for radiation protection. Three types of quantities are important for monitoring external exposure: the basic physical quantities, the protection quantities and the operational quantities.

The basic physical quantities (ICRU Report 60, 1998) fluence Φ, kerma K and absorbed dose D are universally accepted for the characterization of the radiation beam (Stadtman, 2001). Since it is not possible to use these quantities for dose limitation purposes, ICRP (ICRP Publication 60, 1991) recommended the use of the protection quantities H_T and E, respectively, the equivalent dose in a tissue or organ T and the effective dose.

However, both H_T and E are not directly measurable. To overcome this ICRU defined a set of operational quantities (ICRU Report 51, 1993) that are measurable are derived from the basic physical quantities by appropriate conversion coefficients and aim to provide a conservative estimate for the value of the protection quantities H_T and E (ICRP Report 74, 1997; ICRU Report 57, 1998).

The operational quantities for external exposure are the ambient dose equivalent, $H^*(10)$, the directional dose equivalent, $H'(0.07, \Omega)$ and the personal dose equivalent, $H_p(d)$. For area monitoring the quantities $H^*(10)$ and $H'(0.07, \Omega)$ are used. For individual monitoring $H_p(d)$ is used where $H_p(d)$ is the dose equivalent in ICRU tissue at an appropriate depth d, below a specified point in the human body, normally taken to be where the individual dosemeter is worn. To estimate E, H_{skin}, and H_{lens_eye}, the quantities $H_p(10)$, $H_p(0.07)$ and $H_p(3)$ are, respectively, used.

For internal radiation exposure the assessment of E relies on the calculation of the intakes of radionuclides (the activity of a radionuclide taken into the body) and the contributions due to ingestion and to inhalation of radionuclides need to be taken into account.

If only external radiation is of concern $E \approx H_p(10)$ (in the case of area monitoring, $E \approx H^*(10)$). In either case, on the left-hand side is the ICRP defined protection quantity that is not measurable, and on the left-hand side the result of a measurement which includes the estimation of an uncertainty.

3. Developments in standards for IM

The International Organization for Standardization (ISO) and the International Electrotechnical Commission (IEC) through their respective technical committees ISO TC85 SC2 "Radiation protection" and IEC TC45 SC45B "Radiation protection instrumentation", generate standards for use in the field of radiation protection.

Over the last few years there has been a huge increase in the development of new standards and on the revision and updating of existing ones. This issue has been dealt by several authors (Ambrosi et al., 2004; Bartlett, 2007; Behrens and Ambrosi, 2007; Fantuzzi, 2007).

In this section, developments in relevant standards for individual monitoring will be mentioned organized by reference fields, measuring devices, uncertainty, statistics, characteristic limits, quality assurance, accreditation, performance testing and intercomparisons. To avoid extensive citing the reader is also directed to the above mentioned papers and to the references therein.

Metrologists at calibration laboratories use reference fields to create the basic physical quantities and to derive the operational quantities by use of the appropriate conversion coefficients. Standardized procedures are available for reference fields in the form of families of standards: ISO 4037 for photon (X and gamma), ISO 6980 for beta particle and ISO 8529 for neutron reference radiation fields. Within each family of standards (ISO 4037-1 to -4; ISO 6980-1 to -3; ISO 8529-1 to -3) the same organization is observed. Part 1 relates to characteristics and methods of production of the radiation fields; Part 2 to calibration fundamentals related to the basic quantities characterizing the radiation field; Part 3 to calibration of area and personal dosemeters and the determination of their response as a function of radiation energy and angle of incidence. A further volume exists for the case of photons for the calibration of area and personal dosemeters in low energy X reference radiation fields. Recent developments have been observed particularly in the case of beta particle reference radiation that was split into three parts, in line with the previous photon and neutron counterparts.

Similar trends are being followed for standards for simulated workplace neutron fields and for dosimetry at flight altitudes (cosmic radiation fields), respectively, the ISO 12789 and 20785 families.

Concerning standards on measuring instruments, several different standards exist, depending on the detection technique, on the measurement quantity, on whether the device will be used for area or for personal monitoring, on the type of radiation it is sensitive to and on whether the device is an active or passive detector. For personal monitoring using passive detectors to measure photon and beta radiation, there are standards for film for whole body (ISO 1757, 1996), TLD for whole body (IEC 61066, 2006) and TLD for extremity dosemeters (ISO 12794, 2000). Instead, if neutron radiation is of concern, the (ISO 21909, 2000) can be used for TLD, bubble and nuclear track whole body detectors (see Table II in Ambrosi et al., 2004).

In the case of active personal dosemeters (APD) the recent (IEC 61526, 2005) combines four previously existing standards (IEC 61238 for photon and beta radiation, IEC 61323 for neutron radiation, IEC 61525 for photon, beta and neutron and IEC 61526 for photon and beta radiation). A similar trend is

Table 1
Summary of relevant standards and guidance for IM of external radiation

ICRP Publications 60, 74, 75	Recommendations
ICRU Reports 47, 51, 57, 60	Definitions
ISO 4037-1 to -4, 6980-1 to -3, 8529-1 to -3, ISO 12789-1 and -2, 20785-1 and 2	Reference fields
ISO 1757, 12794, IEC 61066, 62387, 61526, 60846, IEC 61005 (61283, 61323, 61525)	Measurement devices
ISO GUM, GUM Suppl. 1 ISO 3535-1, 5725-1 to -6, 11929-1 to -8	Uncertainty, statistics, limits
ICRU Report 76, ISO 9000, 9001, 9002, 9004, EN ISO/IEC 17025	QA/QC, accreditation
ISO 14146	Performance testing

observed in the case of IEC/FDIS 63387-1, 2007 that has an objective to harmonize requirements for all types of passive dosimetry systems for photon and beta radiation fields.

A thorough comparison on the requirements of the existing standards can be found elsewhere (Ambrosi et al., 2004; Behrens and Ambrosi, 2007).

Concerning the acceptable accuracy of instruments for practical radiation protection measurements of dose equivalent, ICRU (ICRU Report 47, 1992) states *an overall uncertainty of one standard deviation of* 30% *should be acceptable*. . . . *This uncertainty can be compared with the* +/− 10% *uncertainty generally accepted for the calibration of instruments*. ICRP (ICRP Publ. 75, 1997) states in § 251. . . *in practice*, *it is usually possible to achieve an accuracy of about* 10% *at the* 95% *level for measurements of radiation fields in good laboratory conditions*. . . . *In the workplace*, *where the energy spectrum and orientation of the radiation field are generally not well known*, *the uncertainties in the measurement made with an individual dosemeter will be significantly greater*. *Non-uniformity and uncertain orientation of the radiation field will introduce errors in the use of standard models*. *The overall uncertainty at the* 95% *confidence level in the estimation of the effective dose around the relevant dose limit may well be a factor of* 1.5 *in either direction for photons and may be substantially greater for neutrons of uncertain energy and for electrons. Greater uncertainties are also inevitable at low levels of effective dose for all qualities of radiation*. At the 95% confidence level, the overall uncertainty as suggested by ICRU will be slightly larger than the 1.5 factor.

The general rules for the estimation of the uncertainty are laid down in the Guide to the Expression of Uncertainty in Measurement (ISO GUM, 1995; ISO GUM Suppl. 1, 2007), published by the Joint Committee for Guides on Metrology (JCGM).

All components to the overall uncertainty should be considered (Thomas et al., 2006). If the models of the measurement are being used, the input quantities have associated probability density functions. Their propagation should also be taken into account (van Dijk, 2006, ISO GUM Suppl. 1, 2007).

The JCGM also publishes the International Vocabulary of Basic and General Terms in Metrology (ISO VIM, 1993, 2007). Other standards also refer terms and vocabulary on statistics (ISO 3534-1, 1993) on accuracy (ISO 5725 family, 1994) and on characteristic limits (ISO 11929-7, 2005).

Quality assurance and quality control (QA/QC) methods are necessary for establishing, evaluating and maintaining the quality of ionizing radiation calibrations and measurements. Several standards (ISO 9000, 2000 series and ICRU Report 76, 2006) provide suggestions and guidelines to implement a quality management system, and to evaluate the performance of a particular dosimetry system (ISO 14146, 2000). Regular participation in intercomparison exercises is an important tool for QA/QC assessment and of ensuring the reliability of the measurements.

There presently is an increasing pressure for accreditation of services and laboratories particularly in conformity with the (EN ISO/IEC 17025, 2005). Accreditation and the mutual recognition and validation of dose results presently play a central role in Europe as it encloses an extended range, beyond national borders.

Several different standards have been mentioned, which indicates the complexity and difficulty of understanding and using the adequate standard in routine work (see Table 1).The main participants in the field of IM, e.g. metrologists, radiation protection authorities, individual monitoring services, users, etc. will naturally raise different questions on their relative importance, if all items mentioned therein are to be fulfilled, to what extent, and finally if they are compulsory. Guidance on the use of all these documents is needed in order to achieve harmonization of practices and procedures.

Concerning internal exposure and although out of the scope of this paper dedicated to IM for external exposure, the (ISO 20553, 2006) standard has recently been published. It addresses the monitoring of workers occupationally exposed to a risk of internal contamination with radioactive material. Its publication triggered the revision of two existing standards that are presently circulating as CD, the first on performance criteria for radiobioassay (ISO/CD 28218, 2007) and the second one on dose assessment for the monitoring of workers for internal radiation exposure (ISO/CD 27048, 2007).

4. Other guidance for IM

In March 2007, the ICRP approved a new set of fundamental recommendations on the protection of man and the environment against ionizing radiations that will be published in the *Annals of the ICRP* and will replace ICRP Publication 60. Based on the draft of the new recommendations of the ICRP available on the IRPA web site (ICRP, 2007), new tissue and radiation weighting factors have been proposed, the protection and the operational quantities will not change, although some doubts remain on the future use of $H_p(3)$.

The radiation protection concepts and principles recommended by the ICRP have inspired the main legislative documents currently enforced, namely, the Basic Safety Standards of the International Atomic Energy Agency (IAEA) and of the European Commission (EC) (SS115, 1996; 96/29/EURATOM, 1996). Since their publication, the use of the operational quantities $H_p(10)$ and $H_p(0.07)$ generalized, QA/QC became increasingly important within the Europe and worldwide, thus contributing to harmonization of IM.

In order to implement the radiation protection principles laid down in the BSS and to provide guidance to radiation protection authorities and officers, individual monitoring services, users, etc. the IAEA and the International Labour Office (ILO) published the Safety Standard Series (Orpguide CD-ROM, 2000) comprising, Safety Fundamentals, Requirements and Guides on Occupational Radiation Protection.

With the same aim the EC publishes the Technical Recommendations for monitoring external exposure (EC, 1975, 1994) the most recent was published in 1994 as EUR 14852. The BSS and EUR 14852 have also largely contributed to the generalized use of the operational quantities and harmonized procedures for IM in Europe.

However, EUR 14852 was written with passive detectors in mind particularly TLDs, for instance APDs were not addressed. On the contrary, APDs are presently evolving from just work control devices to fulfilling all the legal aspects of IM and nowadays they cannot be left out of the scope of recommendations or standards. Obviously the document did not take into consideration the development of standards and other guidance since it was published.

Considering the need for an update of EUR14852, the EC opened a call for a tender for the Establishment of European technical recommendations for monitoring individuals exposed to external radiation in September 2006. This will be dealt later in the text.

5. EURADOS WG2: 10 y of harmonization actions in IM

The European Radiation Dosimetry group's working group 2 (EURADOS WG2) on Harmonization of Individual Monitoring in Europe has been active since 1996.

In the period 1996–2000 WG2 activity was partially supported under EC's 4th framework programme (FP4). WG2 was composed by one representative from each of the then 15 member States and Switzerland and was chaired by D. Bartlett. The 96/29/EURATOM Council Directive had just been published and its state of implementation was analyzed. The WG's activity is summarized in a report entitled *Harmonization and dosimetric quality assurance of IM for external radiation* published as a special issue (Bartlett et al., 2000) and covered three main areas, namely, Procedures for routine individual dose assessment of external radiation within the EU countries; A catalogue of dosemeters and dosimetric services within the EU and Switzerland able to estimate external radiation doses as personal dose equivalent; and Performance test of dosimetric services in the EU and Switzerland for the assessment of individual doses (photon, beta and neutron).

At the end of the 1996–2000 period the IM-2000 workshop was held in Helsinki. The proceedings are also published as a special issue (Hyvönen et al., 2001).

In the period 2001–2004 WG2 was partially supported by EC's FP5. WG2 was chaired by J.W.E. van Dijk and was composed by representatives from the 15 EU member States, Switzerland and from the then 10 candidate member States.

The WG's activity was also published as a special issue (van Dijk et al., 2004) entitled *Harmonization of IM in Europe* comprising the following: Implementation of standards for IM in EU; A catalogue of dosemeters and dosimetric services within EU—an update; IM for internal exposure in EU and the integration of dosimetric data; Workplace monitoring for exposures to radon and to other natural sources in EU: integrations of monitoring for internal and external exposures; APDs for IM and other new developments; and QC and reliability of reported doses.

The IM-2005 workshop was held in Vienna in 2005. The proceedings will be published as a special issue and are already available from Radiat. Prot. Dosim. advance access.

As a consequence of the action developed in the field of APD in WG2, but out of the 2001–2004 workplan, an intercomparison of APD was jointly organized by the IAEA and EURADOS (IAEA, in press).

Facing lack of funding and continuity WG2 identified and voted a priority list of main areas for possible further work. The EURADOS Council decided in 2005 to support a reduced WG2. A mandate was given to WG2 chaired by V. Kamenopoulou for the period 2005–2006 with two tasks: the review of EUR 14852 and to prepare a proposal for the preparation of self-supporting intercomparisons in Europe. Both tasks were completed and a report was presented to the EURADOS Council in January 2007.

6. EU-Trimer project

In order to answer the EC's call for a tender, a consortium agreement comprising the Greek Atomic Energy Commission and EURADOS prepared and presented a proposal. Following the evaluation procedure EC awarded a contract to the consortium (TREN/07/NUCL/S07.70121), which was signed in April 2007 and will last for two years. This is the EU-Trimer project where the acronym stands for *E*uropean *U*nion *T*echnical *R*ecommendations for *i*ndividual *m*onitoring of *e*xternal *r*adiation.

The project is structured in work packages: methodology for drafting; draft preparation; identification of, contact with and ensure inputs from the relevant organizations; collection and evaluation of comments on the draft; and the presentation of the final draft to the Group of Experts (GoE) established under the Article 31 of the EURATOM Treaty for approval.

Inputs are expected from ICRP, ICRU, ISO, IEC, CENELEC, EA, EURAMET, IAEA and Article 31 GoE. The EURADOS WG2 network in the Extended Group of European Countries (EGEC comprises the EU member States, the candidate member States, Switzerland, Norway and Iceland) will be used

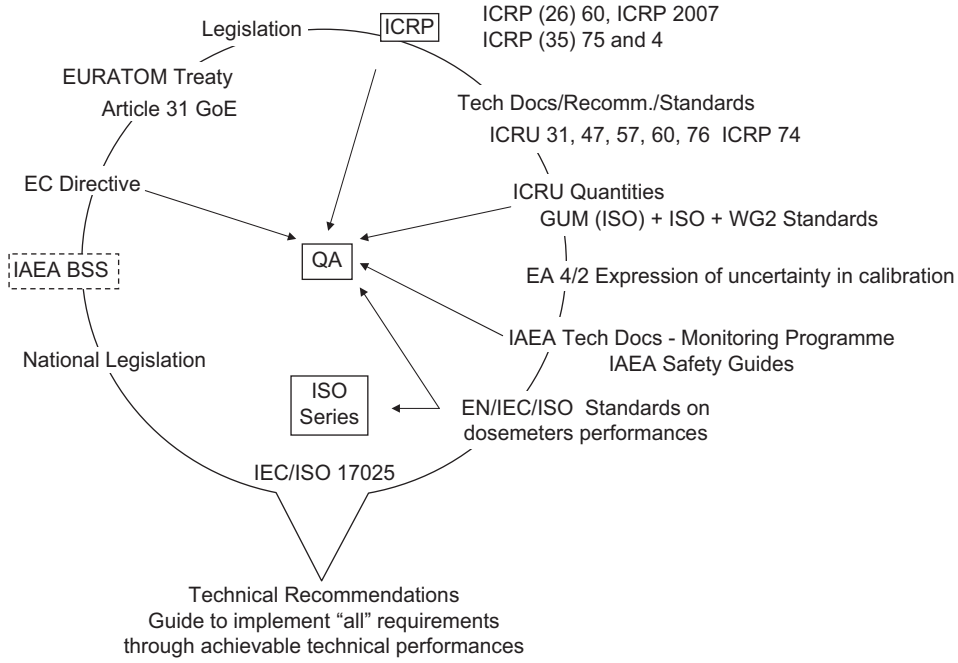

Fig. 1. Methodology for the preparation of the technical recommendations.

to contact national radiation protection authorities, metrology institutes and individual monitoring services.

The new technical recommendations will be prepared taking into consideration the EC Parliament and Council Directives 96/29/EURATOM, 90/641/EURATOM (EC, 1990), 97/43/EURATOM (EC, 1997) and 95/46 (EC, 1995) (respectively the BSS, outside workers, medical and data protection Directives), standards, and other guidance texts important for IM, EURADOS WG2 experience in Harmonization of IM, and with full awareness of the new recommendations being prepared by the ICRP, see Fig. 1.

Up to date scientific and technical knowledge, such as the new developments in the construction of dosemeters, their technical parameters, the development of APD, their use as legal dosemeters will also be considered. Developments in information technology (storage media and wider internet use) with impacts on dose record, dose data transfer and electronic national dose registries will be taken into account.

There presently is an increasing pressure for accreditation of IMS (EN ISO/IEC 17025, 2005). However, no specific guidance on harmonized approval requirements for dosimetric services is available at the moment.

It is expected that this document will provide minimum criteria for approval of dosemeters and dosimetric systems, will form the basis for establishing European norms and standards for dosimetry systems, and will present a possible mechanism toward achieving harmonization of practices and procedures aiming at the mutual recognition of dose results.

The opinion and experience within EGEC will be taken into consideration as it is desirable that consensus is reached across the EGEC. Moreover, the draft technical recommendations will be presented to the GoE established under Article 31 and seek for approval.

7. Concluding remarks

Developments in the standards and other guidance for IM have been covered highlighting the need for harmonization of practices and procedures that has directed EURADOS WG2's activity in this field.

In line with this it is envisaged that the EU-Trimer project will produce the new Technical Recommendations that will make use of the more updated ICRP and ICRU concepts and the more recent standards and documents of relevance to produce a useful document to all the main participants in the field of IM in Europe.

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References

Ambrosi, P., Behrens, R., Böhm, J., Soares, C.G., 2004. Calibration and proficiency testing of dosemeters—recend developments in ISO and IEC standards. In: Proceedings of the 11th International Congress of the International Radiation Protection Association, IRPA 11, Madrid, Spain.

Bartlett, D.T, 2007. Overview of current work of ICRU, ISO & IEC. In presentations from the EURADOS Scientific Symposium. Available from ⟨http://www.eurados.org/meeting2007/general.htm⟩.

Bartlett, D.T, Ambrosi, P., Bordy, J.M., van Dijk, J.W.E. (Ed.), 2000. Harmonisation and dosimetric quality assurance in individual monitoring for external radiation. Radiat. Prot. Dosim. 89 (1–2), 5–154 (special issue).
Behrens, R., Ambrosi, P., 2007. Review of international standards for dosemeters. Radiat. Prot. Dosim., doi:10.1093/rpd/ncm331.
van Dijk, J.W.E., 2006. Uncertainty in personal dosimetry for external radiation: a Monte Carlo approach. Radiat. Prot. Dosim. 121, 31–39.
van Dijk, J.W.E., Bolognese-Milsztajn, T., Fantuzzi, E., Lopez, M.A., Stadtmann, H. (Eds.), 2004. Harmonization of individual monitoring in Europe. Radiat. Prot. Dosim. 112 (1), 1–191 (special issue).
EC, 1975. Technical recommendations for monitoring the exposure of individuals to external radiation. EUR 5287, Luxembourg.
EC, 1990. Council Directive 90/641/EURATOM of 4 December 1990 on the operational protection of outside workers exposed to the risk of ionizing radiation during their activities in controlled areas, OJ EC L349, p. 21.
EC, 1994. Radiation Protection 73. Technical recommendations for monitoring individuals occupationally exposed to external radiation. Report EUR 14852, Luxembourg.
EC, 1995. Parliament and Council Directive 95/46 on the protection of individuals with regard to the processing of personal data and on the free movement of such data, OJ EC L281, pp. 31–51.
EC, 1996. Council Directive 96/29/EURATOM of 13 of May 1996 laying down basic safety standards for the protection of the health of workers and the general public against the dangers arising from ionizing radiation, OJ EC L159, pp. 1–114.
EC, 1997. Council Directive 97/43/EURATOM of 30 of June 1997 on the health protection of individuals against the dangers of ionizing radiations in relation to medical exposure, OJ EC L180, p. 22.
EN ISO/IEC 17025, 2005. General Requirements for the Competence of Testing and Calibration Laboratories, second ed. International Organization for Standardization/International Electrotechnical Commission, Geneva.
Fantuzzi, E., 2007. Standards, documents of relevance and directives in individual monitoring: is European individual monitoring in compliance with standards? Radiat. Prot. Dosim., doi:10.1093/rpd/ncl568.
Fantuzzi, E., Alves, J.G., Ambrosi, P., Janzekovic, H., Vartiainen, E., 2004. Implementation of standards for individual monitoring in Europe. Radiat. Prot. Dosim. 112 (1), 3–44.
Hyvönen, H., et al. (Ed.), 2001. Harmonization and dosimetric quality assurance in individual monitoring for external radiation. Radiat. Prot. Dosim. 89 (1–3), 9–280 (special issue).
International Atomic Energy Agency (IAEA), Intercomparison on measurements of the quantity personal dose equivalent $H_p(d)$ by active personal dosemeters. Joint-IAEA-EURADOS project, in press.
ICRP, 1991. Publication 60. 1990 recommendations of the international commission on Radiological Protection. Ann. ICRP 21 (1–3).
ICRP, 1997. Publication 74. Conversion coefficients for use in radiological protection against external radiation. Ann. ICRP 26 (3).
ICRP, 1997. Publication 75. General principles for the radiation protection of workers. Ann. ICRP 27 (1).
ICRP, 2007. Draft new recommendations of the ICRP (12-Jan-2007). Available from ⟨http://www.irpa.com⟩.
ICRU, 1992. Measurement of dose equivalents from external photon and electron radiations. ICRU Report 47, International Commission on Radiation Units and Measurements (ICRU), Bethesda, MD.
ICRU, 1993. Quantities and units in radiation protection dosimetry. ICRU Report 51, ICRU, Bethesda, MD.
ICRU, 1998. Conversion coefficients for use in radiological protection against external radiation. ICRU Report 57, ICRU, Bethesda, MD.
ICRU, 1998. Fundamental quantities and units for ionizing radiation. ICRU Report 60, ICRU, Bethesda, MD.
ICRU, 2006. Measurement quality assurance for ionizing radiation dosimetry. ICRU Report 76, ICRU, Bethesda, MD.
IEC 61066, Edition 2, 2006. Radiation protection instrumentation—thermoluminescence dosimetry systems for personal and environmental monitoring. IEC, Geneva.
IEC 61283:1995, IEC 61323:1995, IEC 61525:1996. Cancelled. Replaced by IEC 61526, 2005.
IEC 61526, 2005. Radiation Protection Instrumentation—Measurement of Personal Dose Equivalents $H_p(10)$ and $H_p(0.07)$ for X, Gamma, Neutron and Beta Radiations—Direct Reading Personal Dose Equivalent Meters and Monitors, second ed. IEC, Geneva.
IEC/FDIS 62387-1, 2007. Radiation Protection Instrumentation—Passive integrative dosimetry systems for environmental and personal monitoring for external photon and beta radiation using electronic devices for data evaluation—Part 1: General characteristics and performance requirements on dosimetry systems. First Draft International Standard (IEC), Geneva.
ISO 3534-1, 1993. Statistics—Vocabulary and Symbols—Part 1: General Statistical Terms and Terms used in Probability. ISO, Geneva.
ISO 5725, 1994. Accuracy (Trueness and Precision) of Measurement Methods and Results. Part 1: General Principles and Definitions. ISO, Geneva.
ISO 1757, 1996. Personal Photographic Dosemeters. International Organization for Standardization (ISO), Geneva.
ISO 4037-1, 1996. X and gamma reference radiation for calibrating dosemeters and doserate meters and for determining their response as a function of photon energy—Part 1: Radiation characteristics and production methods. ISO, Geneva.
ISO 4037-2, 1997. X and gamma reference radiation for calibrating dosemeters and doserate meters and for determining their response as a function of photon energy—Part 2: Dosimetry for radiation protection over the energy ranges from 8 keV to 1.3 MeV and 4 MeV to 9 MeV. ISO, Geneva.
ISO 4037-3, 1999. X and gamma reference radiation for calibrating dosemeters and doserate meters and for determining their response as a function of photon energy—Part 3: Calibration of area and personal dosemeters and the measurement of their response as a function of energy and angle of incidence. ISO, Geneva.
ISO 4037-4, 2004. X and gamma reference radiation for calibrating dosemeters and doserate meters and for determining their response as a function of photon energy—Part 4: Calibration of area and personal dosemeters in low energy X reference radiation fields. ISO, Geneva.
ISO 6980-1, 2006. Reference beta particle radiations—Part 1: Production methods. ISO, Geneva.
ISO 6980-2, 2004. X and gamma reference radiation for calibrating dosemeters and doserate meters and for determining their response as a function of photon energy—Part 2: Calibration fundamentals related to basic quantities characterizing the radiation field. ISO, Geneva.
ISO 6980-3, 2006. X and gamma reference radiation for calibrating dosemeters and doserate meters and for determining their response as a function of photon energy—Part 3: Calibration of area and personal dosemeters and determination of their response as a function of energy and angle of incidence. ISO, Geneva.
ISO 8529-1, 2001. Reference neutron radiations—Part 1: Characterisitcs and methods of production. ISO, Geneva.
ISO 8529-2, 2000. X and gamma reference radiation for calibrating dosemeters and doserate meters and for determining their response as a function of photon energy—Part 2: Calibration fundamentals of radiation protection devices related to the basic quantities characterizing the radiation field. ISO, Geneva.
ISO 8529-3, 1998. X and gamma reference radiation for calibrating dosemeters and doserate meters and for determining their response as a function of photon energy—Part 3: Calibration of area and personal dosemeters and determination of their response as a function of energy and angle of incidence. ISO, Geneva.
ISO 9000, 2000. Quality Management Systems (QMS)—Fundamentals and Vocabulary. ISO, Geneva.
ISO 9001, 2000. Quality Management Systems—Requirements. ISO, Geneva.
ISO 9002, 2000. Quality Management Systems—Model for Quality Assurance in Production, Installation and Servicing. ISO, Geneva.
ISO 9004, 2000. Quality Management Systems—Guidelines for Performance Improvement. ISO, Geneva.
ISO 12789-1, 2000. Reference Neutron Radiations—Characteristics and Methods of Production of Simulated Workplace Neutron Fields. ISO, Geneva.
ISO 12794, 2000. Radiation Protection—Individual thermoluminescence dosemeters for extremities and eyes. ISO, Geneva.
ISO 14146, 2000. Radiation Protection—Criteria and Performance Limits for the Periodic Evaluation of Processors of Personal Dosemeters for X and Gamma Radiation. ISO, Geneva.

ISO 11929-7, 2005. Determination of the Detection Limit and Decision Threshold for Ionizing Radiation Measurements—Part 7: Fundamentals and General Applications. ISO, Geneva.

ISO 20553, 2006. Radiation Protection—Monitoring of Workers Occupationally Exposed to a Risk of Internal Contamination with Radioactive Material. ISO, Geneva.

ISO 20785-1, 2006. Dosimetry for Exposures to Cosmic Radiation in Civilian Aircraft—Part 1: Conceptual Basis for Measurements. ISO, Geneva.

ISO 20785-2, 2006. Dosimetry for Exposures to Cosmic Radiation in Civilian Aircraft—Part 2: Characterization of Instrument Response. ISO, Geneva.

ISO 21909, Edition 1, 2000. Passive personal neutron dosemeters—Performance and test requirements. ISO, Geneva.

ISO/CD 27048, 2007. Dose Assessment for the Monitoring of Workers for Internal Radiation Exposure. ISO, Geneva.

ISO/CD 28218, 2007. Preformance Criteria for Radiobioassay. ISSO, Geneva.

ISO 12789-2, 2007. Reference Neutron Radiations—Characteristics and Methods of Production of Simulated Workplace Neutron Fields—Part 2: Calibration Fundamentals Related to the Basic Quantities Characterizing Simulated Workplace Fields. ISO, Geneva.

ISO GUM (Corrected reprint), 1995. Guide to the expression of uncertainty in measurement. ISO, Geneva.

ISO GUM Suppl. 1, 2007. Propagation of Distributions Using a Monte Carlo Method. ISO, Geneva.

ISO VIM, 1993. Vocabulary of Basic and General Terms in Metrology. ISO, Geneva.

ISO VIM, 2007. International Vocabulary of Basic and General Terms in Metrology, third ed. ISO, Geneva.

Orpguide CD-ROM, 2000. Occupational Radiation Protection. IAEA Safety Standard Series. IAEA and International Labour Office, Vienna.

Safety Series 115, 1996. International Basic Safety Standards for Protection Against Ionizing Radiation and for the Safety of Radiation Sources. IAEA Vienna.

Stadtman, H., 2001. Dose quantities in radiation protection and dosemeter calibration. Radiat. Prot. Dosim. 96 (1–3), 21–26.

Thomas, D.J., Bartlett, D.T., Fantuzzi, E., Zoetelief, J. (Eds.), 2006. Uncertainties in dosimetry—principles through practice. Radiat. Prot. Dosim. 121 (1), 3–79 (special issue).