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A SHORT HISTORY AND CRITICAL REVIEW OF INDIVIDUAL MONITORING

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Soon after the discovery of X-rays and the radioactive element radium harmful radiation effects occurred, mainly in the medical field. Consequently, the radiologists, a new profession at that time, called for a limitation of radiation exposures. First proposals were to limit the exposure rate to prevent the incidence of skin erythema. It took more than two decades and there were many victims of severe radiation effects until a sound basis for radiation protection and individual monitoring was established. For external dosimetry, the film dosemeter was invented in the 1920s. This device, often combined with an ion chamber-based pencil dosemeter, dominated the systems used in personnel dosimetry until the end of the twentieth century. For internal exposure, the concept of limiting the 'body burden' was commonly used, and only in the late 1970s, the new concept of the 'effective dose equivalent' published in ICRP publication 26 allowed for a unified interpretation and, therefore, addition of the dosimetric quantities for external and internal exposures. By the end of the last century, individual monitoring had to survive an inflation of proposals for new quantities, but fortunately, it was also the time of vast developments of new technologies, methods and procedures. Later on, much room was given to highly sophisticated regulations, requirements, metrological concepts and administrative procedures. In this complex environment, the original task of individual monitoring became more and more hidden behind secondary loads. Now, like about hundred years ago, however with different motivation, once again the ultimate goal of the professional work has to be thought about by asking: Do people always know why they do what they do? Or simply: Why individual monitoring?

INTRODUCTION

This article follows an invited talk at the opening of the International Conference on Individual Monitoring of Ionising Radiation, held in Bruges, Belgium on 20–24 April 2015. The title of the presentation was: Why individual monitoring?

In a short review of the history of individual monitoring, the remarkable development of this highly important and fascinating field of science, technique, regulation and management is shown here, and some critical questions are asked concerning some recent and upcoming developments of this most relevant element of radiation protection.

CHRONOLOGY OF RADIATION PROTECTION

In 1980, Kathren and Ziemer published a paper on the history of radiation protection, structured in chronological steps[1]. This idea is taken here and is extended until today:

- Pioneer Era (1895–1905). Recognition of somatic hazards, simple means to cope with.
- Dormant Era (1905–1925). Major concern towards applications of X-rays and radium, great gains in technical and biological knowledge.
- Era of progress (1925–1950). Development of radiation protection as a science in its own.
- Era of good science (1950–1970). Excellent ICRP publications '1' and 2. Sound basis for practical work in radiation protection.
- Era of struggle with quantities (1970–1990). Beginning of international intercomparison and quality assurance programmes in dosimetry.
- Era of regulations, standardisation and commerce (1990 to today). Vast developments in dosimetry techniques and numerical dosimetry, but also in paperwork and legislation. Market concentration on few key companies.

PIONEER AND DORMANT ERA (1895–1925)

In this early period of mainly medical use of X-rays and radium gamma rays, no radiation protection systems existed and, therefore, there was also no individual monitoring.

Severe radiation damage occurred mainly on radiologists, and the first well-known radiation effect was the skin erythema. The first recommendations on protection measures, therefore, concerned the prevention of skin erythema.

In 1924, Mutscheller recommended a 'limit' of 0.01 skin erythema dose (SED) per month[2]. In 1925, Sievert proposed 0.1 SED per year[2].

In his review of 1996, Lindell assumed 1 SED would correspond to ~6 Sv[2].

ERA OF PROGRESS (1925–1950)

In 1925, the first International Congress of Radiology took place in London. The dominating issues of this congress were measurements and units. The radiologists established at this congress the 'International X-Ray Unit Committee', later on called 'International Commission on Radiation Units and Measurements' (ICRU). The importance of this committee was expressed by the nomination of 24 members right at the beginning.

At the second International Congress of Radiology in 1928 in Stockholm, the 'International X-Ray and Radium Protection Committee', later on called 'International Commission on Radiological Protection' (ICRP) was established. This committee started with seven members.

Both new committees began to work on recommendations, and at their meeting in Zurich in 1934, they finalised their first recommendations, subject of approval by the fourth International Congress of Radiology in St. Moritz in July 1934.

Out of the quite extended recommendations of both committees, three are of special interest here(3):

- 'The International Unit of Quantity of X-radiation shall be called the "roentgen" and shall be designated by the symbol "r"'.
- 'The practical instrument used to measure x-ray quantity shall be called a dose-meter, and shall be calibrated in roentgens'.
- In addition, a 'Tolerance Dose of 0.2 r per day' was recommended.

Lindell assumed in 1996 that 0.2 r per day corresponds to ~500 mSv/a(2).

These recommendations marked the beginning of individual monitoring, and at that time, there was just one single objective for individual monitoring: 'To ensure that the Tolerance Dose is not exceeded'.

In the time period until 1950, different national radiation protection concepts were developed. In Germany, a 'permissible yearly dose' of 5 r was applied around 1950(4). The 5 r per year corresponds to ~0.4 r per month, the exposure period for film dosemeter in Germany. Interestingly, monthly dosemeter readings below 0.4 r per month were not published, because they were in the 'permissible' range, and, therefore, not of further interest, as a publication of Wachsmann(4) from 1961 shows. Only the frequency of 'overdose' readings was published.

In addition to the quantity 'exposure' expressed in 'r', new quantities were introduced:

Absorbed dose (unit: **rad** for **r**adiation **a**bsorbed **d**ose) (1 Gy = 100 rad)

Dose equivalent (unit: **rem** for **r**oentgen **e**quivalent in **m**an) (1 Sv = 100 rem)

ERA OF GOOD SCIENCE (1950–1970)

In the late 1950s, ICRP published two fundamental documents which found wide international acceptance. In the first publication(5) of the 'new series' in 1958, ICRP introduced a formula for the maximum permissible dose for the gonads, the blood forming organs and the lenses of the eye:

$$D = 5(N - 18)$$

where D is the dose in rem, and N is the age of the person in years.

One year later (1959), the comprehensive document on internal dosimetry appeared as ICRP publication 2(6). At that time, internal exposure was limited by the maximum permissible dose to the critical organ, expressed by the maximum body burden, listed for a quite large number of radionuclides in this publication.

These two publications provided a sound basis for radiation protection regulations in many countries.

ERA OF STRUGGLE WITH QUANTITIES (1970–1990)

In 1971, ICRU publication 19 introduced new quantities(7): the absorbed dose index and dose equivalent index. These quantities represent the maximum dose in the newly defined ICRU sphere. This proposal led immediately to intense discussions, and in 1976, ICRU justified this choice in their publication 25(8) by

> ...This is considered better than to adopt a quantity which can easily be measured accurately but from which the required quantity cannot be accurately derived.

The index quantities stayed for more than a decade without being practically applied, and disappeared then quietly.

Fundamental changes were introduced in the limitation system by ICRP publication 26 in 1977. It was the end of the concept of the critical organ and the introduction of organ and tissue weighting factors. New was then the proposal to add the weighted organ dose equivalent from internal and external radiations.

These concepts were so revolutionary that it took several years until they were finally formulated and widely accepted.

The dramatic search for new basic concepts in radiological metrology is well documented by the wealth of proposals for new quantities in this time period. The following list of proposed quantities and units is not complete!

Definitions of quantities by ICRU:

- Absorbed dose, D (rad)
- Exposure, X (R), originally (r)
- Dose equivalent, DE (rem)
- Dose equivalent, H (Sv)
- Absorbed dose index, D_I (Gy)
- Dose equivalent index, H_I (Sv)
- Deep and shallow dose equivalent indices, $H_{I,d}$ and $H_{I,s}$ (Sv)
- Shell dose equivalent, $H(d \rightarrow d')$ (Sv)
- Individual dose equivalent, penetrating, $H_p(d)$ (Sv)
- Individual dose equivalent, superficial, $H_s(d)$ (Sv)
- Personal dose equivalent, $H_p(d)$ (Sv)
- Personal absorbed dose, $D_p(d)$ (Gy)

Definition of quantities by ICRP:

- Organ and tissue dose, D (rem)
- Organ (tissue) dose equivalent, H_T (Sv)
- Annual limit of intake, I (Bq)
- Effective dose equivalent, H_E (Sv)
- Committed effective dose equivalent, $H_{E,50}$ (Sv)
- Collective dose, S (man-Sv)
- Dose equivalent commitment, H_c (Sv)
- Equivalent dose, H_T (Sv)
- Effective dose, E (Sv)
- Committed effective dose, E_{50} (Sv)

The real need for well-defined and widely accepted quantities and units was shown by the results reported in a European intercomparison programme for personal dosemeters in 1982(9). The participants were asked to report their results in their standard routine format. The following units were used in the reports: mR, mrem, mrad (water), mrad (air), mrad (tissue), mGy (tissue) and mSv.

In 1985, the International Atomic Energy Agency (IAEA) called for a technical committee meeting(10) to discuss the actual needs in 'Personnel Radiation Dosimetry'. This committee produced a long list of recommendations, beginning with first priority:

> Investigate the implementation of dosimetric quantities for radiation protection. This involves answering questions such as: Can the new quantities proposed by the ICRU be measured with existing individual dosemeters? Are new developments necessary? What are suitable phantoms? What conversion factors should be used? What is the required angular response?

The dynamic of this era was not limited to the discussion on quantities and calibration procedures but included also the development of many new passive and electronic dosemeter types(11). In internal dosimetry, the implementation of ICRP publication 30 was a dominating issue at that time(12).

ERA OF REGULATIONS, STANDARDISATION AND COMMERCE (1990 TO TODAY)

After 1990, the priorities of topics shifted first from quantities to harmonisation, then to internal dosimetry, later to regulations and finally to quality assurance as is shown by the top number of presentations in the series of conferences on individual monitoring (Table 1).

CRITICAL REVIEW

Conferences on individual monitoring attract a quite large number of participants. Numerous presentations at these conferences reflect the actual work and new developments. Looking years back, it is evident that the topics for research and development in individual monitoring have changed continuously depending on the actual needs. Originally, establishing and improvement of radiation protection of the individuals were of primary interest. Looking at the papers presented at the last conferences, one can easily see that the number of topics is increasing and one may wonder how many of the ongoing activities in this field are targeted towards improving radiation protection.

Therefore, the critical question may come up: Do people always know why they do what they do in individual monitoring? Are the people:

- Improving radiation protection of individuals?
- Collecting data for epidemiology?
- Ensuring legal justification of practices?
- Supporting bureaucracy?
- Following commercial interests?
- Furthering the beauty of metrology?
- Improving scientific knowledge?
- ...

Table 1. Number of presentations on the main specific topics at the conferences on individual monitoring in Villigen (1993)(13), Helsinki (2000)(14), Vienna (2005)(15), Athens (2010)(16) and Bruges (2015)(17).

Main topics presented	1993	2000	2005	2010	2015
Radiation protection quantities	13				
Harmonisation of individual monitoring		17	5		
Developments in *in vivo* and bioassay measurements			20	27	28
Directives, regulations and standards	4	2	3	28	6
Quality assurance, performance tests and intercomparisons	18	18	19	9	55
Recent developments in external dosimetry		6	13	29	40
Individual monitoring in various fields		9	19	20	33
Workplace monitoring			5	19	15
Application of computational codes			15		20
Dosimetry in emergency situations				12	26
Education and training				3	4

CONCLUSIONS

Individual monitoring is today on a high conceptual, technical, legal and procedural level. However, there are from time to time good reasons for new concepts, standards and regulations. But it might be worthwhile to be aware, whether new developments are targeted towards improvements of radiation protection of individuals or driven by other objectives.

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