

# RADIATION DOSIMETRY IN MEDICAL EXPOSURE\*

A SHORT HISTORICAL OVERVIEW.

**Van Loon R. and Van Tiggelen R.**

In early X-ray examination, the radiographer uses his own hand, viewed in a fluoroscope, as a “penetrometer” in order to gauge the exposure required to x-ray the patient ! None of the early experimenters with x-ray photography had taken measures to protect themselves or their patients from exposures, because there was no reason to expect adverse effects. But within some months of Röntgen’s Preliminary Communication, reports of the harmful effects of x-rays began, also in Belgium, to appear in the literature. Precaution, as well as other measures, was needed because, although there was a latent period between the exposure and the development of dermatitis and irreversible lesions of the deeper tissues, illnesses and deaths due to x-radiation were already being widely reported. The first measure was, of course, to abandon the operator’s habit of using his own hand to judge the state of the tube prior to taking a radiograph and to better analyse this phenomena.

The measurement of radiation, quantitatively and qualitatively, has been an important task for physicists throughout the years.

Several ways were indicated to assess the **quality** of the radiation: indirectly by absorption measurements or by measurement of the potential applied to the tube and directly, by measuring the wavelength of the spectrum components,.

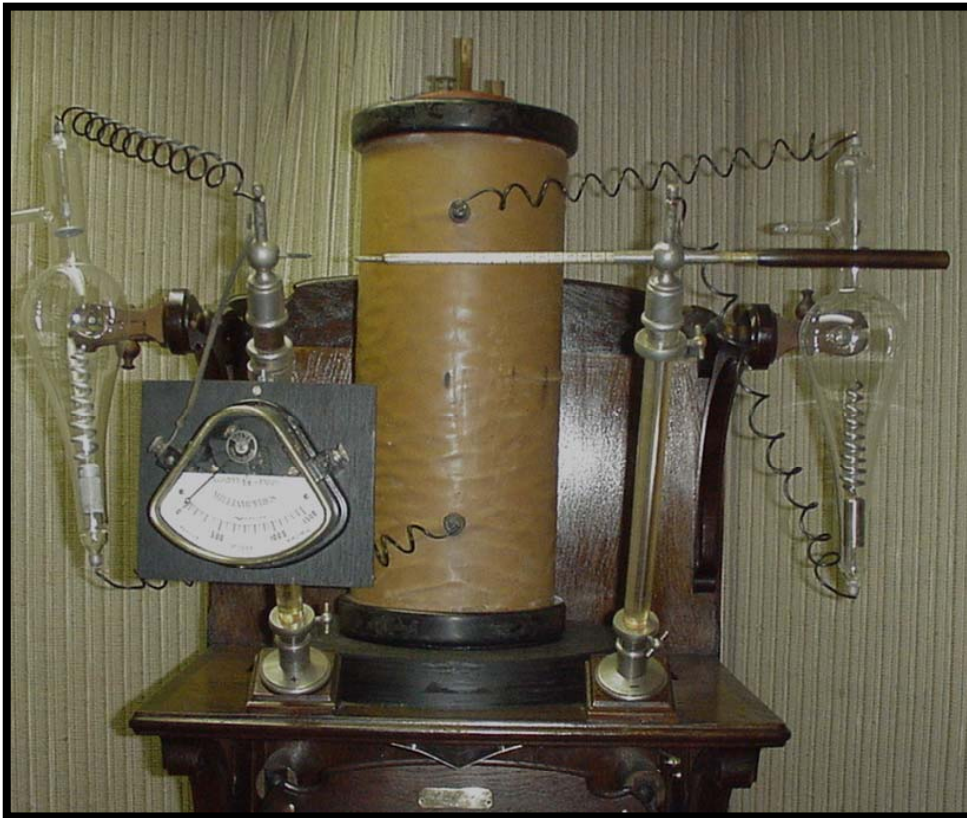
Röntgen W.C. (1845-1923) himself had already demonstrated the variation in penetrative power of X-rays. The “radiochronometer” by Benoist L. (1902-?) is based in 1902 on the X-ray transmission through 12 aluminium sectors of 1 to 12 mm thickness as compared to a 0,11 mm silver plate. The radiochromatic viewer, “le pénétratomètre”, of Belot J. (1876-1953) and the “kryptoradiometer” according to Wehnelt A. (1871-1944) is built on the same principle while the “hardness scale” according to Walter B. (1861-1950) was slightly different.

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Although the first qualitative descriptions “hard” and “soft” used for the penetration of X-rays dated from 1900 (Kienbock R. 1871-1954), we had to wait until 1912 for the introduction of the concept of “half-value layer”. The idea is attributed to the Swiss physician and physicist Christén F.(1873-1920), and was further developed : at the 5<sup>th</sup> International Congress of Radiology it was agreed that for radiological applications the quality had to be expressed in HVL in suitable materials, such as cellophane up to 20kV, then Aluminium, Copper and above 400kV Tin.

Around 1922, Duane W. (1872-1935) introduced the concept of “effective wavelength”: the wavelength of a monochromatic beam with same absorption coefficient as the used radiation beam. This allows a link between these quantities, and effective wavelength can be estimated by absorption measurements. Duane’s results stated that radiation emitted by a tube operating between 80 and 100kV after filtration through several mm of Aluminium, has a effective wavelength of 0.22 to .28 Å. Also he established that the a constant potential of 165kV gave the same effective wavelength as an alternating potential of 200kVp.

The X-ray tube potential, estimated by means of a spark-gap, was used in the “spintermeter” according to A. Béclère (1856-1939) already in 1900. In 1923, Saget of the Gaiffe-Gallot & Pilon Company in Paris proposed an electrostatic voltmeter, connected to the tube through two resistors of 2.000 MΩ. Other methods were based on the measurement of the voltage in the primary coil winding (d’Arsonval A., 1851-1940) or on the reading of a thermic voltmeter on an auxiliary winding on the transformer. The “sclerometer” of Klingenfuss F. (1859-1932) is of that type: but this is only a reading of a mean value, valid for limited working conditions.



Spintermeter of Bécclère, [Belgian Museum of Radiology collection]

For spectral measurements, it became clear that spectrographs such as used by Bragg W. (1862-1942) and de Broglie L. (1892-1987), would not be adequate for medical practice. Some spectrographs nevertheless were proposed : by Seemann H. (1859-?.) or March (1923), in the latter the minimum wavelength  $\lambda_0$  was determined. Since minimum wavelength was not really suitable for quality measurement, formulae gave the relationship between  $\lambda_0$  and  $\lambda_{\max}$  .

The need for **quantifying dosage** had become apparent from the biological effects of the radiations, namely erythema, epilation and necrosis, and pastille and photographic techniques were initiated in 1902.

A first approach was the measurement of the tube current by means of a thermic milliamperemeter (Gaiffe G. 1857-1943) and others.

Holzknicht G. (1872-1931) produced a pastille chromoradiometer based on colour changes of certain chemicals when irradiated, but his system did not prove satisfactory. The first practical method (Le radiomètre X) was developed by Sabouraud R. (1864-1938) and Noiré H. (1878-1937) in 1904 and such ameliorated techniques remained in use until the 1930's.

Another method, based on colour changes in jodoform-solutions was further developed in 1904 by Freund L. (1868-1961) and Bordier L. (1863-1943) and Galimard P. (1879-?) and a precipitation dosimeter, unit “Kalom”, developed by Schwarz G. (1880-1959) in 1906.



Chromoradiometer of Dr. Holzknacht [Belgian Museum of Radiology collection]

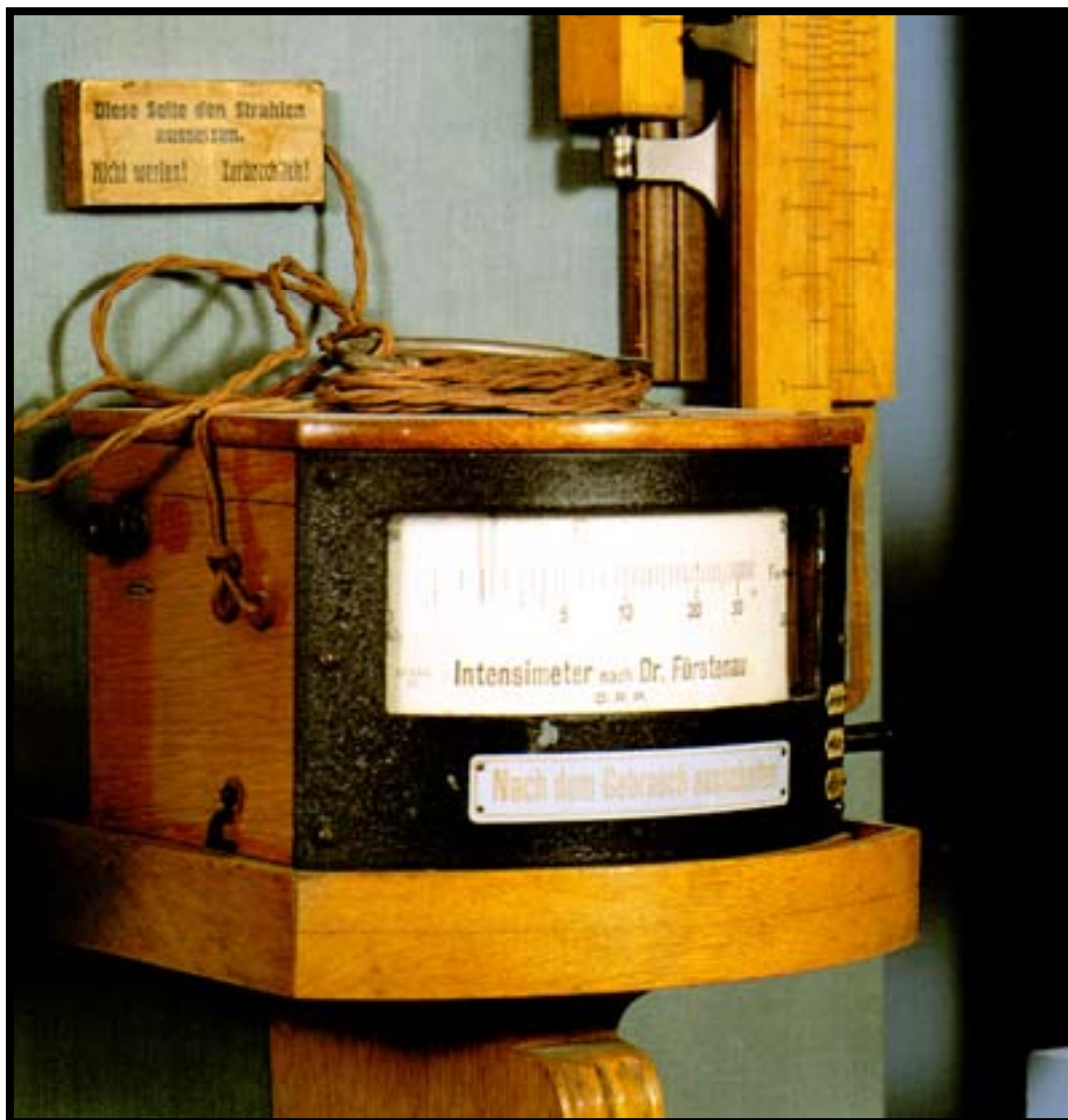
The photographic method was suggested by Kienböck as early as in 1900 and his “quantimeter” with the unit “X” presented in 1905. The unit was so defined that :  $10 X + 5H$ , corresponding to colour B of Saboraud-Noiré. The Kienböckstrips had the advantage of being useful also for depth dose measurements.

Attempts were made to correlate the biological effects with the heat produced in the tube wall (Köhler A. 1874-1947).

Other approaches to the measurement of dosage, including fluorescence techniques in 1908 by Guillemot H. (1869-1932), the change in the resistance of selenium when irradiated already in 1907 by Luraschi C. (?) and in 1915 by Fürstenau R. (1877-?), and the development of formulae for the calculation of relative doses based on the physical

parameters concerned in the irradiation. By 1920, various “erythema doses” were postulated, making direct use of the biological response, but all these approaches had inherent limitation. In spite of the fact that none of these methods seem to have been very successful some were in use at least until the end of the 40’s.

It was, though, not until the late 1940s that thermoluminescence was first used to make quantitative measurements of radiation exposure. Several materials have been

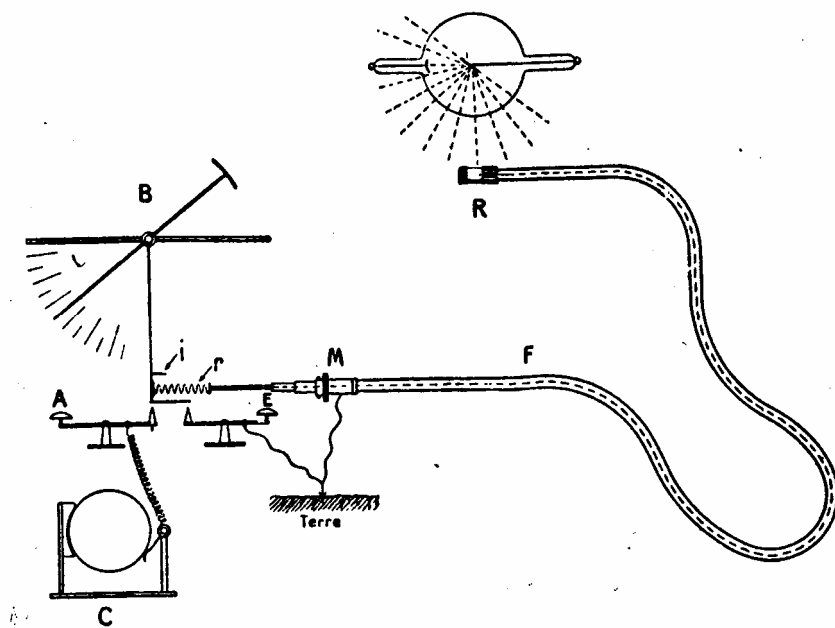


Intensimètre de Fürstenau [From : LOSSAU N.,Röntgen, p95, VGS Verlag,KOLN,1995.]

investigated but lithium fluoride has been to be most suitable as a TLD phosphor.

Soon after the discovery of X-rays by Röntgen in 1895, and of radioactivity by Becquerel A. (1852-1908) in 1896, electroscopes and electrometers were already utilized by Benoist L. and Hurmuzescu D. (1865-1954) to study the emitted radiations by ionometric methods. However, they were not employed for the measurement of dosage until 1907 when Belot J. and others realized their possible advantage over pastille and photographic methods already in use.

Others developed the technique further including Villard P. (1860-1934) in 1908 and Szilard L. (1898-1964) in 1914 who set down detailed requirements for a practical instrument. Indeed, ionisation was to become the method of choice for precision measurements and standards.



Iontoquantimeter of Szilard

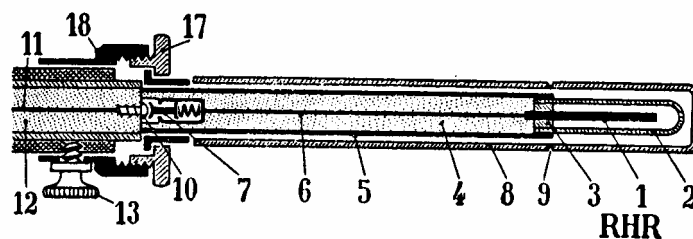
[in: "Précis de Radiothérapie Profonde", I. Solomon, 1926]

Dosemeters were soon also produced industrially, for instance the 'Ionomètre' by Ropiquet, Hazart & Roycourt and the "Iontoquantimeter" by Reiniger, Gebbert & Schall. The accuracy and usefulness of the various methods was investigated by several authors, e.g. by Krönig B. (1863-1917) und Friedrich W. (1883-1968) in 1918. Friedrich was in favour of air ionisation measurements and had introduced the "e" unit for exposure measurements.

Photographic film was used in 1921 by Dessauer F. (1882-1963) and Vierheller (?) in determination of "isointensity curves" and it was later claimed that only this method gave proper results. However, their curves disagreed however from those obtained with ionisation chambers by Coliez R. (1893-?) in 1923 and by Holfelder H. (1891-1944) in

1924. The arguments seems to have been quite intense but moving in favour of ionisation methods.

An ionisation method was proposed in 1907 at a meeting of the American Roentgen Ray Soc. The idea was to adopt a unit ionisation being “*the quantity of electricity passing across a unit gap in unit time under standard conditions of pressure and temperature*”. Consequently, the Villard unit (1908) was defined as “*the quantity of radiation which liberates by ionsation one esu of electricity per  $cm^3$  of air under normal conditions of temperature and pressure*”. This unit was adopted ten years later as the “e” unit by Krönig and Friedrich (1918), and modified in 1924 by Behnken H. (1889-1945) to become the “R”unit or “German unit of X-radiation”. Indeed, it was labelled “German” since in 1925 also appeared the “French Roentgen”, proposed by Solomon I. (1880-1939): it was the ionisation produced 2cm distance from a 1gm radium source. Beclère showed that : 1 German R = 2.25 French R.



Ionisation Chamber of Solomon

[in: “Précis de Radiothérapie Profonde”, I. Solomon,1926]



Ionometer of Solomon [Belgian Museum of Radiology collection]

The first International Congress of Radiology (London 1925) decided there was a need for a definition, but the decision was deferred. The finally accepted international unit in 1928 at the second International Congress of Radiology was the roentgen or r [lower case letter not to be confused with the French or German R, capital letter]: *“1 r is the quantity of X-radiation which, when the secondary electrons are fully utilised and the wall effect of the chamber is avoided, produce in 1 cc of atmospheric air at 0°C and 76cm of mercury pressure such a degree of conductivity that 1 esu of charge is measured at saturation current”*. Extension to gamma rays was decided in 1934 (4<sup>th</sup> ICR Zurich) and implemented in 1937 (5<sup>th</sup> ICR Chicago). From the moment on the Bragg-Gray principle had been established (1935) , ionisation chambers have become the most common instruments for clinical measurements.

In order to implement the defined unit it became necessary to design so called “free air chambers” where the ionisation in a well defined “wall less” air volume could be measured. During the years a number of intercomparisons were undertaken and minor discrepancies

cleared. Since 1962 the BIPM (Bureau International des Poids et Mesures) in Paris offers calibration of national standard instruments, an opportunity which has received global acceptance.

This modest contribution is dedicated to the memory of all x-ray and radium martyrs.

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