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Physics for Medicine at the Milan Institute of Complementary Physics

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Abstract: The interaction between Physics and Medicine was one of the founding issues that guided the establishment and development of the research laboratories of the Milan Institute of Complementary Physics (then Institute of Physics). In this paper, we shall take into consideration the main teaching and research activities that formed a bridge between Physics and Medicine in Milan in the second half of the 1920s, in particular as regards radiology and its connections with the erecting “Vittorio Emanuele III” Institute for the Study and Treatment of Cancer (today’s National Cancer Institute).

Keywords: Radiology, Medicine, Dosimetry

1. Aldo Pontremoli and Enzo Pugno Vanoni

The foundation of the Milan Institute of Complementary Physics in 1924 had a historical impact on the Italian medical community due to the strict collaboration of the new radiology laboratory with the “Vittorio Emanuele III” Institute for the Study and Treatment of Cancer (today’s National Cancer Institute) and the decision to adopt a standard procedure and unity of dosimetry.

The Institute of Complementary Physics was established by Aldo Pontremoli, a young physicist who had graduated in Physics in Rome in 1920. After being Corbino’s assistant and having spent some time at the Cavendish Laboratory in Cambridge he got the “libera docenza” in Advanced Physics in 1924 and was called by the newly established Royal University of Milan as professor of Complementary Physics for the students of the Faculty of Science. In 1926 Pontremoli was ranked as the third winner of the first Italian public competition for a chair of Theoretical Physics, after Enrico Fermi and Enrico Persico. In 1928 he disappeared after the accident of the “Italia” airship during the polar expedition led by Umberto Nobile.

Enzo Pugno Vanoni was one of Pontremoli’s assistants and the most relevant of them. He graduated in Electrotechnical Industrial Engineering at the Polytechnical High School in Milan. In 1925 he became Pontremoli’s assistant and professor of Electrotechnics and Röntgen-ray Physics for the Specialization School of Radiology, and professor of Experimental Physics for the Faculty of Medicine. In 1931-37, he was a member of the governing body of the International X-ray and Radium Protection Committee (today’s International Commission on Radiological Protection), established in 1928 at the 2nd International Congress of Radiology. He was the temporary director of the Institute of Complementary Physics between Pontremoli’s start of the polar expedition and Giovanni Polvani’s arrival to Milan University as professor of Experimental Physics. In 1931, Pugno Vanoni moved to Padua University and became professor of Electrotechnics at the Engineering School. At the same time, he worked on projects for the Röntgen-therapy apparatus for the Radiology Institute in Rome. He prematurely died in 1939.

A vivid picture of Pugno Vanoni’s qualities is given by one of Polvani’s reports as a truly worthy collaborator who had contributed in the most effective way to the cultural and practical improvement of the radiologists in the field of electrical engineering. Polvani appreciated Pugno Vanoni's fundamental and disinterested contribution to the electrotechnical organization of the Institute of Radiology at the "Vittorio Emanuele III" Institute for the Study and Treatment of Cancer, as the technical consultant in particular for the calibrations and measurements on any radiological devices.

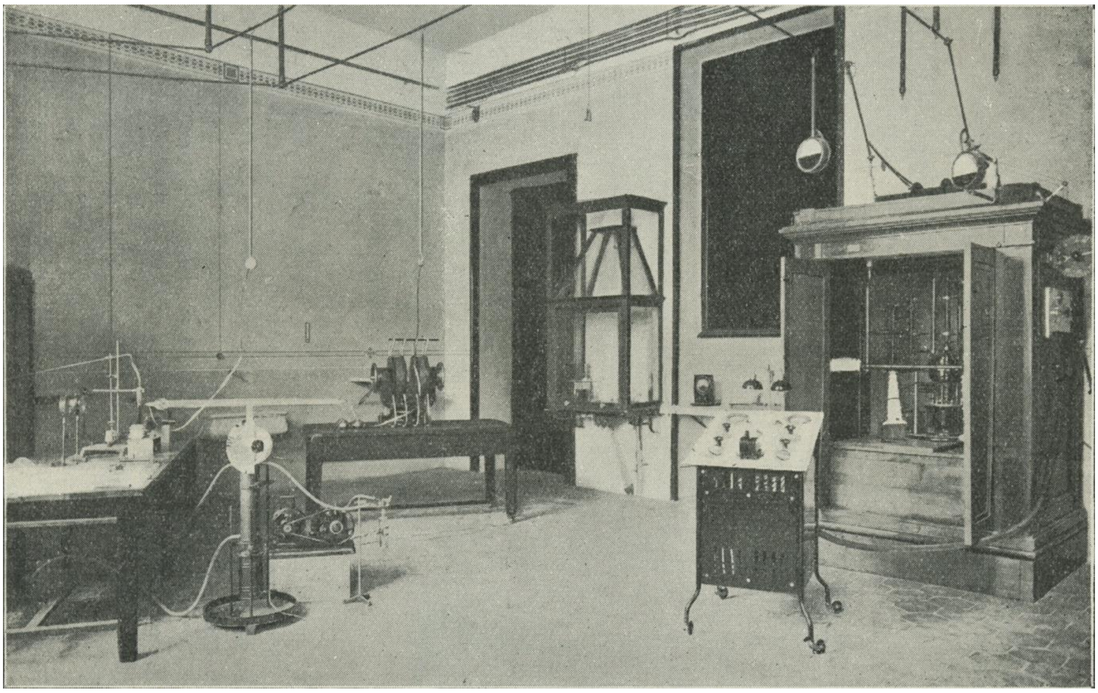


Fig. 1. The Radiology Laboratory of the Institute of Complementary Physics (Regia Università di Milano 1928, p. 182)

The list of the lessons given in the Electrotechnics and Radiation Physics class for the Specialization School of Radiology shows how relevant was Pugno Vanoni's teaching to the future radiologists, with a wide range of topics from basic electrotechnics to advanced X-rays physics. The second-year lessons (9 and 10) focused in particular on the definition and measurement of the dose:

> 1) Preliminaries of electrotechnics. Electricity. Potential. Tension. Capacity. Intensity. Resistance. 2) Preliminaries of electrotechnics. Work. Power. Int^2. Heating. Magnetic field. Solenoid. Flux. 3) Magnetic field. Solenoid. Flux. Inductance. Extra-currents. Induced emf. 4) Induction coil. Primary. Secondary. Switches. Coil devices. Selectors. 5) AC. Maximum, medium, efficient values. Resistance, reactance. 6) Transformers. $E_1/E_2 = n_1/n_2 = I_2/I_1$. Elevators, reductors, self-transformers. 7) Transformers. Selectors. AC coils. Complete DC installations. 8) Transformers (detached parts). Discharges in gases. Ionization by collision, by thermal effect, by radiation absorption. 9) Practical demonstration of a Corbino Trabacchi device. Emptying of a gas tube. 10) Electricity and matter. K lines emission. Atomic number. 11) Gas tubes. Structure and operation. 12) Thermionic emission. Saturation current, valve effect (experiments). 13) Structure and operation of a Coolidge tube. Different kinds of tubes. 14) Lilienfeld and Müller tubes. Photography of focal spots. Transformer selectorless devices. 15) Selectorless devices. Wave shape. Load. Tension fall for resistance on the primary. Practical demonstrations. 16) Transformer and selector device. Transf. and valves. Selector transf. and voltage doubling capacity. 17) Condenser devices with selector and valves. Three-phase device. Selector and valves comparison. Operating defects. 18) High tension dangers. Radiating energy. H.V. Refraction, reflection,

> diffraction, interference, polarization of light and X-rays. 19) X-ray emission. Continuous and line spectra and their properties. K L M N series.
> 20) X-ray absorption (diffusion, fluorescence, β-rays). Measurements of quality (from tension, hardness scales, fluorescent scales, H unit, spectrographs). 21) Seemann spectrograph. Measurements of quantity. Pill. Selenium. Ionization chambers (big, small). Ionometric devices. Visit of the laboratory and measurement with the spark gap. (Pugno Vanoni 1926).

> 1) Coolidge tube. Continuous spectrum. Line spectrum. 2) X-ray absorption. Diffuse and characteristic rays. Photoelectrons. μ. σ. Compton effect. 3) Characteristic absorption. Corpuscular rays. Kinds of measurement classification. 4) Quality measurements. Tension measurements. Formulae which give the qualities from the tension. Maximum and efficient values. Spark gaps. 5) Crest voltmeters. Hardness scales. Relative errors. Mean value determination from the absorption. 6) Halbwertschicht (ionometric and photographic met.). Fluorescent scales. Laue and Bragg's theory of crystals. 7) Spectrometers for X-rays. Rotating crystal, curved one, crystal powders. March and Seemann spectrographs. 8) Radiation intensity. $I = kV^2i/d^2$. Milliamperometers. Röntgen-photometers. Selenium intensimetry. 9) Quantity of radiation. Physical and biological dose. Dosimetry with platinumcyanide and with silver salts. Ionization. 10) Biological dose and dose absorbed by air. R unit. Ionization chambers. Errors. 11) Measurements of saturation currents. Experimental proof of the emission laws $|V^2i/d^2|$. System calibration curves. Tension fall. 12) DC system calibration. Measurement of average λ with the photographic methods and with the ionometric method. 13) Ionometric measurements of λ_m. Spectrographic measurements and verification of the $\lambda_0 = 12.34/V_M$ law. 14) Measurements with the water phantom. Influence of various factors on the dose. Experiences on the influence of diffused rays. 15) X-ray protection. Photographic evidence. Self-protected tubes. Cups. Therapy tube casings. Diffused rays. 16) (General summary of the course) Emission, absorption, quality and quantity measurements. (Pugno Vanoni 1927).

The Laboratory of radiology was established by Pontremoli thanks the financial and material support he succeeded to obtain from private institutions, banks, instrument-maker industries, etc. The main donation was that of 100000 lire given by Banca Popolare di Milano in 1926 with the specific aim to support radiological activities:

> so that a Radiology laboratory can be started in the Institute of Complementary Physics of this Royal University with the purpose of: measurements on X-rays and calibration of the related instruments; tests on radiological devices and generator-tubes, and in general research on what can lead to an improvement and extension in the applications of X-rays to industry and medicine. (Letter from the president of Banca Popolare di Milano, to the rector of the Royal University of Milan, March 5th, 1926. In: Meda 1926).

In order to fully appreciate this donation, we can compare to the yearly financial support of 300000 lire from the Government to the whole Milan University, which had to look for also for other economic sources. In any case, Pontremoli was the most able professor to get funds and instruments from private donors. E.g., in the same 1926, he also got 50000 lire from Società Edison and devices worthy about 50500 lire. In comparison the Faculty of Medicine collected just 87400 lire and devices for 26000 lire.

In a letter to the rector on March 6th, 1926, Pontremoli hoped that the new laboratory could solve important medical and industrial problems still open in the field of X-rays. He and Pugno Vanoni planned a project of activities to be carried out in the Radiology laboratory:

a) Electrical tests on radiological devices;

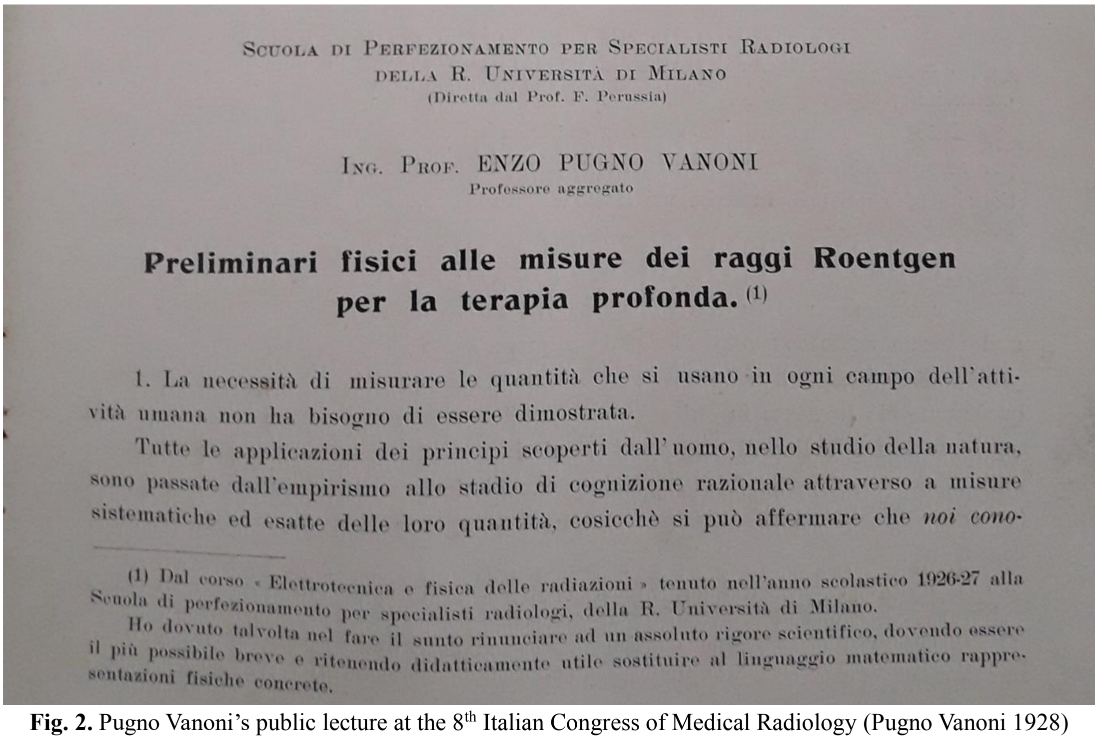
b) Tests on the generator-tubes, with emission spectrograms with DC and AC;
c) Test on ionic and thermoelectric valves;
d) Measurements on X-rays: qualitative measurements (spectrographic tests, check of the spectrographs and of the X-ray hardness levels); quantitative measurements (emission tests; check of ionometric devices, intensimetres, etc.); test on photographic plates sensitive to X-rays; tests on fluorescent screens.

2. Pugno Vanoni's contribution to the Italian dosimetry standard

The close collaboration of Pugno Vanoni with the "Vittorio Emanuele III" Institute for the Study and Treatment of Cancer led him to be asked to deliver a plenary lecture at the 8th Conference of Medical Radiology, held in Florence, in May 1928.

After a long exposition of the main topics of X-ray physics, he advanced the following definition of dose (the mentioned congress in Florence was actually the one where he was giving the lecture):

> Volumetric absorption of Röntgen energy, or Dose of radiation absorbed per cm^3 by a body is the difference between the X-ray flux entering a small 1 cm^3 volume sphere of the same body, and the exiting flux, multiplied by the time during which the flux was prolonged. It represents the absorbed X energy during the application on 1 cm^3 of the body we are operating on (symbol D) […] Naturally this terminology may be modified following discussions at the next Congresses in Florence and Stockholm, and international agreements. (Pugno Vanoni 1928, p. 503).


SCUOLA DI PERFEZIONAMENTO PER SPECIALISTI RADIOLOGI
DELLA R. UNIVERSITÀ DI MILANO
(Diretta dal Prof. F. Perussia)

ING. PROF. ENZO PUGNO VANONI
Professore aggregato

Preliminari fisici alle misure dei raggi Roentgen per la terapia profonda. (1)

1. La necessità di misurare le quantità che si usano in ogni campo dell'attività umana non ha bisogno di essere dimostrata.

Tutte le applicazioni dei principi scoperti dall'uomo, nello studio della natura, sono passate dall'empirismo allo stadio di cognizione razionale attraverso a misure sistematiche ed esatte delle loro quantità, cosicchè si può affermare che *noi cono-*

(1) Dal corso « Elettrotecnica e fisica delle radiazioni » tenuto nell'anno scolastico 1926-27 alla Scuola di perfezionamento per specialisti radiologi, della R. Università di Milano.

Ho dovuto talvolta nel fare il sunto rinunciare ad un assoluto rigore scientifico, dovendo essere il più possibile breve e ritenendo didatticamente utile sostituire al linguaggio matematico rappresentazioni fisiche concrete.

Fig. 2. Pugno Vanoni's public lecture at the 8th Italian Congress of Medical Radiology (Pugno Vanoni 1928)

The first steps towards dosimetry and a few proposals of a unit had been advanced by J. Belot (1906), C.E.S. Philips (1907), P. Villard (1908), B. Krönig and W. Friedrich (1918), H. Behnken (1924) and I. Solomon (1925). The two main concurrent definitions were those by Hermann Behnken (Behnken 1924), working with a compressed air chamber, and Iser Solomon (Solomon 1924, 1925), working with a closed ionization chamber connected by a cable to an electroscope to register the passage of electricity. Pugno Vanoni advocated Behnken's definition of absolute quantity of X-rays as that corresponding to the quantity of rays which produce, when they irradiate 1 cm^3 of air, a conductivity such that the quantity of electricity measured as a saturation current was equal to one electrostatic unit. The measurement had to be carried out with the air at 18°C and 760 mm Hg by taking into account the whole energy of the electrons released in the air and by eliminating any effect from the walls. Pugno Vanoni agreed to use the symbol R (from Röntgen) for this unit, and kept to the suggestion to add the adjective "German" to be sure not to confuse it with Solomon's unit, the French R.

In Pugno Vanoni's opinion, Behnken's definition of the R unit could be used to measure: the intensity of a X-ray source in any given direction by giving the number of R units falling normally on a 1 cm^2 area at 1 m distance in the unit of time; the X-ray illumination of a surface by giving the number of R units falling on 1 cm^2 are in the unity of time; the quantity of X-ray incident on a surface by giving the number of R units on a 1 cm^2 of the body; the dose of the X-rays absorbed by the body by measuring the quantity of R units that arrive in the diseased point in the considered time and knowing the absorption coefficient of the body around the point under consideration.

Eventually, the 8th Italian Congress of Medical Radiology vote in favor of Pugno Vanoni's proposal that a precise terminology be adopted internationally in the field of X-ray measurements as per the advanced definitions; that the quality data be provided by measuring the absorption and the indication of the maximum electrical voltage applied to the tube; that the quantity data be provided by adopting R as a unit according to Behnken's definition; and that the quantity data be never separated from the quality data in order to be able to trace the absorbed dose. The Congress decided to invite all Italian radiologists to follow Pugno Vanoni's proposal as for the terminology, methods and units in their work, and gave a mandate to the representative of the Italian Society of Medical Radiology to support their deliberations within the International Commission for the Radiological Measurement Units.

The long experimental activities that had led to this result had been allowed by the high voltage devices installed in the Radiology laboratory of the Institute of Complementary Physics.

3. The Italian delegation at the International Conference of Medical Radiology in 1928

Following a proposal of the Italian Society of Medical Radiology, Pugno Vanoni was appointed by the National Research Council to represent Italy in the International Commission for Measurement and Radiological Units for the physics part. As such he participated in the work that the latter commission carried out in Stockholm in July 1928. With Mario Ponzio, a professor of medical radiology from Turin, he advanced the Italian proposal of international dosimetric units as identical to those already adopted in Italy.

The International Committee for X-ray units met on the afternoon of Wednesday July 25th 1928, with two delegates from each of the following countries: Austria, Belgium, Bulgaria, Czechoslovakia, Denmark, France, Germany, Greece, Hungary, Italy, Japan, Netherlands, Norway, Soviet Union, Spain, Sweden, Switzerland, United Kingdom, and the United States of America. Manne Siegbahn was elected chairman of the commission, Edwing Augustus Owen and Hermann Holthusen secretaries. They discussed the proposals formulated by Owen, following the requests received in advance in writing from the delegates of the different nations.

Solomon raised the major objections against the proposals which were converging towards the acceptance of Behnken's definitions. Solomon supported the adoption of a unit defined through the γ-rays of radium. Other objections were raised by Dauvillier who proposed the adoption of the unit of energy (the erg) for the measurement of X-rays.

The Italian report of the discussion highlighted the role played by the two Italian delegates, Pugno Vanoni and Ponzio: "After a long discussion, which lasted about three hours, during which the Italian delegations had the opportunity to intervene several times and have their own views adopted, the following proposals were approved". (Perussia & Pugno Vanoni 1928, p. 971).

This sentence must obviously be read by removing the nationalist rhetoric that characterizes the entire report. Actually, the final recommendation were much more shaped by the United States delegates and followed much of the report of the Standardization Committee of the Radiological Society of North America, made at New Orleans in 1927. The few historical reconstructions of radiological dosimetry do not mention a particular contribution by Italian physicists or physicians (Jennings 2007). We can assume that the Italian delegation, bringing their experience of the national adoption of a single standard procedure, had acted more in the direction of supporting Behnken's proposal rather than explicitly advancing it and convincing other delegations.

Eventually the Stockholm commission decided to adopt an international unit for X-rays, the quantity of radiation which, when all the secondary electrons are taken into account and the wall effects of the chamber are taken into account and cancelled, produces in 1 cm^3 of air at 0°C and 760 mm Hg a conductivity such that the measured saturation current is equivalent to one electrostatic charge. The international unit of X-rays had to be called "Röntgen" and written with a low-case r. To determinate the unity, various standard methods could be adopted, whereas Solomon's method was strictly dependent on the devices he used (he had actually sold some 1500 ionometers of his kind). However, for all comparative tests, only ionization chambers which have been calibrated with a standard chamber, had to be used. The device of practical use for measuring X-rays had to be called a dosimeter. The consistency of the dosimeter indications had to be checked by means of the γ-rays emitted by a defined quantity of radio-element, always carrying out the measurement in identical conditions. A dose specification had to be considered incomplete if the quality of the source and the quantity of radiation were not indicated.

The resolutions of the commission were submitted to the generally assembly of the congress and approved without discussion in the closing session on July 27th, 1928. In the opinion of the Italian delegates, they constituted a great advance in the field of radiological measurements. The ratification of the international dosage unit in radiotherapy also concerned some proposals on the international protection of the work of radiologists.

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