Reflections of an Old Scout
Exposures* from Various Sources of Ionizing Radiation

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During an assignment with the U.S. Public Health Service (USPHS) Radiological Health Branch in Washington, DC, in February 1952, my supervisor, Dr. Samuel C. Ingraham, suggested that we embark on two major projects. These subsequently proved to be among the most important of my career.

The *first project* was to estimate the radiation exposures being received due to the rapid increase in the application of x rays for purposes of medical and dental diagnosis. This trend, however, was not new.

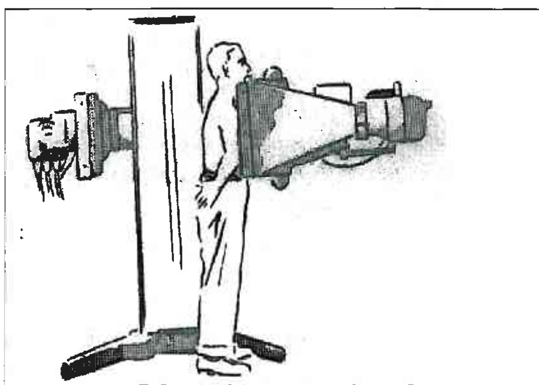
During the early 1940s, concerned about the rapidly rising incidence of tuberculosis within the U.S. population, the federal government had installed chest x-ray units in mobile trailers. Their design was based on what became known as a photofluorographic unit. In reality, this represented a brilliant advance in diagnostic x-ray technology. Rather than using film on which to record the x-ray image of the lungs, they focused the beam on a fluoroscope, the image of which was then photographed by a camera. This not only eliminated the necessity of replacing the film after each examination, but it also electronically recorded all the information about the patient (i.e., name, date, time, etc.). This significantly reduced both the costs and the time (only a few seconds) to process each individual. In addition, the accompanying 1 R exposure to the chest was far less than the 2.7 R exposure due to the use of radiographic units commonly used in hospitals and clinics.

At that time, about 100,000 x-ray machines were being used for medical diagnosis, with about 200,000 workers being exposed (Moeller et al. 1953). In general, the exposure rates to the workers were less than 50 mR per week. Some (about 0.4 percent) of them, however, received exposures in excess of 300 mR per week (Spacing et al. 1949).

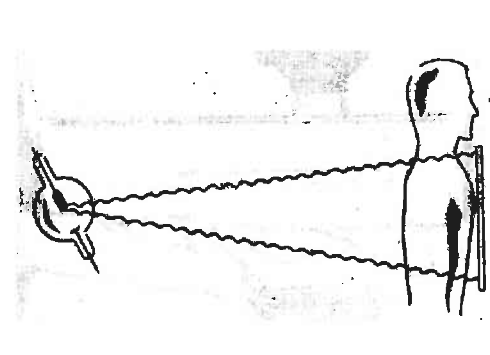
Details of these two types of x-ray units are shown below.

Performing the required exposure surveys immediately proved to be a challenge. At that time, the only readily available radiation survey instruments were those that had been developed for purposes of responding to a potential nuclear attack. Based on the need, these were limited to the assessment of the exposure rates from sources that were emitting radiation on a continuous basis. In the case of diagnostic medical x-ray units, such as a chest x-ray examination, the exposure was completed in about one-tenth of a second. Under these conditions, the needle on the survey meter would simply jump up and immediately fall back to zero. Exposure-rate meters were therefore useless. The Victoreen Condenser R-meter, manufactured in Canada for purposes of research, did not become commercially available until a few years later.

Using his electronics expertise, Sam and I took one of the civil defense survey meters to the experts at the National Institutes of Health (NIH) in nearby Bethesda, Maryland. NIH's electronics experts immediately replaced the resistors in these meters with condensers. Since this converted them from exposure-rate to exposure-integrating meters (as illustrated by the name given to the previously cited Victoreen meters), our problem was solved. Using the survey meter calibration facilities at NIH, we soon had instruments that we were confident would provide the data we were seeking. So far as we know, this was the first time such a survey meter had become available and assessments of



Schematic presentation of photofluorographic chest x-ray unit



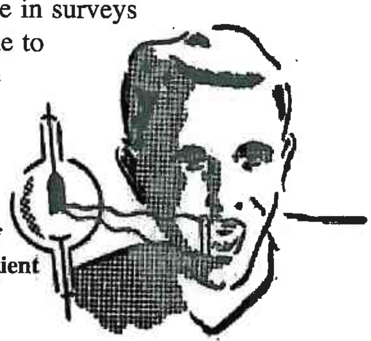
Schematic presentation of radiographic chest x-ray unit

*All data mentioned in this article were determined in units of exposure (roentgen, R), which was the quantity in use at the time.

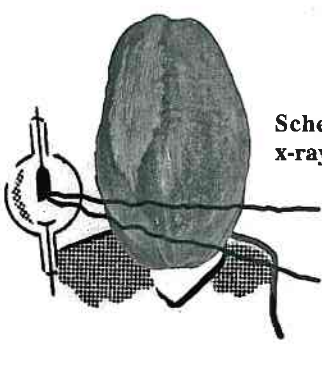
the exposures to medical and dental x-ray patients had been made.

As an initial effort, we monitored the exposures to the patients being examined at the 20 USPHS hospitals. They were soon expanded to include those due to scattered radiation that exposed both the x-ray unit operators and workers and also patients in adjacent rooms. One immediate observation was that the x-ray tubes seldom had filters to remove the softer x rays. As a result, the exposures to the patient were higher than necessary. In addition, the operators had removed the collimating cones from their units. Due to the poor orientation of the x-ray tubes, the beam had previously often missed the lungs of the patient. With the absence of the cones, however, the beam generally exposed the patient from the top of the head to the thighs.

Another problem for me in fulfilling my role as the person conducting the surveys was that, although there were always a sufficient number of patients to perform the necessary surveys during chest x rays, this was not the case for dental x-ray patients. Due to my determination to gather the necessary survey data, I often "volunteered" as the patient for half a dozen or more dental x rays. The associated exposure to my head for each such examination was at least 5 R. Shortly thereafter, my wife and I were vacationing in Florida. While walking on the beach along the Atlantic Ocean, we saw a coconut with its husk still intact that had been washed up on the sand. Recognizing that it had many of the characteristics of a human head, including an internal cavity similar to that of the human mouth, we decided to evaluate it as a possible phantom for use in surveys of scattered radiation due to dental x-ray exams. The results confirmed that measurements using the coconut with husk and a human patient were almost precisely the same. I therefore used it during all subsequent evaluations. So far as I know, this was the first application of a phantom in diagnostic x-ray surveys.

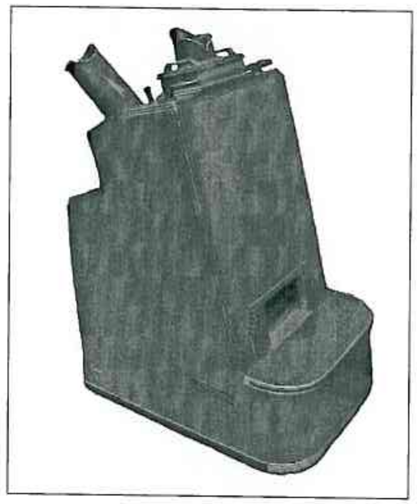


Schematic presentation of dental x-ray exam of a patient



Schematic presentation of dental x-ray exam using a coconut phantom

The outcome of these efforts was the publication of *Guide for the Inspection of Medical and Dental Diagnostic X-Ray Installations* (Ingraham et al. 1953). Shortly thereafter, thousands of copies were published and distributed for use by every state, county, and local health department, as well as all major metropolitan areas in the United States. Sam and I then applied these techniques for monitoring the exposures to workers who were applying x rays in industry, including research activities involving electron diffraction units, particle accelerators, and cyclotrons. In every case, we found that the exposure rates were much higher than anticipated.



X-ray shoe-fitting machine

One of the surprises was that one of the most important sources of radiation exposures to the public was the use of x-ray fluorographic units in shoe stores. Unknown to us until then, this fact had been revealed by Smith (1940). This application was promoted by marketers to assure parents that the shoes they were buying for their children were the proper size. Since this increased sales in shoe stores that featured them, their use dramatically increased. Subsequent surveys showed that the exposure to the feet of the customers ranged from 7 to 14 R per 20-second viewing. Exposure rates from scattered radiation ranged up to 1 R per minute. Ultimately, about 10,000 such units were in the United States, with 100,000 or more "examinations" being conducted annually. Finally, in 1950, health officials in Washington, DC, ruled that such units could be used only if a licensed physiotherapist would be permitted to operate shoe-fitting fluoroscopes. This was followed by similar restrictions being imposed by Massachusetts and other states. It was not until 1958, however, that their use was terminated nationwide. During the intervening years, about 100,000 or more "examinations" were conducted annually, leading to a total of upwards of 1 million having been conducted (Moeller 1996). In addition, 30,000 to 40,000 shoe-store employees were exposed, with some very serious accompanying injuries. Follow-up studies confirmed that a saleslady in Copenhagen had developed x-ray dermatitis on her hands, and another in Massachusetts had received such a serious burn that her leg had to be amputated (Bavley 1950).

The *second major project* was to expand the data developed in assessing the exposure rates from medical and dental x rays and shoe-fitting fluoroscopes to include those from other radiation sources. This proved to be far more challenging than the first. It, for example, required that we assess the exposures due to:

1. The uses of x rays in industry, such as radiographic and fluoroscopic units to detect defects in metal castings, fabricated structures, and welds, as well as those used for the detection of foreign materials in packaged foods. This effort included assessing the exposures to the approximately 5,000 workers employed at about 800 U.S. industrial radiographic installations. Other applications involved the manufacturing, testing, and operation of high-voltage electron tubes. Surveys showed that the exposure rates to workers ranged up to 2.5 R per day. In seeking to prevent pilfering, fluoroscopes were sometimes used to scan workers as they departed at the end of the day. The accompanying exposures ranged from 45 to 90 mR per inspection. In addition, high-voltage x-ray machines were frequently used in conjunction with the manufacture, testing, and operation of high-voltage electronic tubes. Also contributing to such exposures was the use of high-voltage x-ray machines in conjunction with research on atomic and nuclear physics. In fact, such units were a familiar feature in universities and similar institutions of research facilities in hospital, medical, and industrial-research laboratories. Although records indicated few reports of injuries to the workers, this may have been due to the frequent turnover of personnel. In contrast, laboratories where cyclotrons, linear accelerators, and positive ion tubes—as well as high-voltage x-ray machines—were used, there was a reported frequency rate of one palpable injury per 20-30 person years of active employment in radiation work. Another significant source of exposure was the use of electron microscopes. As of 1953, about 500 were in use. The exposures rates due to scattered x rays from these units ranged up to 15 R per hour.

2. Other components of these activities were (a) the nationwide internal and external exposures due to the fallout from the atmospheric nuclear weapons tests being conducted at the Nevada Test Site and (b) the exposures from releases of uranium, radium, and other decay products due to uranium mining and processing in the Colorado Plateau. These activities, for example, led to extensive radium contamination of the Animas River. Another source of environmental contamination was the increasing production of ^{239}Pu and ^{241}Am in conjunction with the "cold war." For a time, the liquid wastes from the chemical separation of these two radionuclides from the spent fuel were directly discharged into the environment. It was not until 1952 that a waste-treatment plant was placed in operation in Los Alamos, New Mexico, to remove these two contaminants. From that time on, there were increasing releases of radioactive materials due to their use in radiopharmaceutical, medical and industrial research. Another source was the use of radioactive materials such as ^{210}Po in static eliminators, thickness gauges, and brushes used to remove the static charge from phonograph records and photographic film. Another source of significant exposure during World War II was to pilots of aircraft of the Army Air Corps and U.S. Navy. This was due to the use of ^{226}Ra in self-luminous paints on the instrument panels in the cockpits so they could be read at night. Also of interest were the deaths from bone carcinomas of the women who applied the radium to watch dials and licked the brushes as they did so.

At the conclusion of this second task, we prepared a summary report, "Radiation Exposure in the United States" (Moeller et al. 1953). At that time, the commercial nuclear power industry was in its infancy. Quite surprisingly, in 2005 (52 years later), Delta Omega, the public health honorary society of accredited schools and programs of public health, selected our paper as *one of the 35 most significant such papers published between 1878 and 2005.*

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