The X-ray Shoe Fitter— An Early Application of Roentgen's 'New Kind of Ray'

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This paper provides some history of Roentgen's famous discovery of x-rays, a technical review of radiation exposure units, and a history and overview of the risk associated from using or being near one of the earliest of x-ray applications, the x-ray shoe fitter.

While browsing through an antique store in Bethlehem, NH, I was asked by the owner if I needed any help. I made my usual query about the availability of red Fiesta Ware (the radioactive kind) or Vaseline Glass (also radioactive), and I got the usual response, "No, that stuff never stays here very long. You might try eBay." So I resigned myself to another 15 or 20 minutes of following my wife around, looking at high-priced items that I used to own, but had foolishly thrown away over the years (is the Corning Ware I got as a wedding present 24 years ago really *antique*?). Then I saw what I had only heard of previously through word of mouth. It was an x-ray shoe fitter. The machine, an essential fixture of successful shoe stores during the 1940s and 1950s, was in perfect condition (see Fig. 1). With the press of a button, you could look at a real-time x-ray image of your foot inside a pair of prospective new shoes. Always looking for a new way to present topics to excite students about physics, I realized the x-ray shoe fitter would both intrigue and surprise them as they were introduced to the concept of x-rays.

Roentgen Discovers 'New Kind of Ray'

Every student has had the experience of sitting in the dentist chair, chomping down on the bitewing film, and feeling the weight of the heavy lead apron draped over his torso. After the dentist positions the x-ray machine centimeters from the cheek and then leaves the room, it's hard not to feel a bit uneasy and to wonder about the safety of the procedure. The history of x-ray applications spans over a century now and begins on the night of Nov. 8, 1895, in the laboratory of Wilhelm Roentgen. Roentgen, a professor of physics and director of the Physical Institute of the University of Wurzburg, was experimenting with a discharge tube, which had been completely enclosed within a sealed black carton. Inside the darkened room there happened to be a paper plate lying on a nearby table covered on one side with fluorescent barium platinocyanide. A shimmering of the plate caused Roentgen to experiment with it a bit. He noticed that when the plate was in the path of the rays, it would fluoresce (regardless of whether the painted or the unpainted side was facing the tube)! Knowing that cathode rays (i.e., electrons) were blocked by the tube, and the visible and ultraviolet light were both blocked by the black carton, he knew he had discovered a new kind of penetrating ray. Roentgen was so excited about his discovery that he began eating his meals and even sleeping in his laboratory for the next eight weeks, repeating his experiment and investigating the penetrating ability of the "x"-rays in various substances. (Roentgen used "x" to indicate that the identity of the ray was unknown.) He quickly published the results of his experiments, "On a New Kind of Rays,"on Dec. 28, 1895, in a medical physics journal of the University of Wurzburg. Much of his investiga-

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tion consisted of measuring the absorption of x-rays in many materials. Roentgen noted that "Thick blocks of wood are permeable. Boards of pinewood, 2-3 cm thick absorb very little. A sheet of aluminum with a thickness of 15 mm did not make the fluorescence vanish completely but reduced the effect markedly. … If one holds a hand between the discharge apparatus and the screen, one can see the dark shadows of the bones surrounded by the faint shadow of the hand."[1] Roentgen soon photographed these shadows. The first noninvasive peek inside the human body by these newly discovered x-rays was performed on the hand of Roentgen's wife, Anna Bertha. Placing her hand over a photographic plate for 15 minutes, he was able to produce an image that clearly showed the shadows of her bones as well as a ring she was wearing.

"On a New Kind of Rays" created an immediate sensation within both the scientific community and the general public. The "new kind of ray" began to be used almost immediately to assess bone fractures and to locate foreign bodies, so as to avoid painful manipulation. Within a month radiographic photography began to be developed. Simultaneously, therapeutic applications of x-rays in the treatment of cancers were investigated. All this before the identity of this mysterious ray was known. Non-medical applications for the x-ray also were developed, such as the use of x-ray machines in some beauty shops to eliminate facial hair.[2] Perhaps the most interesting and widespread of these applications was the x-ray shoe fitter, a machine used by shoe stores for decades to view the x-ray image of both feet inside new shoes.


Fig. 1

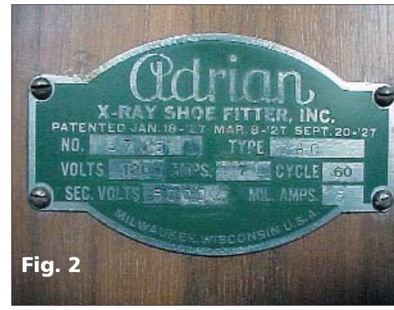

Fig. 2


Fig. 3

Fig. 1. The antique x-ray shoe fitter. Fig. 2. Adrian X-ray Shoe Fitter, Inc. Fig. 3. Patrons looked inside to see how their shoes fit—x-ray exposure was anywhere from 5 to 45 seconds long.

Clarence Karrer, who worked for his father's surgical and x-ray equipment business, invented the x-ray shoe fitter (also known as the shoe-fitting fluoroscope) in 1924. He built it for a company that manufactured orthopedic shoes, believing it would be of help to doctors. However, after he had built five of them the Radiological Society of North America insisted he stop because it "lowered the dignity of the profession of radiology."[3] Although he stopped manufacturing the machines, an employee of the company quit and began making them himself. Eventually, there were approximately 10,000 of these fluoroscopes in use, being made by companies such as Adrian X-ray Shoe Fitter, Inc. (see Fig. 2). The machines grew in popularity, and from the late 1940s to the early 1950s they were very common and most shoe stores had them. Concerns about radiation hazards were noted, though, as early as 1949, leading to the banning of the x-ray shoe fitters in many states. By 1970 they had been banned in 33 states and so strictly regulated in the remaining 17 that their use became impractical.[4] (Some states required that only an M.D. could operate them.) However, even in the late 1970s one of the members of the Department of Labor and Industries in Massachusetts found one in a "corner store" in Boston. The owner would let children take a look at their feet through the machine for the price of 10 cents worth of candy![5]

To use the x-ray shoe fitter, a person would stand in his or her prospective new shoes on a platform that led to an opening inside the cabinet of the machine (see Fig. 3). There were three viewing ports, one each for the person standing on the platform, the salesman,

Table I. Typical x-ray absorbed dose.

Source of Exposure	Absorbed Dose (mGy)
Extremities x-ray	0.010
Chest x-ray	0.080
Dental x-ray	0.100
Head/neck x-ray	0.200
Hip x-ray	0.830
Upper GI Series	2.45
CT (head and body)	1.10
x-ray shoe fitter	100–1,160

Table II. Ionizing radiation dose equivalent from various sources.

Source of Exposure	Dose Equivalent
Average dose to U.S. public from all sources	3.60 mSv/yr
Occupational exposure limits for declared pregnant women radiation workers	5 mSv/yr
Occupational dose limit for radiation workers	50 mSv/yr
X-ray shoe fitter (leakage within 10 ft of back for 2 hours per day)	2 mSv/day

and for another observer. The viewing port for the customer could be raised for persons of different height (see Fig. 1). X-rays would strike a fluorescent screen covered with a sheet of lead glass to stop all the x-rays. The fluoroscopic image could be viewed through any of the ports, allowing viewers to see the outline of the feet inside the shoes. The exposure was limited by a timer (on many machines, but not on the one photographed for this article) that could be preset for any time increment between 5 and 45 seconds, but the typical time seems to have been about 20 seconds. The safety of the timer was compromised, however, by the fact that additional exposures could be made by simply pushing the timer button repeatedly. In fact, the x-ray shoe fitters were commonly used as a diversion by the bored children of shopping mothers. Also, the novelty of the devices made it hard for children not to stop for a peek or two inside their shoes on the way home from school.

Radiation Exposure

Were the shoe fitters really dangerous, or was it simply an overreaction by a 1950s Cold War mentality increasingly concerned about the effects of *radiation*? Williams (1949) provides a highly quantitative study of the radiation exposures from shoe-fitting x-ray machines.[6] He tested 12 of the machines and notes that the units consisted of a 50-kv x-ray tube operating at 3 to 8 mA through a 1-mm aluminum filter, with a focal spot to skin distance between 7.5 and 20 cm. The cabinets were lined with lead or steel and contained a fluorescent screen, shielded with lead glass to stop the x-ray beam. There was a large variation in radiation from the machines he tested. A Victoreen radiation monitor, placed inside a shoe, recorded dose rates ranging from 0.5 to 5.8 rads per second. Thus, the dose to the feet during a 20-second viewing could range between 10 and 116 rads.

To consider these doses from the perspective of today's recommended dose limits for radiation workers and the general public, it is useful to review units for absorbed dose and equivalent doses. The amount of absorbed dose in the tissue is the energy absorbed by a given mass. The rad was defined as 100 erg/g. In MKS units the absorbed dose is given in gray (Gy) where 1 Gy equals 1 J/kg (or 100 rads). Radiation doses to patients, such as for cancer, are given in terms of absorbed dose in Gy. However, for the case where the measured dose is used for radiation protection purposes, the *equivalent dose* was introduced. The equivalent dose is obtained by multiplying the absorbed dose by the radiation weighting factor, WR, for the radiation used. The WR for x-rays, beta rays, and gamma rays is 1.0. The WR for fast neutrons is 10, and the WR for alpha particles is 20. That is, the biological damage of fast neutrons is assumed to be 10 times that of gamma rays, while the biological damage of alpha particles is assumed to be 20 times that of gamma rays for a given absorbed dose. The equivalent dose is given in rem if the dose is in rads, and in sieverts (Sv) if the dose is in Gy. The equivalent dose given to the feet by the 12 machines tested ranged from 100 to 1,160 millisieverts (mSv) per 20-second exposure. Compare this to the International Commission on Radiological Protection's annual dose limit of

500 mSv to the feet for radiation workers.[7] Table I[8] shows a comparison of exposures. It is sobering to consider that at the lower limit, the x-ray shoe fitters gave exposures similar to 1,000 modern dental x-rays and at the upper limit, something like 1,400 hip x-rays.

In addition to the radiation exposure to the feet of the person using the machine, there was substantial leakage from the foot opening, as well as from all surfaces of the machine. Williams noted that the worst of the leakage came from the bottom rear of the machine: "In most installations this amounts to more than [1 mSv/hr] at 10 feet from the unit."[6] Assuming a clerk was within 10 feet of the rear of one of Williams' machines for the equivalent of two hours a day, it was entirely possible to be exposed to 2 mSv per day. This would be equivalent to two CT head and body scans! And some clerks were in the habit of placing their hands directly in the path of the x-rays as they held young children's feet still in the machine. Table II provides comparisons of various sources of chronic radiation exposure, as well as national standards for current maximum annual exposure.

The comparison of the exposure from the x-ray shoe fitter with other exposures and with current maximum exposures is alarming. However, it must be kept in mind that the current maximum industry exposures are extremely low. This is because of the hypothesis "of a linear, no-threshold relation between dose and stochastic effects right down to zero dose. For example, the probability of developing a cancer due to the absorption of ionising radiations isn't zero until the dose is zero, namely never."[7] With this in mind, the attitude is to always recommend very, very conservative limits for radiation exposure.

Idaho State University's Radiation Information Network provides some data concerning the biological effects of radiation, necessary for a fuller perspective.[8] The exposures from the x-ray shoe fitters should be compared to the whole body dose of 750 mSv necessary to produce the nausea, diarrhea, and weakness associated with radiation sickness. And it is also important to consider the predicted increase in risk of cancer due to exposure to ionizing radiation. The Biological Effects of Ionizing Radiation committee V (BEIR V) puts the risk of cancer death at 0.08% per

10 mSv for doses received rapidly (acute), and might be two to four times (0.04% per 10 mSv) less than that for doses received over a long period of time (chronic). The current death rate from cancer in the United States is approximately 20%. Thus, you would expect that in a population of 10,000, if all were exposed to 10 mSv of whole body radiation, the number of cancers in this population would rise from 2,000 to 2,008—not enough to be statistically noticed given the natural fluctuation in cancer rates.

This is not to say that the shoe fitters were safe. Indeed, a shoe model who was exposed to excessive radiation received such a severe radiation burn that her leg needed to be amputated.[9] In another case, a 56-year-old woman who had been a 10-year employee of a shoe shop equipped with an x-ray shoe fitter suffered from x-ray dermatitis (including symptoms of thickened and partially detached toe nails as well as ulcers below the toe nails).[10] Still, there is little evidence of significant and long-term health risks to those who worked near the machines and no evidence of health problems due to the machines for casual users of the x-ray shoe fitter.

It seems that the biggest problem associated with the x-ray shoe fitter was its claim to do a better job at assessing the quality of shoe fit than the shoe store clerk. It was truly a bad use of a new technology. Because of the highly penetrating ability of the x-ray through soft tissue, the fluoroscopic image of the foot allowed the observers only an image of the outline of the shoes and the bones of the feet. Yet the fleshy part of the foot (responsible for much of the fit) still needed to be manually checked by the clerk. But if you owned a shoe store and a competitor had the "new x-ray shoe-fitter technology," you had to get one in order to stay competitive. Most shoe stores were actually happy to get rid of their x-ray shoe fitters when states began banning them. They were costly, took up space, and were useless outside of the gimmick of being able to measure shoe fit more accurately.

The x-ray shoe fitter is a relic now—taking its place amongst the depression glass and decades-old magazines of a few antique shops. Many "senior" physics teachers may remember getting a fluoroscopic look at their feet while trying on their new school shoes. And students learning about x-rays for the first time will undoubtedly be intrigued as they hear about the unusual technology spawned by Roentgen's "new kind of ray."

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