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Cover Page Footnote

Based on work under National Science Foundation Grant SBR-9808684 to Allan Mazur for the re-evaluation of public warnings raised during the 1950s and 60s about ostensible hazards to health or the environment. Nothing expressed here necessarily reflects the views of the NSF. Kevin Jacobson assisted in this work.

Looking Back: Unneeded X-rays*

Allan Mazur**

Introduction

I recall shopping for shoes in the 1940s. To check the fit, I, my mother and the salesman peered down into an x-ray fluoroscope while I wiggled my toes. At the pediatrician's office, the doctor and my mother also looked at a screen showing my insides.¹ This had no important diagnostic value for healthy-appearing children, but low level x-rays were not regarded as too costly for entertainment.

Thomas Edison set an assistant to work on the fluoroscope in 1896, only a year after Wilhelm Roentgen discovered x-rays. The assistant's hair fell out after frequent exposure to the rays, and his hands become ulcerated and then cancerous; eventually the disease killed him. Because of such experiences, it was thought that radiation had to inflict ulceration or other gross damage to cause malignancy, and that if dosages large enough to produce burns or other severe bodily changes were avoided they were safe. With this mindset, early workers tested the functioning of their machines on their own hands as they began work each day, eventually accumulating massive doses.

By the 1920s, it was apparent from the large number of burns and other skin problems suffered by radiation workers, and some ensuing cancers, that safety standards were desirable. A British group led the way, recommending that x-ray and radium workers keep distance and lead shielding between themselves and the radiation source, and that they work not more than 35 hours per week or have less than one month's holiday per year. Not until 1934, did the U.S. National Committee on Radiation Protection (NCRP) recommend a maximum

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¹ See Allan Mazur, *Why Do We Worry About Trace Poisons?* 7 Risk 35 (1996) and Allan Mazur, *A Hazardous Inquiry* (1998).

permissible exposure level. The NCRP fixed 0.1 rem (r) per day as a limit adequate to prevent overt skin damage and more serious consequences.²

In 1949 two articles appeared in *The New England Journal of Medicine* about shoe-fitting fluoroscopes. One reported that exposures to customers and clerks often exceeded the maximum permissible dose. The other claimed that the most likely injuries from shoe fluoroscopy were malformation of growing feet, skin damage, and injury to the blood-forming tissues of store clerks. These were all dangers that could have been controlled by proper regulation of the machines, and posting signs to warn against too many exposures.³ There was no move to eliminate shoe fluoroscopy entirely.

In 1954, a Japanese fishing boat, the Lucky Dragon, was accidentally showered with fallout from an U.S. hydrogen bomb test. As a result, a social movement aimed specifically at halting atmospheric testing began first in Japan and then moved to the U.S. and then Europe.⁴ This anti-testing movement, more generally an expression of opposition to the arms race and nuclear confrontation with the Soviets, had an enormous effect on public perceptions of environmental radiation and its dangers, which became a presidential election issue in 1956. Partly in response, and also anticipating the introduction of peaceful nuclear energy, the National Academy of Sciences (NAS) in 1956 reported that the U.S. population was being exposed to far less radiation from weapons-testing fallout than from either naturally-occurring sources such as cosmic rays or, surprisingly, from medical and dental x-rays.⁵

By this time it was known, experiments on fruit flies and mice had yielded that sizable doses of x-rays could produce genetic mutations in

² Lauriston Taylor, *History of the International Commission on Radiological Protection*, 1 Health Physics 97 (1958). Prior to World War II, the roentgen was the common measurement unit for x-rays. Newer units, the rad and rem, were defined to incorporate other forms of ionizing radiation, and these too have been superceded, confronting the historian with confusing terminology. Fortunately, these units are essentially equivalent for x-rays, so I have expressed them all in terms of rems. The NCRP has evolved, under a slightly extended name, into a quasi-governmental authority on radiation risks.

³ Edward Lawless, *Technology and Social Shock* (1977).

⁴ See Mazur, *A Hazardous Inquiry*, *supra* note 1.

⁵ See Lawless, *supra* note 3.

the descendants of irradiated individuals, and that the mutation rate increased with the dose of radiation. The NAS committee, dominated by geneticists, focused on this danger and asserted in its report more than had truly been demonstrated experimentally. Namely, that any amount of radiation to the gonads, however small, can cause mutations, and that “a little radiation to a lot of people is as harmful as a lot of radiation to a few, since the total number of mutant genes can be the same in the two cases.”⁶ The committee estimated that the amount of radiation required to double the naturally-occurring mutation rate in humans was probably 30 to 80r. It recommended — without any clearly stated rationale — that average cumulative exposure to the population’s gonads from man-made sources should not exceed 10r from conception to age 30 (the mean age of reproduction). The committee estimated fallout exposure from weapons testing to be only one percent of this limit, while exposure from medical x-rays and fluoroscopy was 30 times higher than from fallout! Dr. Warren Weaver, a principal of the report, warned at an NAS press conference, “We have been rather profligate about using x-rays.... If anything is stupid from a genetic point of view, it is to use x-rays to fit shoes on people.” He also condemned obstetricians who x-ray pregnant women merely to show them how “beautifully formed” is the skeleton of their baby.⁷

These conclusions were widely reported, including a prominent story on the front page of the most important agenda-setter of the American press, *The New York Times* (June 13, 1956), which published the entire genetics portion of the report. Rather than lessening public worries about fallout, the effect of the report (and of subsequent media coverage) was to extend these concerns to medical and dental x-rays. Radiologists blamed most over-exposure to x-rays on faulty equipment or sloppy procedures by untrained technicians, saying that the public was becoming unduly frightened of a valuable diagnostic procedure.

⁶ National Academy of Sciences (NAS), *Biological Effects of Atomic Radiation* (1956); U.S. News & World Report 64 (June 22, 1956). The NAS committee seems to have chosen 10r as a limit because it is the lowest round number above the 4r that an average person receives from naturally-occurring background radiation. In 1957 the NCRP lowered its maximum permissible dose for the average person to the level recommended by the NAS.

⁷ *Id.*

The anti-fallout movement ended abruptly in 1963 when President Kennedy and General Secretary Nikita Khrushchev, frightened by a clash the previous year over Soviet missiles in Cuba, agreed to halt atmospheric testing of nuclear weapons and eased Cold War tensions. Once exacerbated by the fallout controversy, press and public concern with medical x-rays also declined. However, public concern arose again in 1967 when many color TVs were discovered to emit significant amounts of x-rays. Congressional hearings rejuvenated public concern⁸ and led to Food and Drug Administration responsibility for reducing unnecessary human exposure to manmade radiation from television and from medical and dental radiology.

By this time most states had banned the use of x-rays on humans by anyone other than medical or dental personnel, and shoe fluoroscopy had fallen out of favor. The last functioning shoe fluoroscope, as far as I know, was discovered in 1981 in a West Virginia department store and finally donated for display in a medical museum. Gratuitous x-rays in medical practice, including fluoroscopy in routine pediatric and obstetric examinations, were also eliminated, especially as sonograms provided an innocuous replacement. When medial or dental radiation was warranted, there was a clear trend toward increased shielding, better focusing of the ray, and reduced exposures permitted by more sensitive film. Marginal uses of the ray were reconsidered, notably the curbside radiology vans sponsored by tuberculosis associations, in which the public had been urged since the 1940s to get a yearly chest x-ray.⁹ The possibility was raised that mammography screening for breast cancer might cause more tumors than it discovered among younger women. By this time, irradiation of children's throats and heads was stopped for the treatment of minor problems like enlarged tonsils, ringworm or acne, because these exposures caused thyroid cancer many years after exposure (in my own case, 28 years later).¹⁰

⁸ Lawless, *supra* note 3, at 197.

⁹ (By 1970 tuberculosis had declined to an extent that the disease was rarely discovered through x-rays, and in any case, the tuberculin skin test had become the preferred and less expensive method of screening.) See Bryce Nelson, *Mobile TB X-ray Units: An Obsolete Technology Lingers*, 174 Science 1114 (1971) Nelson, *infra* note 10.

¹⁰ See Nelson, *supra* note 9 and Allan Mazur, *The Dynamics of Technical Controversy* (1981).

Risk Assessment

The 1956 NAS committee knew from emerging data on leukemia in Japanese atomic-bomb survivors, and from malignancies in women who had painted radium on luminous watch faces, that ionizing radiation at high doses could cause leukemia and bone cancer. But it showed little concern about cancer from the low doses that the average person received from fallout, x-rays, and natural sources, which it estimated at less than 10r over 30 years. Instead the committee's emphasis was on the harm of genetic mutations to future generations, which it regarded as the primary problem of low doses.

The committee's reasoning is clear enough. A mutation in an egg or sperm cell might be caused by a single hit of ionizing radiation to the gonads; that could suffice to break one chemical bond in a gene, altering its function in all subsequent replications. Therefore any degree of radiation, however small, carried the possibility of mutation. Cancers, on the other hand, did not develop until years or decades after a person's exposure to radiation, making it implausible that carcinogenesis was a single-stage process, fully implemented by one hit of radiation. It seemed more likely that some minimum threshold level of radiation exposure was required before cancers are induced. If the threshold was above 10r, as was widely assumed, cancers would not be caused by the low exposures of concern to the committee in 1956.

In 1958, Linus Pauling published *No More War*, his polemic against atomic war and weapons testing, a book as important as *Silent Spring* in launching public concern about environmental contamination.¹¹ Pauling, winner of the Nobel Prize in Chemistry, argued that there was no exposure threshold and that even the lowest levels of exposure could cause cancer, just as they caused genetic mutation. Pauling estimated that if a population's radiation exposure were increased by only one rem it would produce two additional cases of leukemia per million people per year, and about one-fifth as many new bone cancers. He calculated that worldwide fallout from the atmospheric testing of a single large nuclear weapon eventually would

¹¹ Rachel Carson's *Silent Spring* (1962) is better remembered today, but Pauling's book was as important at the time of publication, contributing to his receipt of the 1962 Nobel Peace Prize. Carson adapted the imagery of radioactive fallout, famously picturing pesticides as white powder, falling like snow on the roofs of an American town, causing a mysterious affliction that kills first animals, then humans.

lead to the deaths of 10,000 people by leukemia and bone cancer, and possibly 90,000 more by other diseases, plus genetic effects in babies.¹² These were controversial claims.

After the 1963 Atmospheric Test Ban Treaty public fears about fallout lessened and the scientific debate about cancer hazards from low-level radiation remained of interest only to professionals. But the respite was brief, and by 1970 the debate had returned to the newspapers atop another public issue: the growing nuclear power industry. Drs. John Gofman and Arthur Tamplin, two health physicists at the Lawrence Radiation Laboratory in California, accepted the assumption that radiation has no threshold for cancer, that even the smallest exposures are carcinogenic. They asserted to public audiences, including Congress, that if the American population were exposed to radiation from nuclear power plants at the maximum level permitted by federal regulations, there would be, each year, an additional 32,000 cases of leukemia and other types of cancer. Hearing echoes of Pauling, the nuclear industry nearly overheated with denial.¹³

Responding to the tumult, the NAS again convened a committee of experts to re-evaluate the hazards of low-level radiation in the light of new knowledge, and on the assumption that cooler heads working outside the limelight might reach a rational conclusion. By 1966, an excess of roughly 100 leukemia cases had been observed among 117,000 survivors of the Hiroshima and Nagasaki bombings. From these and studies of patients who had gotten cancer from medical irradiation, it was clear that the number of malignancies produced in a population is proportional to the cumulative dose of radiation to the whole body. However this linear relationship was confidently observed only at sizable exposures, above 50r. If excess cancers were being produced at lower doses, they were too few in number to be confidently recognized. Nonetheless, the new NAS committee concluded — consistent with Pauling, Gofman and Tamplin — that “the only workable approach to numerical estimation” of low-exposure effects is to extrapolate the linear dose-response relationship, known for sizable exposures, down to zero dose. On this assumption, the

¹² Linus Pauling, *No More War* at 105 (1958), acknowledged some uncertainty in his numbers.

¹³ Mazur, *supra* note 10.

committee calculated that if the American population was exposed to radiation at the maximum level permitted by federal regulations, there would be an additional 6,000 cancer deaths each year. The committee's 1972 report recommended that the maximum permissible exposure to the public be lowered and sharply admonished the medical profession to voluntarily limit its use of x-rays.¹⁴

NAS committees have continued to assess biological effects of x-rays. By 1985, fortunately, no statistically significant excess of genetic defects had been detected among the children of A-bomb survivors, but hundreds of excess cancers had appeared among the survivors themselves. Clearly, solid cancers as well as leukemia increase in frequency with increasing dose, but this has been confidently observed only at exposures above 10r. The most recent NAS committee to evaluate x-ray effects reported in 1990 that it did not know the degree to which doses below 10r produce cancer, or if x-rays at such low doses cause any cancer at all. Nonetheless, this committee, like the others since 1972, extrapolated the dose-response curve down to zero dose, assuming no threshold.¹⁵

Conclusion

In 1956, dental x-rays and fluoroscopy might have delivered several rems in a single exposure, whereas a single shot today should be less than one rem. The 1990 NAS committee estimated that the average American is exposed to .04r per year from diagnostic x-rays. How many cancer deaths does this cause in the American population?

Assuming no threshold of exposure, the 1990 NAS committee estimated that if one million people of all ages continuously received 0.1r of x-rays annually, this would cause about 5,600 extra cancer deaths during their remaining lifetimes (or about 0.5% more cancer deaths than would normally be expected). At low doses, the committee's risk estimate is directly proportional to dose, so a yearly

¹⁴ NAS, *The Effects on Populations of Exposure to Low Levels of Ionizing Radiation* (1972). Robert Gillette, *Radiation Standards: The Last Word or at Least a Definitive One*, 178 *Science* 966 (1972). The committee estimated the effect of radiation on leukemia to be half of Pauling's estimate, and it discounted radiation-induced thyroid cancers because they are not usually fatal.

¹⁵ NAS, *supra* note 6: BEIR V (1990) [2d].

exposure of 0.04r — the average American's annual exposure to diagnostic x-rays — would eventually cause 2,250 extra cancer deaths per million, or a total of 604,800 cancer deaths among the 270 million Americans alive today. On the other hand, if there is a threshold of 1r or higher, a possibility the committee does not deny, then there are zero extra deaths from diagnostic x-rays.¹⁶

Ambiguity may always remain about the harm caused by very low doses of ionizing radiation. The reason is that doses below 10r are expected, even in the worst case, to cause so few cancers that it would take a huge number of irradiated individuals — far more than 100,000 A-bomb survivors (or laboratory mice) — to detect with confidence any increase above the far larger number of normally-occurring cancers. Responding to this gap in knowledge, and mindful of the possibility of a threshold, the Health Physics Society, a professional organization promoting radiation safety, recommended in 1996 against any quantitative estimation of health risks for lifetime doses below 10r above background radiation.

Happily, despite continued disagreement about actual effects, a consensus has evolved among responsible authorities that unneeded x-rays, even at low exposures, cannot be justified, given the possible adverse effects. No one today would favor shoe fluoroscopy or the irradiation of fetuses. Furthermore, it is widely held that when x-rays are needed, exposures should be kept as low as is reasonably achievable.¹⁷



¹⁶ *Id.*, at 7 and 171-81. At low doses, the committee's preferred risk models are linear.

¹⁷ See, e.g., NCRP, *The Application of ALARA for Occupational Exposures* (1999).