Mid-Century: Average Annual Per Capita Dose from Diagnostic Medical Xrays

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● Part 1. An Important Illustration of Uncertainty

   In the second half of the Twentieth Century, some developments in medicine tended to reduce the average annual per capita dose from medical radiation --- while other developments tended to increase such doses (Chapter 2, Part 3). What might have been the magnitude of the average annual per capita dose at mid-century?

   Appendix-K offers an approximate ("ballpark") answer. The process of obtaining an answer illustrates an important fact: All such estimates are highly uncertain and will necessarily remain so. For making the 1950 estimate, our two key references are:

   1951: S.W. Donaldson, M.D. (Director of the Professional Bureau of the American College of Radiology), "The Practice of Radiology in the United States: Facts and Figures," American Journal of Roentgenology Vol.66, No.4: 929-946. December 1951.

   1953: Dade W. Moeller, M.S. (Public Health Service) + James G. Terrill, Jr., C.E., M.B., + Samuel C. Ingraham, II, M.D., M.P.H., "Radiation Exposure in the United States," Public Health Reports Vol.68, No.1: 57-65. January 1953.

● Part 2. How Many Xray Examinations Occurred per Year?

   According to Donaldson (1951, p.935, Table 1), there were 151,267 practicing physicians (USA) in 1950. Within this total, there were 3,000 certified radiologists devoting full time to the specialty, plus 500 specialists devoting most of their time to radiology, plus 600 second and third year residents in radiology --- a total of 4,100 active practitioners in radiology (Donaldson p.931, and p.937, Table 7).

   Donaldson estimates that the typical radiologist administered 20 non-therapeutic radiologic examinations per day, worked 306 days per year, and thus administered about 6,000 examinations per year (Donaldson 1951, p.932, p.937, and p.945, Table 34.)

   2a. Radiologists: The Number of Annual Xray Exams

   Using these figures, Moeller reasonably estimates that 4,100 radiologists, each giving about 6,000 examinations per year, gave a total of about 25 million xray examinations per year (Moeller 1953, p.58).

   In 1950, the U.S. population was 150 million persons. It follows that, every year, the equivalent of one sixth of the entire population was receiving an xray examination FROM A RADIOLOGIST. But radiologists do not constitute the whole "story." Far from it. A few reminders from Chapter 2 (Part 2c) are appropriate:

   In 1923, Dr. Preston Hickey reported to the American Roentgen Ray Society that "It is interesting to note also the large number of internists who have placed fluoroscopes in their offices, not

with the idea of specializing in xray work, but simply wishing to have conveniently at hand an xray control of their physical findings" (Hickey 1923).

In 1937, Dr. Eugene Leddy of the Mayo Clinis reported, "In fact, roentgenologic methods of diagnosis are so important that no investigation of a patient is considered complete without roentgenologic examinations, which generally include roentgenoscopy [fluoroscopy]. These studies are often carried out by a general practitioner or surgeon in his office because of lack of facilities for expert study nearby or because the physician sees no need to refer the patient to a roentgenologist" (Leddy 1937, p.924).

By 1940 (perhaps much earlier), some pediatricians (not all) performed fluoroscopic examinations as part of the routine monthly check-ups for problem-free babies (Buschke 1942).

2b. Non-Radiologists: The Number of Annual Xray Exams

If radiologists in 1950 gave 25 million xray examinations per year, how many additional xray exams were given by the non-radiologists?

In the absence of the data which we would like, we can begin with some other estimates from Donaldson 1951. He writes (p.931): "Information was obtained from experienced investigators in the field of the costs of medical care, who estimate that the 150,000 practicing physicians render annually 750,000,000 medical services to the 150,000,000 persons in the United States." Out of 150,000,000 persons, approximately 430,000 (about 0.3%) were "confined to general hospitals" on the average day (p.931). There were 4,761 registered general hospitals (Donaldson p.931).

If the estimate above is nearly correct, then on the average, every man, women and child received 5 medical services from physicians each year --- some receiving none at all, and others receiving many more than 5.

How many of the estimated 750,000,000 annual services included an xray examination rendered by a NON-radiologist? Important additional information, confirming appreciable xray activity by non-radiologists, is presented in our Box 1 (from Donaldson's Tables 25 and 27).

● Lesson One: General practitioners owned even more xray units (20,000) than the total number located in hospitals (13,000).

● Lesson Two: Out of a total of 50,000 xray equipment "units," approximately 31,000 or more were owned by non-radiologists.

But 31,000 is an underestimate because Donaldson does not consider equipment owned by osteopaths and chiropractors. Moeller reports that there were 11,000 osteopaths and chiropractors, plus 67,000 dentists (Moeller 1953, p.57). We assume that many or most of these 78,000 persons were using xrays.

The Issue of Dental Xrays

At mid-century, xrays beams were allowed to expose much more area than needed, and we suspect (but do not know) that dental xrays may have irradiated significant segments of the head, neck and even some of the chest. Nonetheless, we exclude dental xrays from our considerations, unless some reliable information becomes available.

Number of Annual Exams: A 2-to-1 Ratio (Box 1)

Having excluded xray units dedicated to dental xrays, we will approximate (a) that about 38,000 xray units were under the control of non-radiologists (~31,000 from Box 1 plus 7,000 assigned by us to osteopaths and chiropractors), and (b) that about 16,000 units were under the control of radiologists (3,000 directly and 13,000 located in hospitals). This is an equipment ratio of 2 to 1, non-radiologists to radiologists.

How often did non-radiologists use their xray equipment? We (and others) are left to speculate --- which is one of the reasons that estimates of annual average per capita xray dosage are inherently

unreliable. Leddy's comments (Part 2a) might suggest "every visit."

Would non-radiologic physicians take the time? Not many minutes are consumed in giving the patient a fluoroscopic "once over." Moreover, fluoroscopy provides instant information, without any delay and without the expense and expertise required for proper film exposure and chemical processing. In offices which did make xray films (roentgenograms or radiographs), the person who did it was often a technician, nurse or clerk. Xrays enjoyed a good reputation, and some anecdotal evidence supports the expectation that patients (and parents of children) were pleased --- even pressing --- to have xray exams.

In view of the distribution of xray units (2:1), we will explore the proposition that non-radiologists (combined) administered twice as many xray exams each year as did radiologists (combined).

2c. Total Yearly Xray Exams, by (Radiologists + Non-Radiologists)

If non-radiologists administered twice as many xray exams per year at mid-century as did radiologists (who administered ∿ 25 million exams per year), then the total xray exams in 1950 would be 50 million plus 25 million, or 75 million xray exams. In 1950, the U.S. population was 150 million persons, so 75 million xray exams/year would be an annual rate of 1 exam per 2 persons, or 500 exams per 1,000 population.

This estimate for mid-century excludes dental xrays and therapeutic uses of xrays. A radiological examination is not an xray treatment.

For comparison with our 1950 estimated rate, we consider an estimated rate for 1964. Excluding dental xrays, the "estimated total number of diagnostic xray procedures" during 1964 is presented as 109 million, or 580 xray exams per 1,000 population (NCRP 1989, p.15, Table 3.7 --- taken from Mettler 1987).

● Part 3. What Might the Average Dose Have Been, per Xray Exam in 1950?

Now we pile more uncertainties upon the considerable uncertainties identified in Part 2.

3a. Relative Shares: Films, PhotoFluorograms, Fluoroscopies

Donaldson provides a Table entitled "Comparative Distribution of Roentgen-Ray Examinations" (Donaldson 1951, p.944, Table 30). It is based on the experience of the University of Minnesota Hospitals with 58,497 radiologic patients:

Roentgenographic examinations (30,355)	30,355	51.88%
Photofluorograms (19,677)	19,677	33.64%
Roengenoscopic examinations (8,465)	8,465	14.48%

A photofluorogram is a photograph taken of an image while the
image is present on a fluoroscopy screen.

Total patients	58,497	100.00%

This is the distribution, at ONE set of hospitals, of examinations generally performed by or for radiologists. It is uncertain whether or not the distribution was TYPICAL for hospitals. There is very little reason to assume that the distribution was typical for non-radiologists. Indeed, it is likely that many non-radiologists used fluoroscopy even more often than did radiologists, for the reasons mentioned in Part 2b. Nonetheless, this distribution is what we have to work with, and we will treat it as applicable to all 75 million annual xray examinations (est.) at mid-century.

3b. Weighted Average Entrance Dose per Xray Exam

Moeller embraces the distribution provided by Donaldson (above). Then Moeller assigns each type of examination an average dose in roentgens (almost comparable to rads; see Appendix-A). These dose-estimates are entrance doses at the skin, where the xray beam enters the body. Moeller (1953,

pp.58-59) provides the following dose-estimates in Column A, borrows the distribution in Column B from Donaldson, and arrives at a weighted average entrance dose per exam in Column C.

Type of examination	(A) Avg. dosage (roentgens)	(B) Share of Exams	(C) A times B
Radiographic	2.7	0.5188	1.401
Photofluorographic	1.0	0.3364	0.336
Fluoroscopic	65.0	0.1448	9.412
Weighted Average Dose per Xray Examination ----->			11.149

Are the Doses in Column A Credible?

Moeller's Reference List, which provides no sources for the values in Column A, includes the notation that "a complete bibliography of the source material for this article" is available upon request. That was in 1953. A request 45 years later might be impossible to honor.

The values in Column A appear credible to us for radiologic practice, in view of certain surveys conducted in the 1970s (discussed in Gofman 1985) and in view of certain reports about fluoroscopy machines in the 1930s and 1940s (discussed in Gofman 1995/96).

However, if Moeller's figure of 2.7 roentgens per radiographic exam is based on the practice of well-trained radiologists and radiologic technologists, and if twice as many exams were given by poorly trained personnel, then that average dose/exam could be quite an underestimate.

With respect to fluoroscopy, if some readers think that 65 roentgens "must be too high" for the TYPICAL fluoroscopic exam, they might consider this: In the 1930s and 1940s, the dose-rate from many fluoroscopy machines employed in medical practice was in the range of 25 to 35 roentgens per minute (Buschke 1942, p.525, p.527). Carl B. Braestrup, of the New York City Department of Hospitals, called such machines "a lethal diagnostic weapon" (Braestrup 1942, pp.210-211). Depending on the milli-amperes during operation, the dose-rate could exceed even 100 roentgens per minute --- without the operator realizing it (Buschke 1942, p.525). In fact, the Wappler Fluoroscope produced 125-150 roentgens per minute at the panel (Braestrup 1969). Some mobile units, operating close to the skin at bedside and during surgery, could deliver 1,000 roentgens per minute (Braestrup 1942, p.213).

Such considerations make 65 roentgens of entrance dose, during a typical fluoroscopic exam at mid-century, seem credible. Fluoroscopes in current medical practice typically operate in the dose-range of 2 to 20 rads of skin-dose per minute (FDA 1994, pp.2-3) --- and there are several surgical procedures during which a fluoroscope operates for 50 minutes or more (Chapter 2, Part 3d).

3c. An Independent Check on the Number of Annual Xray Examinations: Box 2

If there were 75 million xray exams per year at mid-century (Part 2c), and if 51.88% were radiographs, 33.64% were photofluorographs, and 14.48% were fluoroscopies (Part 3a), then:

Total radiographic exams, 1950 =	∿39,910,000
Total photofluorographic exams, 1950 =	∿25,230,000
Total fluoroscopic exams, 1950 =	∿10,860,000

We can make an independent check, on the reasonableness of the estimate of 75 million, if we assume that the AGES of patients receiving fluoroscopy was about the same in 1950 as it was in the early 1970s. We have done that work in Box 2. It suggests that the estimate of 75 million xray exams per year might be a bit low.

● Part 4. The Average Annual Per Capita Whole-Body Organ-Dose in 1950

The dose-estimate which is relevant to induction of Cancer of ALL types, in the U.S. population, is the Average Per-Capita Whole-Body Internal Organ-Dose. To arrive at such an

estimate, we must employ the estimates in Parts 2 and 3 plus some additional approximations.

4a. Radiographic Exams: Est. Annual Per Capita Whole-Body Organ-Dose

	Dose
● A) Per radiographic exam, entrance dose in roentgens =	2.700
● B) Per CAPITA entrance dose = (Row A) * (39.910 million exams from Part 3c) / (150 million persons) =	0.718
● C) Average dose to irradiated organs in the xray beam = (Row B * 0.4) because we will apply an average conversion-factor of 0.4 rads of average internal organ-dose per roentgen of entrance dose (details in Gofman 1985, p.404, Table C) =	0.287
● D) Average dose to ALL the internal organs, both inside and outside the xray beam = (Row C * 0.6), because we approximate that during the typical mid-century radiographic exam, about 60% of the body (excluding the limbs) was in the beam =	0.172

● SUMMARY: On the basis of these approximations, the average annual per capita "whole-body" internal organ-dose from diagnostic medical radiographs was about 0.172 rad at mid-century.

4b. Photofluorograms: Est. Annual Per Capita Whole-Body Organ-Dose

	Dose
● A) Per photofluorogram, entrance dose in roentgens =	1.000
● B) Per CAPITA entrance dose = (Row A) * (25.230 million exams from Part 3c) / (150 million persons) =	0.168
● C) Average dose to irradiated organs in the xray beam = (Row B * 0.334) because we will apply an average conversion-factor of 0.334 rads of average internal organ-dose per roentgen of entrance dose (this factor differs from Part 4a because photofluorograms are largely lung procedures) =	0.056
● D) Average dose to ALL the internal organs, both inside and outside the xray beam = (Row C * 0.6), because we approximate that during the typical mid-century photofluorogram, about 20% of the body (excluding the limbs) was in the beam =	0.011

● SUMMARY: On the basis of these approximations, the average annual per capita "whole-body" internal organ-dose from diagnostic medical photofluorograms was about 0.011 rad at mid-century.

4c. Fluoroscopies: Est. Annual Per Capita Whole-Body Organ-Dose

	Dose
● A) Per fluoroscopic exam, entrance dose in roentgens =	65.000
● B) Per CAPITA entrance dose = (Row A) * (10.860 million exams from Part 3c) / (150 million persons) =	4.706
● C) Average dose to irradiated organs in the xray beam = (Row B * 0.5) because we will apply an average conversion-factor of 0.5 rads of average internal organ-dose per roentgen of entrance dose (all beam-directions combined) =	2.353
● D) Average dose to ALL the internal organs, both inside and outside the xray beam = (Row C * 0.2), because we approximate that during the typical mid-century fluoroscopic exam, about 20% of the body (excluding the limbs) was in the beam =	0.471

● SUMMARY: On the basis of these approximations, the average annual per capita "whole-body" internal organ-dose from fluoroscopic xrays was about 0.471 rad at mid-century.

4d. Est. TOTAL Annual Per Capita Whole-Body Internal Organ-Dose

Now the estimates from 4a, 4b, and 4c need to be combined:

From diagnostic medical radiographs:	0.172 rad
From diagnostic photofluorograms:	0.011 rad
From fluoroscopies:	0.471 rad

Average annual per capita internal organ-dose from non-therapeutic
use of xrays in medicine, mid-century: 0.654 rad

Many consequential approximations are incorporated into the estimate. For what it covers, the estimate might be either too low or too high. It covers no contribution from dental xrays and no contribution from therapeutic uses of xrays, which were still used at mid-century to treat a variety of non-malignant diseases (Chapter 2, Part 2).

When readers are offered such estimates, for either past or current values, they need to keep such uncertainties in mind.

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Box 1 of Appendix-K.
Estimated Distribution of Physicians in the United States Owning
Their Own Roentgen-Ray Units, by Type of Practice (Modern Medicine 1949).

The title and reference above, and the entries in Columns A, B, C, and E below, are reproduced from Donaldson 1951, p.943, Table 25. We have inserted Column D, and the "All Combined" row, and the comments.

Col. A Type of Practice	Col.B Total Physicians	Col.C Est. number Owning Xray Equipment	Col.D Percent of Each Sub-set (ColC/ColB)	Col.E Percent of the 32,250 Owners
General practitioners	73,079	19,680	26.9%	61.0%
General surgery	19,976	3,000	15.0%	9.3%
Internal medicine	12,079	2,200	18.2%	6.8%
Radiology	3,559	1,300	36.5%	4.0%
Eye, ear, nose, throat	10,788	1,090	10.1%	3.4%
Dermatology	2,110	1,050	49.8%	3.3%
Industrial medicine	2,122	840	39.6%	2.6%
Orthopedic surgery	2,532	810	32.0%	2.5%
Pediatrics	6,321	750	11.9%	2.3%
Urology	2,869	700	24.4%	2.2%
Cardiology	916	290	31.7%	0.9%
Gastro-enterology & TB	2,277	200	8.8%	0.6%
Obstetrics & Gynecology	6,798	180	2.6%	0.6%
Allergy	703	160	22.8%	0.5%
All combined	146,129	32,250	22.1%	1

● - For Radiology, the 36.5% entry in Column D is a reminder that physicians of all types were able to use and share xray equipment which they did not personally own.

● - Among the 32,250 owners, 61% were general practitioners. Clearly, such physicians dominated the ownership at mid-century. The approximately 20,000 units owned by general practitioners exceeded even the estimated 13,000 units at the hospitals (see below).

● - Fluoroscopes (roentgenoscopes) were among the xray equipment commonly used by various non-radiologists (text, Part 2a).

● - The estimated total number of "Roentgen-Ray Equipment Units" was 50,000, located as follows (from Donaldson p.944, Table 27):

20,000 units with 19,600 General Practitioners (1 unit each).
13,000 units in 5,200 Hospitals (~3 units each --- some owned by radiologists, p.942).
12,000 units with ~12,000 non-radiologic specialists (1 unit each).
3,000 units with 1,300 Radiologists (~2.5 units each).
2,000 units in 1,000 Clinics and other groups (2 units each).

Sum --> 50,000

Box 2 of Appendix-K.

Independent Checks on Est. Number of Annual Xray Examinations at Mid-Century.

- In Col.B, the population entries for 1950 come from Grove 1968 (p.789).
- In Col.C, the rates per 100 persons come from Shleien 1977, Figure 2, and are estimates from sampling in the early 1970s. Shleien provides no entries above age 74.
- The upper tabulation is for the annual number of medical radiographs, with the exclusion (by Shleien) of examinations of the extremities. The lower tabulation is for the annual number of fluoroscopic examinations, including spot films and plates. Shleien provides no separate rates for "photofluorograms."
- Unless the AGES at which patients received examinations changed a great deal between 1950 and the early 1970s, the entries in Col.C permit an independent check on our estimates in the text, Part 2c.

Col.A	Col.B	Col.C	Col.D
		Annual Number	Absolute
	1950	of Radiographs	Number of
Age-band	Population	per 100	Exams/Year =
		Persons	(B*C)/100
Under 1 yr	3,146,948	16	503,512
1-4 yrs	13,016,623	16	2,082,660
5-14 yrs	24,318,953	16	3,891,032
15-24 yrs	22,098,426	42	9,281,339
25-34 yrs	23,759,267	56	13,305,190
35-44 yrs	21,450,359	65	13,942,733
45-54 yrs	17,342,653	72	12,486,710
55-64 yrs	13,369,520	73	9,759,750
65-74 yrs	8,339,960	73	6,088,171
75-84 yrs	3,277,751	73 assumed	2,392,758
85 and over	576,901	73 assumed	421,138
Sums --->	150,697,361	Radiographs/yr ---> excluding extremities	74,154,992

Col.A	Col.B	Col.C	Col.D
		Annual Number	Absolute
	1950	of Fluoroscopies	Number of
	Population	per 100	Exams/Year =
		Persons	(B*C)/100
Under 1 yr	3,146,948	1	31,469
1-4 yrs	13,016,623	1	130,166
5-14 yrs	24,318,953	1	243,190
15-24 yrs	22,098,426	3	662,953
25-34 yrs	23,759,267	5	1,187,963
35-44 yrs	21,450,359	9	1,930,532
45-54 yrs	17,342,653	12	2,081,118
55-64 yrs	13,369,520	13	1,738,038
65-74 yrs	8,339,960	15	1,250,994
75-84 yrs	3,277,751	15 assumed	491,663
85 and over	576,901	15 assumed	86,535
Sums --->	150,697,361	Fluoroscopies/yr --->	9,834,621

Estimated Yearly (Radiographs + Fluoroscopies), excluding
examinations of the extremities, at mid-century   ----->   83,989,614