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RADIUM AND MESOTHORIUM POISONING AND DOSIMETRY AND INSTRUMENTATION TECHNIQUES IN APPLIED RADIOACTIVITY

Annual Progress Report

May 1958

Radioactivity Center
Massachusetts Institute of Technology
Cambridge, Massachusetts

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Radium and Mesothorium Poisoning and Dosimetry and Instrumentation Techniques in Applied Radioactivity

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May 1958

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A. Radium and Mesothorium Toxicity in Human Beings

1. Introduction

The study of the toxicity of Ra and MsTh in human beings is continuing along lines described in previous reports. Special emphasis, however, has been placed on the acquisition of data on patients selected by record of exposure rather than by symptom. The results thereby obtained will permit a more accurate statistical interpretation of the incidence of various effects of radiation as dependent on magnitude of Ra and MsTh body burden.

During the year measurements pertinent to the Ra and MsTh burden of about 40 individuals have been obtained. About half of these measurements have been made on living persons, about half on tooth or bone specimens from persons now dead. Most of these cases are reported here for the first time. Medical evaluations have been completed on essentially all of the living persons, and an attempt has been made to collect available pertinent information on those no longer living.

Efforts are continuing to locate new subjects for observation. During the year 185 new names of medically

or occupationally exposed individuals have been found, and 137 new individuals have been located.

2. Evaluation of Radiation Dose

The several types of samples or subjects available for Ra and MsTh assay, and the problems associated with the measurement of each, have been described in previous progress reports. Only the new information obtained on dosimetry techniques during the year is described below.

a. Whole body Ra burden of living subjects

As in the past, whole body Ra burdens have been estimated either from Rn exhalation rate measurements alone or from Rn measurements combined with external scintillation counting of the RaB and RaC γ rays emitted from the body. The data are given in Tables 1a, 1b, and 4.

(1) External γ counting. Two basic methods have long been in use in this laboratory for assay of RaB and RaC burdens by external γ counting. The first, referred to as the meter-arc method,[1] permits a rather direct absolute measurement of RaB,C burdens, but suffers from low sensitivity. The second, wherein the counter is positioned near the base of the spine of the seated patient, has a

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1. R. D. Evans, Am. J. Roentgenol. 37, 368 (1937)

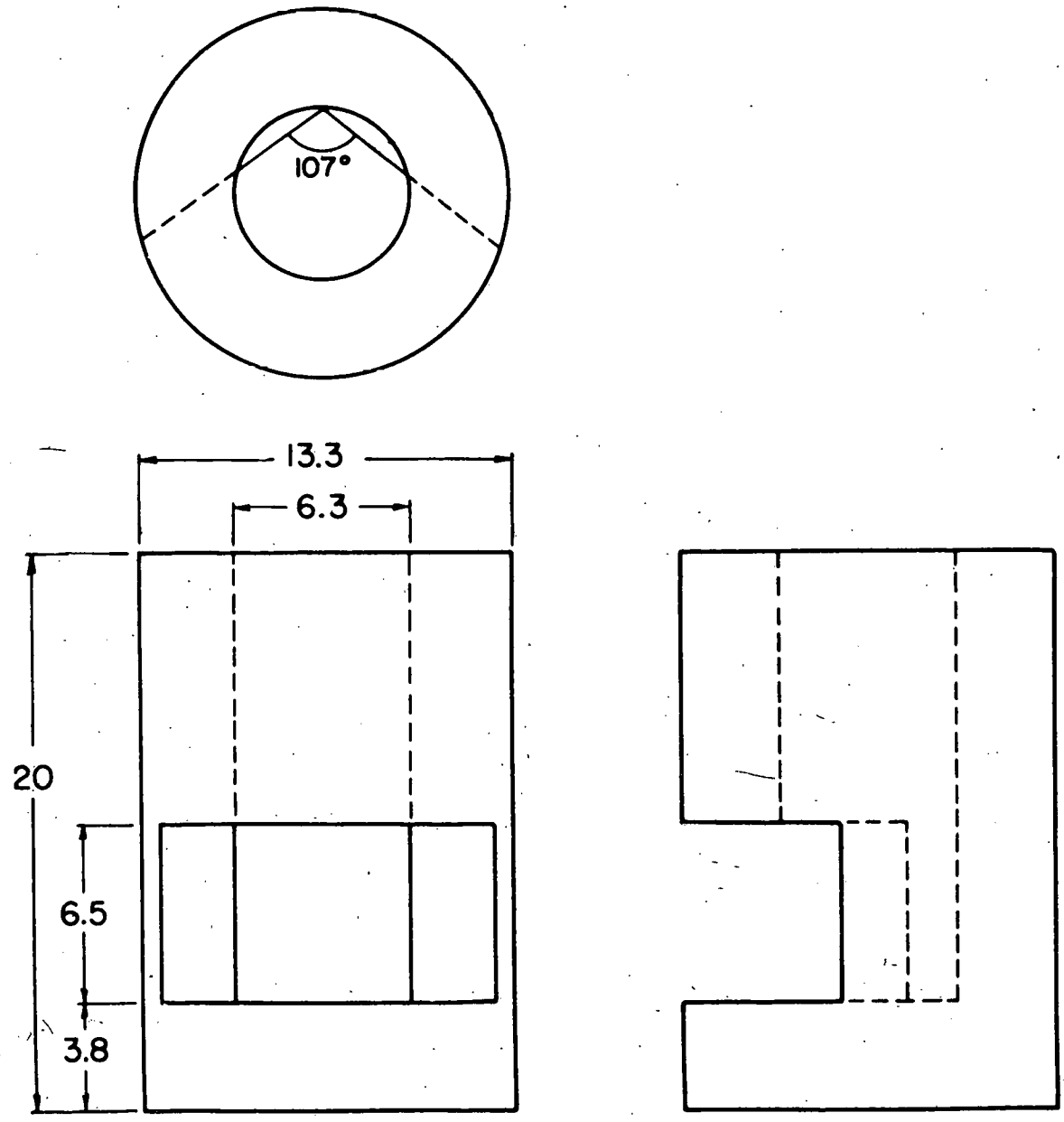
sensitivity about ten times as great as the first. However, this second method can be calibrated only indirectly by means of a patient who has been previously measured by the meter-arc technique. The policy has been to measure persons containing sufficient activity by both methods, and others by the second method only. In actual fact, however, it has been possible this year to measure only one subject by both methods. The calibration resulting from this measurement is discussed later.

Since the scintillation equipment employed during this year has been somewhat different from that of earlier years certain pertinent details are given on these methods and their calibration.

The equipment used has consisted of a 2" × 2" NaI crystal, RCA 6655 photomultiplier tube, Model 100 linear amplifier, Atomic Instrument Company single channel pulse height selector, and scaler. In normal operation the pulse height selection has been optimized for the photopeak of the 0.35-Mev γ emitted in 44 percent of the RaB disintegrations, using a pulse height window width of about 70 kev. In two cases an additional measurement was made with conditions optimized for the 0.609-Mev γ emitted in 36 percent of the RaC disintegrations, using a window width of

about 80 kev. The errors associated with counting statistics have been found to be closely similar in the two cases.

To reduce background the crystal is shielded by about 1 1/2" Pb, of configuration shown in the accompanying sketch. The crystal and photomultiplier are inserted in the hole, with the crystal centered at the window.



All dimensions in cm.

In the chair measurement this assembly is located with the geometrical center of the crystal approximately at the height of the fourth lumbar vertebra and at a distance of 6 cm. from the back. In the meter-arc measurement this assembly, with additional shielding in the form of Pb bricks, is positioned with the crystal at the center of the one-meter arc defined in principle by the patient's body.

Since all patients studied in the normal course of this investigation were found to contain too little Ra to allow calibration of the chair measurement by a meter-arc measurement, a remeasurement specifically for calibration purposes was carried out on a higher activity patient (J. Ja.) studied several times in the past. Both a meter-arc measurement and a chair measurement were performed with energy discrimination optimized, in turn, first for the 0.35-Mev RaB γ and second for the 0.61-Mev RaC γ. Results obtained are given below. By "chair calibration factor" is meant the number of μc of RaB or RaC located one meter from the counter which gives the same counting rate as 1 μc of RaB or RaC in a patient seated in the chair. Previous measurements[1] have indicated that this factor does not vary greatly between different individuals.

	Body burden by meter-arc measurement	Computed chair calibration factor
RaB (0.35-Mev γ)	0.53 ± 0.04 μc	4.1 ± 0.3
RaC (0.61-Mev γ)	0.52 ± 0.03 μc	3.6 ± 0.3

(Errors shown are calculated from counting statistics. Other systematic errors are estimated to lie in the domain of 10 to 20 percent.) From these results a chair calibration factor of 4.0 has been adopted in all other measurements.

While this meter-arc calibration measurement appeared satisfactory in every respect, and, together with data on Rn exhalation, yields a very reasonable Rn exhalation fraction of 57 percent, it must be recognized that this estimated Ra body burden is lower than that indicated by previous measurements on this patient. These previous measurements in five different years between 1937 and 1953 show a progressively decreasing RaB,C burden (estimated by body γ measurement) from 2.7 to 1.3. Measurements on exhaled Rn in these same five years, plus 1957, show a nearly constant value consistent with the present exhalation rate.

(2) Fractional Rn exhalation. In those cases for which the only (or only reliable) measurement available is of breath Rn exhalation rate, the estimate of total Ra body burden requires an assumption as to the fraction of

the Rn which is exhaled. It seems probable that this fraction depends on position,[2] being highest while the patient is reclining and lowest while he is standing. A value averaged over the daily routine should be used, and is taken here as that associated with the seated position.

Six results have become available during this year on this fraction, based on measurements of Rn concentration in expired air, breathing rate, chair γ-ray measurement, and an assumed chair calibration factor of 4.0. (Data on five of these six results are included for the first five subjects listed in Table 1a, which gives RaB in body and Rn outside body. The sixth is J. Ja., whose Rn exhalation has already been given as 57 percent.) These individual values range from 42-63 percent and average 54 percent Rn exhaled.

b. Whole body MsTh burden of living subjects

The data accumulated on MsTh burden of living subjects are presented in Tables 1a and 1b.

The problem of estimating MsTh body burden from measured Tn exhalation rate has been discussed in previous reports. The calculation is assumed to be much less reliable than the corresponding estimate of Ra burden from measured Rn

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2. E. J. Martin and J. K. W. Ferguson, Science 118, 112 (1953)

(Text continues on pg. 13)

Table 1a. All subjects included in this table are living persons formerly employed as dial painters at the Waterbury Clock Co. The first six on the list were selected for study on the basis of real or presumed clinical symptoms attributable to radiation. The remainder were selected on the basis of employment records, and more nearly approach the statistically desirable random sample of exposed individuals.

Data on γ rays emitted in the body have been obtained by the chair measurement technique, whose calibration against the meter-arc technique has been previously described. The amount of Rn outside the body has been computed from breathing rate as measured in a spirometer and Rn concentration in exhaled breath as determined by pulse ionization chamber measurements on concurrently collected breath samples. The minimum activity which can be determined with some confidence is about 0.005 to 0.01 μc in each case. The errors indicated are based on counting statistics only, and do not include systematic errors of measurement.

The total Ra burden of the body is equal to the sum of the results in column (1) and column (2), as given in column (3). In some cases the Rn measurement is more accurate than the RaB γ measurement, and an estimate of Ra burden is possible from the Rn measurement alone assuming 55 percent Rn exhalation as previously discussed. The result of this computation is given in column (4).

The amount of Tn external to the body is based on the α activity of the descendants of exhaled Tn. This activity is measured by scintillation counting of ThB deposits electrostatically collected from the exhaled breath stream. Results are given in column (5), together with the statistical errors of counting. The MsTh burden of the body is calculated from the Tn external to the body, assuming secular equilibrium between ThX and MsTh in the body, and assuming 0.2 percent Tn exhalation. The results are in column (6). The MsTh/Ra ratio of column (7) is computed from the data of columns (3) and (6).

Table 1a. Body γ-ray Measurements and Breath Analyses-

Dial Painters Exposed at Waterbury Clock Co.

	patient yr. of birth	exposure period	(1) Ra equiv. by γ (μc)	(2) Ra equiv. by Rn (μc)	(3) est. total Ra content RaB + Rn (μc)	(4) est. total Ra content from Rn (μc)	(5) ThX equiv. by Tn (μμc)	(6) est. $MsTh_1$ content 1957 (μc)	(7) $MsTh_1/Ra$ (μμc/μμc) 1957	1926 or last exposure, if earlier
selected by symptoms	C. Do. 1904	7 yrs. 1920-1928	0.086 ± 0.021	0.06 ± 0.01	0.15 ± 0.02	0.11 ± 0.02	20 ± 1.2	$7.1 \times 10^{-3} \pm 0.4 \times 10^{-3}$	0.05	1.3
	E. DeB. 1906	3 yrs. 1923-1926	0.060 ± 0.009	0.09 ± 0.02	0.15 ± 0.01	0.16 ± 0.04	30 ± 2.6	$11 \times 10^{-3} \pm 0.9 \times 10^{-3}$	0.07	1.9
	Y. Gi. 1900	10 mos. 1921-1922	0.065 ± 0.004	0.08 ± 0.01	0.15 ± 0.01	0.15 ± 0.02	39 ± 1.3	$14 \times 10^{-3} \pm 0.5 \times 10^{-3}$	0.09	3.8
	M. Da. 1900	4 yrs. interm. 1920-1927	0.075 ± 0.004	0.07 ± 0.009	0.14 ± 0.01	0.13 ± 0.02	18 ± 0.9	$6.4 \times 10^{-3} \pm 0.3 \times 10^{-3}$	0.05	1.3
	M. Kl. 1902	3 yrs. 1921-1924	0.033 ± 0.004	0.05 ± 0.008	0.09 ± 0.009	0.09 ± 0.001	21 ± 2.7	$7.5 \times 10^{-3} \pm 1.0 \times 10^{-3}$	0.08	3.0
	H. McG. 1904	1 yr. 1924-1925	0.017 ± 0.005	0.017 ± 0.004	0.034 ± 0.006	0.031 ± 0.007	7.4 ± 0.6	$2.6 \times 10^{-3} \pm 0.2 \times 10^{-3}$	0.08	2.4
randomly selected	W. Fa. 1912	4 yrs. interm. 1927-1933	0.018 ± 0.003	0.047 ± 0.004	0.065 ± 0.005	0.09 ± 0.007	-0.9 ± 0.6	$-3.2 \times 10^{-4} \pm 2.1 \times 10^{-4}$		
	P. Te. 1910	15 mos. 1926-1927	0.009 ± 0.005	0.004 ± 0.002	0.013 ± 0.005	0.007 ± 0.004	-1.2 ± 0.6	$-3.9 \times 10^{-4} \pm 2.1 \times 10^{-4}$		
	B. Ga. 1910	15 mos. 1927-1929	0.007 ± 0.004	0.003 ± 0.003	0.010 ± 0.005	0.005 ± 0.005	-1.5 ± 0.6	$-5.3 \times 10^{-4} \pm 2.1 \times 10^{-4}$		
	G. Ki. 1909	10 mos. interm. 1925-1926	0.006 ± 0.004	0.004 ± 0.001	0.010 ± 0.004	0.007 ± 0.002	-0.9 ± 0.6	$-3.2 \times 10^{-4} \pm 2.1 \times 10^{-4}$		
	A. Le. 1910	21 mos. 1927-1929	0.004 ± 0.004	0.005 ± 0.004	0.009 ± 0.005	0.009 ± 0.007	-1.7 ± 0.6	$-6.1 \times 10^{-4} \pm 2.1 \times 10^{-4}$		
	C. Ca. 1912	2 mos. 1927	0.006 ± 0.004	0.003 ± 0.001	0.009 ± 0.004	0.005 ± 0.002	-0.4 ± 0.6	$-1.4 \times 10^{-4} \pm 2.1 \times 10^{-4}$		

Table 1a. (cont.)

randomly selected

patient yr. of birth	exposure period	(1) Ra equiv. by γ (μc)	(2) Ra equiv. by Rn (μc)	(3) est. total Ra content RaB + Rn (μc)	(4) est. total Ra content from Rn (μc)	(5) ThX equiv. by Tn (μμc)	(6) est. $MsTh_1$ content 1957 (μc)
R. Os. 1909	20 mos. interm. 1925-1927	0.001 ± 0.004	0.008 ± 0.002	0.009 ± 0.004	0.015 ± 0.004	-0.4 ± 0.6	$-1.4 \times 10^{-4} \pm 2.1 \times 10^{-4}$
M. LaF. 1911	1 yr. 1927-1928	0.003 ± 0.003	0.003 ± 0.002	0.006 ± 0.004	0.005 ± 0.004	-2.0 ± 0.6	$-7.1 \times 10^{-4} \pm 2.1 \times 10^{-4}$
D. Ra. 1899	3 mos. 1920-1921	0.003 ± 0.003	0.002 ± 0.002	0.005 ± 0.004	0.004 ± 0.004	-1.6 ± 0.6	$-5.7 \times 10^{-4} \pm 2.1 \times 10^{-4}$
G. Pa. 1910	4 mos. 1927	0.000 ± 0.005	0.002 ± 0.004	0.002 ± 0.006	0.004 ± 0.007	-0.6 ± 0.6	$-2.1 \times 10^{-4} \pm 2.1 \times 10^{-4}$
R. Ba. 1901	4.5 mos. 1920	0.000 ± 0.003	0.002 ± 0.002	0.002 ± 0.004	0.004 ± 0.004	0.2 ± 0.6	$7.1 \times 10^{-4} \pm 2.1 \times 10^{-4}$
J. Ke. 1910	3 mos. 1927	-0.003 ± 0.004	0.004 ± 0.001	0.001 ± 0.004	0.007 ± 0.002	-0.1 ± 1.7	$-3.6 \times 10^{-4} \pm 6.1 \times 10^{-4}$
K. Wds. 1901	14 yrs. interm. 1920-1936	-0.002 ± 0.004	0.002 ± 0.003	0.000 ± 0.005	0.004 ± 0.005	-1.2 ± 0.6	$-4.3 \times 10^{-4} \pm 2.1 \times 10^{-4}$
J. Ga. 1908	6 wks. 1927	-0.003 ± 0.004	0.002 ± 0.001	-0.001 ± 0.004	0.004 ± 0.002	-0.2 ± 0.6	$-7.1 \times 10^{-4} \pm 2.1 \times 10^{-4}$
L. Ma. 1909	2.7yrs. interm. 1927-1936	-	-	-	0.03+	-	-

+ Estimate based on 1-liter breath sample only.

Table 1b. This table is the same as Table 1a except that the two subjects were exposed by means other than dial painting.

Table 1b. Results of Whole Body Measurement of Two Subjects

patient yr. of birth	exposure: type and date	RaB in body by γ-ray meas. (μc)	amount of Rn outside body by breath meas. (μc)	est. amt. of total body Ra from RaB + Rn (μc)	est. Ra content of body from Rn meas. (μc)	amt. of Tn external to body by breath meas. (μμc)	est. $MsTh_1$ content of body, 1957 (μc)	$MsTh_1/Ra$ 1957	$MsTh_1/Ra$ last exposure
J. Ja. 1883	oral Radithor 1926-1929	0.53 ± 0.04	0.70 ± 0.01	1.23 ± 0.04	1.27 ± 0.02	17 ± 0.5	$6.1 \times 10^{-3} \pm 0.2 \times 10^{-3}$	5.1×10^{-3}	0.09 in 1929
J. Br. 1924	uranium miner 1949-1950	-	0.001 ± 0.008	-	0.002 ± 0.002	-0.6 ± 0.9	$-2 \times 10^{-4} \pm 3 \times 10^{-4}$	-0.1	-

exhalation rate. The Tn half period is so short that the fraction exhaled depends critically on the rates of body processes (e.g., mean blood circulation time) which may vary among different individuals.

The most direct method of estimating the fraction of Tn exhaled is still that described in the 1957 Annual Progress Report. The following data are required on a single individual: (1) Tn exhalation rate, (2) RdTh burden of body sample (tooth or stool), (3) Ra burden of body sample, (4) Ra burden of whole body. The assumption is made that RdTh is deposited in the same location as, and is in secular equilibrium with, its precursor, MsTh, which as an isotope of Ra will be distributed throughout the body in a constant activity ratio with Ra. The total body burden of RdTh is then calculated from the proportion

$$\left(\frac{\text{RdTh}}{\text{Ra}}\right)_{\text{body}} = \left(\frac{\text{RdTh}}{\text{Ra}}\right)_{\text{body sample}}$$

The Tn exhalation rate and RdTh body burden are then combined to determine fractional Tn exhalation. The total set of data on fractional Tn exhalation rate available to date is given in the following table.

Subject	Sample	Calculated fractional Tn exhalation	Year measured
J. Ja.	stool	0.2 percent	1951
J. Ja.	tooth	0.07 percent	1958
M. Da.	tooth	0.2 percent	1957

A less direct method of estimating fractional Tn exhalation, but one upon which somewhat more information can be brought to bear, is available for the Waterbury dial painter group. Results on a considerable number of teeth (almost all from subjects now dead) are by now available, providing data on the average and range of MsTh/Ra ratio within the group. Radium burdens and Tn exhalation rates have been measured on several living representatives of this group. If it is assumed that on the average the MsTh/Ra ratio of the living subjects was the same at time of exposure as for the nonliving subjects, the data can be combined to give an estimate of the average Tn exhalation fraction. These data are summarized below.

MsTh/Ra ratio of teeth - Waterbury dial painters
(at last exposure or 1926, if earlier)

No. of individuals	Range	Mean	Standard error of mean
11	1.1-5.3	2.5	0.4

(Eight of these values were reported in the 1957 Annual Progress Report, three in Table 2 of this report)

Percent Tn exhalation by living subjects - Waterbury dial painters (assuming MsTh/Ra = 2.5 in 1926 or last exposure, if earlier)

No. of individuals	Percent Tn exhaled: Range	Mean	Standard error of mean
6	0.09-0.28	0.16	0.03

(Complete data are given in Table 1a.)

From these values it may be concluded that the best average value of Tn exhalation is about 0.2 percent. This is the same value used on the basis of less information in the preceding progress report, and is retained in this report.

c. Analysis of RdTh and Ra in teeth and bones

The results obtained are given in Tables 2 and 3.

The procedures for assay of Ra and MsTh in bone and tooth specimens have remained essentially the same as in the 1957 Annual Progress Report. As a check on these procedures, an intercomparison of samples is being carried out with Dr. Andrew Stehney of Argonne National Laboratory. A piece of normal cow bone has been ashed, ground, and divided into aliquots, with fractions analyzed for natural Ra and MsTh (actually RdTh) at both Argonne and M.I.T. The concentrations of Ra and RdTh are in the domain of 0.1 to 0.5 μμc/g ash, an appropriate level for the testing of techniques.

Table 2. This table presents data on the Ra and MsTh content of tooth specimens from Waterbury Clock Co. dial painters. The total Ra burden of the skeleton is estimated according to the proportion

$$\left(\frac{Ra}{Ca}\right)_{specimen} = \left(\frac{Ra}{Ca}\right)_{body}$$

coupled with an assumed body Ca content of ~1050 g. Tooth dry weight means weight of unashed specimen; teeth were dissolved directly in HNO_3.

Table 2. Analysis of Tooth Specimens - Dial Painters Exposed at Waterbury Clock Co.

patient yr. of birth	specimen	exposure period	age at beginning of exposure	dry wt. specimen (g)	Ra/Ca (μμc/g)	est. Ra content (μc)	$\frac{MsTh_1/Ra}{1926 \text{ or last exposure, if earlier}}$ (μμc/μμc)	mortality	present health
F. Co. 1903	tooth (molar)	13 yrs. 1920-1933	17	0.587	109	0.11	2.4	osteo-sarcoma rt. leg 1943	-
E. Da. 1903	tooth (molar)	5 days 1920	16	0.725	93	0.10	5.3	osteo-myelitis, anemia, Ra poisoning 1937	-
J. La. 1905	tooth (pre-molar)	7.5 yrs. 1921-1928	15	0.405	98	0.10	2.3	-	squamous cell ca. ear, 1957

Table 3. The Ra content of the body as estimated from the sample analyzed is based on the proportion

$$\left(\frac{Ra}{Ca}\right)_{specimen} = \left(\frac{Ra}{Ca}\right)_{body}$$

coupled with an assumed body Ca content of $\sim$1050 g. The last three columns give other results obtained by various measurements on the whole body (Rn in breath, sometimes with body γ also) or skeletal samples. Tooth dry weight means weight of unashed specimen; tooth was dissolved directly in HNO_3.

Table 3. Analysis of Tooth and Bone Specimens - Subjects Exposed at Other Plants, and by means other than Dial Painting

patient yr. of birth	specimen	type of exposure	exposure period	age at beginning of exposure	ashed wt. specimen (g)	Ra/Ca (μμc/g)	est. Ra content (μc)	$MsTh_1/Ra$ in yr. last exposure	Ra burden by other measurement: burden (μc)	measurement technique	laboratory
L. Ar. 1870	bone (long shaft)	oral Ra water	1918	48	0.987	4.7×10^3	5.0	<0.0006	10.5 3.0	Rn + body γ bone sample	M.I.T. Argonne
I. Da. 1906	bone (unident.)	dial painter	3 mos. 1922	16	1.03	1.62×10^3	1.7	0.23	3.8	Rn + body γ	Argonne
I. Ja. 1905	bone (long shaft)	dial painter	3 yrs. 1924-1927	18	1.52	1.64×10^3	1.7	0.018	1.3	?	Argonne
A. St. 1903	bone (unident.)	dial painter	3 yrs. 1919-1922	16	1.328	1.37×10^3	1.4	0.11	-	-	-
M. Pa. -	femur	chemist	unknown	unknown	1.05	1.01×10^3	1.1	$<2 \times 10^{-4}$ (1940)	0.1-0.2	bone and tooth samples	NYOO
R. Wi. 1907	bone (unident.)	dial painter	26 yrs. 1924-1950	17	0.961	0.92×10^3	1.0	<0.001	1.3 0.6	Rn + body γ bone sample	Argonne Argonne
C. Da. 1898	bone (long shaft)	injection	1931	33	2.08	0.52×10^3	0.55	0.002	0.8	Rn + body γ	Argonne
J. Un. 1889	mixed cadaver ash	chemist	20 yrs. 1912-1932	23	1.73	0.38×10^3	0.40	<0.003	0.3-0.5 0.3-0.6	Rn γ's from ashes*	M.I.T. M.I.T.
C. La. 1900	bone (long shaft)	injection	1931	31	0.958	0.36×10^3	0.38	$<10^{-3}$	3.6	Rn + body γ	Argonne
J. Ja. 1883	tooth (canine)	oral Radithor	3 yrs. 1926-1929	43	0.275**	0.23×10^3	0.28	0.29	1.2	Rn + body γ	M.I.T.

* Uncertainty in aliquot fraction obtained accounts for spread

** Dry weight - weight of unashed specimen. Tooth was dissolved directly in HNO_3

These intercomparisons have suggested an apparently consistent difference between M.I.T. and Argonne, the M.I.T. values being about one-half of the Argonne values for both Ra and RdTh. At least one value is significantly in error. The RdTh standards used at both Argonne and M.I.T. are from the same sample of old Th, a fact which essentially excludes calibration discrepancies and focuses attention on the techniques themselves. The Ra standards have not been intercompared. As yet the discrepancy is unexplained, and further intercomparisons are in progress.

The MsTh/Ra ratio of the skeleton as estimated from the tooth or bone specimen is thought to be fairly reliable (assuming validity of the experimental technique), since these two substances, being isotopes, would be deposited in the same proportion everywhere provided their ingestion was simultaneous.

The estimation of total skeletal Ra burden (or MsTh burden) by extrapolation from a small body sample is not very accurate since variations in Ra concentration are known to occur from one part of the skeleton to another. The most reliable method of extrapolation is considered to be via the proportion $(Ra/Ca)_{body} = (Ra/Ca)_{specimen}$, coupled with the assumption of ~1050 g Ca in the total body. (This latter assumption is very good in the present context.) It has

been possible thus far to check this proportion experimentally by measurement of the Ra content of a tooth and also the whole body of four individuals (although some ambiguity remains in that the body burden measurement was not made at the time of tooth extraction). The results are shown below.

Subject	$\left(\frac{Ra}{Ca}\right)_{tooth} / \left(\frac{Ra}{Ca}\right)_{body}$	Age at first exposure	
E. Ca.	1.4	16	from 1957 Annual Progress Report
K. Wd.	0.3	28	
M. Da.	0.4	20	
J. Ja.	0.2	43	

The data suggest that the Ra/Ca ratio of the tooth tends to be somewhat lower than that of the body, perhaps especially so if Ra intake occurs long after tooth formation.

Table 4. Estimated Ra content of body is based on Rn concentration in 1-liter samples of exhaled breath, an assumed breathing rate of 8 liters per minute, and an assumed exhalation fraction of 55 percent. The estimate under these conditions is not very reliable.

Table 4. Analysis of Breath Samples - Subjects Exposed by Various Means

patient yr. of birth	type of exposure	exposure period	age at beginning of exposure	net meas. Rn (μμc/l)	est. Ra content (μc)*	present health 1958
H. Ma. 1895	injection+	3 mos. 1914	19	19.8	2.3	poor
K. Wd. 1893	dial painter	4 yrs. 1921-1925	28	16.6	1.9	good
I. Ni. 1900	oral Radithor**	1927	26	12.5	1.4	poor
L. St. 1874	occup. x-ray + Ra	10 yrs. 1905-1915	31	0.3	0.03	poor
R. Ha. -	paint mixer	unknown	unknown	0.2	0.02	good

* Estimates, based on 1-liter breath samples only, assume an average breathing rate of 8 liters per minute, and an average fraction of Rn exhaled to be 55 percent.

\+ 24 injections $RaCl_2$ and "some Ra water".

** About 200 bottles Radithor.

3. Spectrum of Ra Burden in Waterbury Cases

The group of Waterbury cases is the only one under study in this laboratory which may yield correlations of radiation dose and incidence of effect having some statistical significance. Even for this group the goal can be achieved only if a considerably greater fraction of the total number of cases in the pool can be studied than has yet been possible.

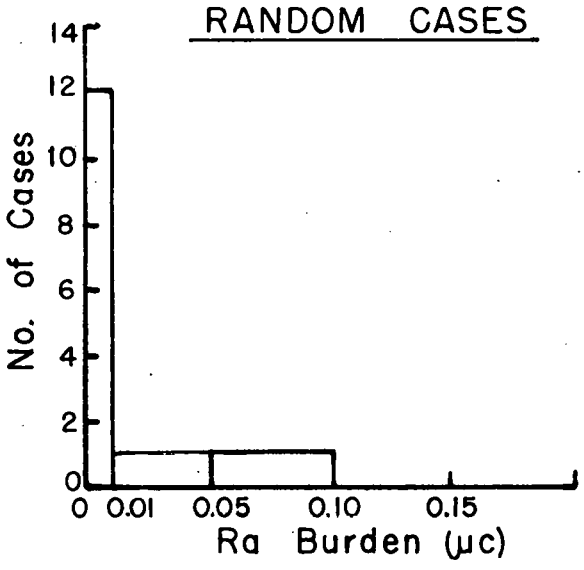
It is of interest at this early stage to examine the spectrum of Ra burdens which have thus far been measured, and to estimate the spectrum which may describe the total pool. Obviously, the conclusions extracted from the small fraction of cases yet studied are of a preliminary nature. The total number of Waterbury cases measured to date is 30 (including those reported in the 1957 Annual Progress Report). Ten of these cases are represented only by teeth, whose Ra concentration permits only an approximate estimate of the total body burden as discussed earlier. Fourteen of the 30 cases have been traced following initial discovery on employment records. These are hereafter referred to as "random" cases, signifying that they represent a statistical sample more or less free of bias with regard to dose-effect correlations. The qualification "more or less" is necessary for several reasons. First,

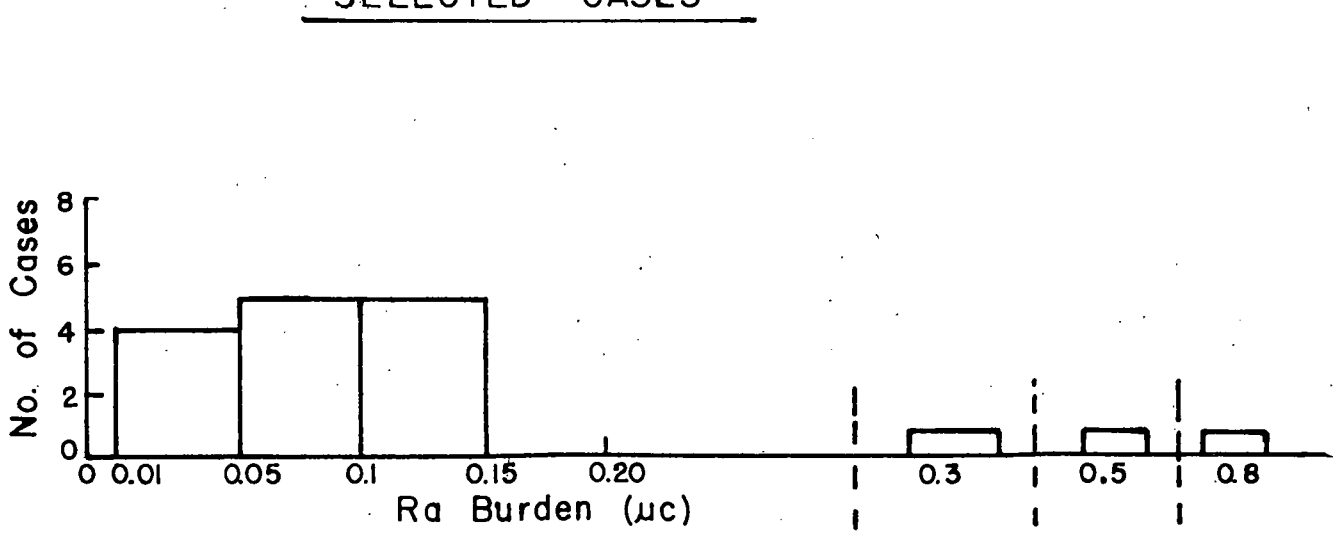
it is apparent from employment dates that most of these 14 were exposed toward the end of the period in which Ra poisoning was a common occurrence in the dial painting industry; this is a nonrandom feature. Second, the fact that these cases are alive, while others possibly more sensitive to radiation are now dead and therefore unavailable for study, is a nonrandom feature. The remaining 16 of the 30 cases were discovered as a result of real or suspected radiation effects. (All cases represented by tooth samples have been assigned to this group.) They presumably represent a biased sample, biased first toward greater Ra burdens than the average, and second toward greater sensitivity to radiation than the average. This group is called the "selected" cases. The statistical difficulties resulting from this biased selection will be ameliorated only through study of a larger fraction of the total Waterbury pool of cases.

For dosimetry purposes it is important to bear in mind the MsTh which accompanies these Ra burdens. As previously discussed, the subjects who painted prior to 1926 showed average MsTh/Ra ratios at the time of exposure averaging about 2.5. (Later cases probably show a reduced ratio, although the data are inadequate.) Making reasonable assumptions about the retention of Ra element (either Ra^{226} or MsTh) as a function of time, and retention of their decay products in the body, one can calculate that the cumulative

radiation dose from an initial 2.5 μc of MsTh ingested in 1926 would by now equal the cumulative dose from about 3 to 4 μc of Ra^{226} ingested simultaneously. Therefore the total dose received by these individuals is about four to five times that which would have been received from the Ra burden alone.

The spectrum of Ra burdens of individuals in these two groups is depicted in the following histograms. (Note the nonuniformity of the horizontal scale.)





In the second histogram (selected cases) three of the four lowest burdens are estimated from teeth. They are therefore unreliable by a factor of two to four, and should not be taken as data demonstrating radiation effects at these levels. The three highest burdens are also estimated from teeth, all from persons now dead.

The histogram for random cases leads one to predict that only a small fraction (e.g., the order of 10 percent) of the living Waterbury dial painters have burdens of sufficient magnitude that demonstrable radiation effects can be expected. The two histograms together, showing no living cases with Ra burdens greater than 0.15 μc, suggest that either few such burdens resulted from the dial painting operations at Waterbury Clock Co. and New England Watch Co., or that the radiation dose from these Ra burdens (with the accompanying approximately three to four times greater dose from MsTh) were usually lethal within 30 years.

4. Individual Medical Reports

Case history summaries are presented here on persons being studied by this laboratory. The detailed medical protocols, together with a list of normal values for the laboratory tests carried out, will be found in Appendix 1. Information on all individuals in Table 3, except (J. Ja.) and (J. Un.), will be found only in Appendix 1.

It will be noted that most of these cases concern former dial painters from Waterbury, Conn. The largest number of this group was employed after the dangers of radium compounds were manifest, as noted earlier in this report. By contrast eight of this group worked prior to 1926 and took no particular precautions to avoid exposure.

A summary of the physical findings on the luminous dial painters (all but one of whom worked at Waterbury Clock Co. or its subsidiary, New England Watch Co.) will be found in Table 5. It should be emphasized that the majority of the individuals listed therein are, and have been, in good health. They would appear to have no greater incidence of disease than a similar group chosen at random in any presumably nonhazardous occupation.

Six individuals are listed in Table 6 who were injected with radium compounds, ingested radium water, or who were exposed to radioactivity in occupations other than dial painting. While three of these people have not yet been examined, we know from the family physicians of two (I. Ni., H. Ma.) that they show definite evidence of pathology and this pathology can be presumed to be the result of radiation.

Table 5. A summary of data on luminous dial painters, with particular reference to Ra content, occupational history, past medical and dental history, marital status, fertility, physical examination, x-ray and laboratory findings. Brief summaries of all cases will be found following Table 6. Complete histories are given in Appendix 1, together with a list of normal values for the laboratory tests done. Only significant abnormal results of laboratory work are included here. The gradations in amount of brush tipping and in severity of dental pathology are as follows:

brush tipping:

- 1+ occasional, over an indeterminate time period
- 2+ frequently, up to 1 month
- 3+ routine pointing of brush in mouth, for less than 6 months
- 4+ routine pointing of brush in mouth, for 6 months or more

dental pathology:

- 1+ slight to moderate dental caries or pyorrhea, or loss of 1 to 6 teeth
- 2+ severe caries or pyorrhea, or loss of over half the teeth
- 3+ loss of all teeth but without osteomyelitis or necrosis of jaw
- 4+ severe dental pathology with loss of many teeth and history of osteomyelitis or necrosis of jaw

Table 5. Summary of physical findings and body burdens of dial painters

patient yr. of birth	exposure: time and date	est. Ra content (μc)	years after initial expos.	age at beginning of expos.	effects of radiation exposure	brush tipping	dental pathology	marital status	number of children	past medical history	1957-8 physical examination	x-ray findings bones	lab. findings	present health 1957-8
K. Wd. 1893	4 yrs. 1921-1925	1.9	37	28	minimal	?	3+	s	-	non-contrib.	negative	-	-	good
C. Do. 1904	7 yrs. 1920-1928	0.15	37	16	marked	4+	3+	m 1930-2	2	spont.fract. rt. femur 1942,1951; arthritis	severe arthritis shortened rt. femur	diffuse changes	normal	fair
E.DeB. 1906	3 yrs. 1923-1926	0.15	34	16	prob. minimal	4+	2+	m 31 yrs.	1	pan-hysterect. 1946	osteoarthritis ankylosis hips	osteoporosis inactivity	normal	fair-prob. primarily neuras-thenia
Y. Gi. 1900	10 mos. 1921-1922	0.15	35	20	minimal	4+	3+	s	-	spont.fract. lt. femur 1947	multiple aches in bones	marked mottling skull	NPN 49	good
M. Da. 1900	4 yrs. intermit. 1920-1927	0.14	37	20	minimal	4+	3+	s	-	occ. pain ribs + back 1955-7	arthritis hands, benign tumor breast	mild chgs. calvarium. long bones	NPN 63	good
J. La. 1905	7.5 yrs. 1921-1928	0.10	36	15	marked	4+	4+	m	1	fracts. femurs, ribs; osteomy. mandible	carcinoma ear	osteitis 1953	-	poor
M. Kl. 1902	3 yrs. 1921-1924	0.09	37	18	moderate	4+	3+	married twice 29 yrs.	0	spont.fract. lt. femur 1954	degen.arthritis, probable ca.ear	mild rad'n. osteitis calvarium, long bones	normal	fair
W. Fa. 1912	4 yrs. intermit. 1927-1933	0.065	30	15	none	0	3+	m, 27 yrs. (1 tubal preg.)	4	non-contrib.	negative	negative	normal	good
H.McG. 1904	1 yr. 1924-1925	0.034	33	20	none	4+	3+	s	-	non-contrib.	negative	mod. rad'n. osteitis skull	normal	good
L. Ma. 1909	32 mos. intermit.* 1927-1936	0.03	28	21	none	?	?	m	1	-	not done	-	-	good

P. Te. 1910	15 mos. 1926-1927	0.013	32	15	none	4+	2+	m 15 yrs.	1	non-contrib.	mild high blood pressure 150/100, pyorrhea	negative	normal	good
B. Ga. 1910	15 mos. 1927-1929	0.010	31	17	none	?	1+	m 30 yrs.	2	non-contrib.	negative	negative	normal	good
G. Ki. 1909	10 mos. intermit. 1925-1926	0.010	32	16	none	4+	2+	m 23 yrs.	2	non-contrib.	negative	negative	normal	good
A. Le. 1910	21 mos.+ 1927-1929	0.009	31	17	none	0	2+	m 30 yrs.	3	non-contrib.	negative.	? osteitis lt.trochan.	anemia hgb 9.7	good
C. Ca. 1912	2 mos. 1927	0.009	31	15	none	0	3+	m 8 yrs.	1 misc.	non-contrib.	negative	negative	normal	good
R. Os. 1909	20 mos. intermit. 1925-1927	0.009	33	16	none	1+	3+	m 30 yrs.	4	non-contrib.	negative	negative	normal	good
M.LaF. 1911	1 yr. 1927-1928	0.006	31	16	none	0	2+	m 19 yrs.	0	tb.1 yr.1931 retinal hem. 1957-8	retinal hemorrhages	negative	normal	fair
D. Ra. 1899	3 mos. 1920-1921	0.005	38	21	none	0	3+	m 32 yrs.	1	non-contrib.	high blood press. 170/110	negative	urine:1+ albumin	fair
G. Pa. 1910	4 mos. 1927	0.002	31	16	none	0	1+	m 26 yrs.	2	? disc in spine	mild high blood pressure 152/100	negative	normal	good
R. Ba. 1901	4.5 mos. 1920	0.002	38	18	none	3+	1+	s	-	non-contrib.	Paget's dis. bones; enlarged thyroid	Paget's disease	alk. phos. 12.5	fair
J. Ke. 1910	3 mos. 1927	0.001	31	16	none	0	1+	m 28 yrs.	1	non-contrib.	negative	negative	normal	good
K. Wds. 1901	14 yrs.** intermit. 1920-1936	0.000	38	19	none	2+	2+	s	-	pan-hysterect. 1948	obesity pyorrhea	negative	normal	good
J. Ga. 1908	6 wks. 1927	-0.001	31	18	none	0	2+	m 19 yrs.	1	non-contrib.	High blood press. 190/110	negative	normal	good

* 22 months painting watches, 10 months painting clocks - brush-tipping habits not known.
\+ 9 months painting watches, 1 yr. painting clocks - did not tip brush in either department.
** 3 weeks painting watches-tipped brush; rest of employment in clock-painting departments - no brush tipping.

Table 6. A summary of data on individuals exposed to radioactive materials by means other than dial painting, with particular reference to Ra content, occupational history, past medical and dental history, marital status, fertility, physical examination, x-ray and laboratory findings. Brief summaries of all cases will be found following this table. Complete histories are given in Appendix 1, together with a list of normal values for the laboratory tests done. Only significant abnormal results of laboratory work are included here. The gradations in severity of dental pathology are given below.

1+ slight to moderate dental caries or pyorrhea, or loss of 1 to 6 teeth

2+ severe caries or pyorrhea, or loss of over half the teeth

3+ loss of all teeth but without osteomyelitis or necrosis of jaw

4+ severe dental pathology with loss of many teeth and history of osteomyelitis or necrosis of jaw

Table 6. Summary of physical findings and body burdens of individuals exposed to radioactive materials by means other than dial painting

patient yr. of birth	exposure: type and date	est. Ra content (μc)	years after initial expos.	age at beginning of expos.	effects of radiation exposure	dental pathology	marital status	number of children	past medical history	1957-8 physical examination	x-ray findings bones	lab. findings	present health 1957-8
H. Ma. 1895	injection 1914*	2.3	44	19	marked	4+	m	?	arthritis	-	radiation osteitis	-	poor
J. Ja. 1883	oral Radithor+ 1926-1929	1.3	31	43	minimal	2+	s	-	non-contrib.	mild angina pector. blood pressure 170/85, hypertrophic arthritis	multiple osteolytic changes	alkaline phosph. 5.5	good
I. Ni. 1900	oral Radithor 1927**	1.4	31	26	marked	4+	m	2	multiple spont. fractures, arthritis	ununited fracture femur	marked radiation osteitis	-	poor
J. Un. 1889	chemist 1912-1932	0.40	45	23	minimal 1951	-	m	2	non-contrib.	-	minimal 1951	-	died 1957 ca. lung
L. St. 1874	occup. x-ray + Ra 1905-1915	0.03	52	31	marked	?	m	-	skin lesions loss one finger	atrophy, skin hands	-	-	poor
J. Br. 1924	uranium miner 1949-1950	0.002	8	24	none	0	s	-	non-contrib.	neg.	none	-	good

* 24 i.v. injections $RaCl_2$ and "some Ra water" + about 400 bottles Radithor

** about 200 bottles Radithor

Case history summaries

(R.Ba) Born 1901. Living and in fair health. Luminous dial painter for 4 1/2 months in 1920 at age 18. Body burden Ra 0.002 μc in 1958. No effect demonstrable from radiation 38 years after exposure.

Teeth generally good. Unmarried. Fertility not assessable. Past medical history noncontributory. Pointed brush in mouth frequently. Present exam shows Paget's disease of bones and thyroid enlargement. X-ray and laboratory findings confirm Paget's disease only.

(J.Br.) Born 1924. Living and in good health. Prisoner of war in Joachimsthal uranium mines 14 months starting 1949. Body burden 0.002 μc Ra in 1957. No demonstrable effect from radiation eight years after exposure.

Past medical history noncontributory. No x-ray or lab work done. Present examination shows no pathology.

(C.Ca.) Born 1912. Living and in good health. Luminous dial painter two months in 1927 at age 15. Body burden Ra 0.009 μc in 1958. No demonstrable effect from radiation 31 years after exposure.

Teeth poor since 15. Only two teeth left in 1958. Married eight years, 1933 to 1942. One miscarriage only. Past medical history noncontributory. Denies putting

brush in mouth. Present exam shows no pathology. X-ray and laboratory findings show no pathology.

(F.Co.) Born 1903. Died 1943 of osteogenic sarcoma. Luminous dial painter for 13 years starting in 1920 at age 17. Body burden Ra 0.11 μc in 1958. Osteogenic sarcoma presumed due to radiation 23 years after beginning of exposure.

X-rays of skull, shoulder, pelvis, and hips taken in 1931, 1934, and 1935 showed patchy areas of decalcification and mottled appearance considered typical of radium poisoning.

(M.Da.) For previous history on this patient see Annual Progress Report, May 1957. Body burden Ra 0.14 μc in 1957. Minimal effects from radiation 37 years after initial exposure.

This former dial painter was examined by Dr. William H. Baker in the Waterbury Hospital during June of 1957. She had no complaints and except for past history and occasional pain in back and rib areas she had very little evidence of radium poisoning. Laboratory studies were normal except for NPN of 63. Skeletal survey showed relatively mild bone changes in the long bones and calvarium, due to radiation osteitis.

(E.Da.) Born 1903. Died 1937 of radium poisoning, osteomyelitis of maxillae, otitis media, left, and anemia. Luminous dial painter for 5 days in 1920, starting at age 16. Body burden Ra 0.10 μc based on analysis of tooth sample.

(E.DeB.) Born 1906. Living, in fair health. Luminous dial painter 3 years starting in 1923 at 16. Body burden Ra 0.15 μc in 1958. Minimal effects from radiation, probably primarily neurasthenia, 34 years after beginning of exposure.

Very few teeth remaining. Married 31 years 1926 to present, one miscarriage and 1 child, 29 years old. Panhysterectomy 1946. Tipped brush. Physical exam in 1957 at Waterbury Hospital by Dr. William H. Baker showed Ra-MsTh intoxication with osteoporosis of inactivity, possible compression fractures of the lumbar and thoracic spine, calcification of node overlying the thyroid gland and possibly part of the thyroid gland. Lab tests normal. X-rays showed osteoporosis of inactivity. At the present time the patient is bedridden at home.

(C.Do.) Born 1904. Living and in fair health. Luminous dial painter 7 years starting in 1920 at age 16. Body

burden Ra 0.15 μc. Marked effects from radiation 37 years after beginning of exposure.

Edentulous. Married 1930, 2 children. Spontaneous fractures right femur 1942 and 1951. Tipped brush. Physical exam 1957 at Waterbury Hospital by Dr. Elser showed severe arthritis, shortened right femur. Lab findings normal. X-ray studies indicated diffuse changes particularly right femoral shaft.

(W.Fa.) Born 1912. Living and in good health. Luminous dial painter 4 years intermittently starting 1927 at age 15. Body burden radium 0.065 μc in 1958. No demonstrable effect from radiation 30 years after beginning of exposure to radiation.

Teeth poor from age 18. Lost all of teeth by age 30. Married for 27 years (1931 to present). Four normal children and one tubal pregnancy. Past medical history noncontributory. Denies ever putting brush in mouth. Present physical exam entirely negative. X-ray and laboratory findings negative.

(B.Ga.) Born 1910. Living and in good health. Luminous dial painter 15 months starting 1927, age 17. Body burden Ra 0.010 μc in 1958. No demonstrable

effect from radiation 31 years after beginning exposure.

Teeth fairly good. Lost only 6 to 7 teeth to date. Married 30 years, 1928 to present. Two normal children, 26 and 15. Past medical history noncontributory. Uncertain as to putting brush in mouth. Present physical examination, x-rays, and laboratory work all negative.

(J.Ga.) Born in 1908. Living and in good health. Luminous dial painter for 6 weeks in 1927 at age 18. Body burden Ra -0.001 µc in 1958. No demonstrable effect from radiation 31 years after exposure.

Teeth were good until 20 years after dial painting. Married 19 years, 1939 to present. One child, caesarean section, now 10 years old. She denies putting brush in mouth. Physical examination, x-ray of the skeleton, and laboratory work were all negative, except for hypertension, 190/110.

(Y.Gi.) Born 1900. Living and in good health. Luminous dial painter for 10 mos., 1921-2. Body burden 0.15 µc in 1957. Minimal effects from radiation 35 years after exposure.

Spontaneous fracture left femur in 1947 presumed due to radiation 25 years after beginning of exposure.

Edentulous. Pointed brush in mouth occasionally. Physical examination by Dr. W. H. Baker at Waterbury Hospital in June 1957 essentially negative. Laboratory studies normal except for NPN of 49. X-ray examination showed changes consistent with radium poisoning, with marked mottling present in the skull.

(R.Ha.) Age is uncertain. Allegedly mixed radium paint at Waterbury Clock Company for several years. Body burden Ra 0.02 μc 1958. No demonstrable effect from radiation many years after theoretical exposure.

(J.Ja.) For previous history see Medicine 31, 274 (1952). Drank Radithor 1926-1929. Body burden Ra 1.3 μc. No demonstrable effect from radiation 31 years after initial exposure.

Physical exam in 1957 by Dr. John T. Quinby showed mild angina pectoris, blood pressure 170/85, hypertrophic arthritis. Lab findings normal except for alkaline phosphatase of 5.5. X-rays showed multiple osteolytic changes.

(J.Ke.) Born 1910. Living and in good health. Luminous dial painter for 3 months in 1927 at age 16. Body

burden Ra 0.001 μc in 1958. No demonstrable effect from radiation 31 years after exposure.

Teeth are generally good. Married 28 years from 1930 to present. Only one child, two years after marriage. Past medical history was noncontributory. She did not point brush in mouth. Present physical examination was essentially normal. Mild hypertension. X-ray and laboratory findings were negative.

(G.Ki.) Born 1909. Living and in good health. Luminous dial painter for 10 months in 1925 and 1926 starting at age 16. Body burden Ra 0.010 μc in 1958. No demonstrable effect from radiation 32 years after exposure.

Teeth are generally poor. Married 23 years from 1935 to present. Two children, who are 19 and 17. Past medical history was noncontributory. She definitely pointed brush in mouth. Present physical examination was normal. X-ray and laboratory findings were negative.

(M.Kl.) Born 1902. Living and in fair health. Luminous dial painter for about 3 years, 1921-1924. Body burden Ra 0.09 μc in 1957. Moderate effects from radiation 37 years after exposure.

Spontaneous fracture left femur in 1954 presumed due to radiation 34 years after beginning of exposure. In 1958 developing a possible carcinoma of ethmoid region. Edentulous. Married twice, no children. Pointed brush with lips. Physical examination by Dr. Wm. H. Baker at Waterbury Hospital in 1957 essentially negative. Laboratory studies normal. X-ray examination showed mild radiation osteitis of calvarium, radius, ulna, and femurs bilaterally.

(M.LaF.) Born in 1911. Living and fairly well. Luminous dial painter for about one year 1927-1928 starting at age 16. Body burden Ra 0.006 μc in 1958. No demonstrable effect from radiation 31 years after exposure.

Teeth have gradually deteriorated to present. Married 19 years 1939 to 1958. No pregnancies. She denies pointing brush in mouth. She had tb. in 1931 for 1 year. Physical examination now shows retinal hemorrhage in one eye and poor teeth. Skeletal, x-rays, and laboratory work were all negative.

(J.La.) Born in 1905. Living but in very poor health. Luminous dial painter for 7.5years starting in 1921 at

age 15. Body burden Ra 0.10 μc on basis of tooth sample. Marked effect from radiation 36 years after exposure.

Teeth were very poor with osteomyelitis of mandible. Married and one child by caesarean section in 1932. Presumably pointed brush in mouth for many years. Past medical history shows numerous fractures and cataracts. She now has squamous cell carcinoma of ear. X-rays in 1953 showed radiation osteitis in several bones.

(A.Le.) Born in 1910. Living and well. Luminous dial painter for about 2 years starting in 1927 at age 17. Body burden Ra 0.009 μc in 1958. Minimal, if any, effect from radiation 31 years after exposure.

Teeth have remained in fair condition. Married 30 years, 1928 to present. Three children 28, 24, and 17. Denies pointing brush in mouth. Negative medical history. Physical examination in 1958, laboratory tests, and skeletal x-rays were negative except for hgb 9.7 g, and possible mild radiation

osteitis left trochanter.

(H.Ma.) Born in 1895. Living and in poor health because of severe arthritis of many joints. Received 24 intravenous injections of radium salts in 1914 at the age of 19. Estimated body burden Ra 2.3 μc in 1958. Definite effect from radiation 44 years after exposure.

Teeth were very poor. All had to be removed with great difficulty. Married, number of children not known. Past medical history aside from arthritis noncontributory. Present examination by family physician shows marked changes in the bones, presumably due to radiation osteitis.

(L.Ma.) Born in 1909. Living and in good health. Luminous dial painter about 3 years intermittently

1927 to 1936 starting at age 18. Body burden Ra 0.03 µc. No demonstrable effect from radiation 31 years after exposure.

(H.McG.) For previous history see Annual Progress Report, May 1957. Body burden Ra 0.034 µc in 1957. No demonstrable effect from radiation 33 years after exposure.

She was examined by Dr. W.H.Baker in the Waterbury Hospital during June 1957 and the impression at that time was that she had no evidence of difficulty from her ingestion of Ra-MsTh. Bone survey, including heart and lungs, was essentially negative, except for the skull which showed changes consistent with radiation osteitis. Laboratory studies were normal.

(I.Ni.) Born in 1900. Living and in poor health. Drank Radithor for five months in 1927 at age 27. Body burden Ra 1.3 µc. Multiple bone fractures due to radiation exposure 31 years after ingestion of radium salts. Great deal of dental trouble with osteomyelitis of the jaw resulting in eventual removal of all teeth.

Married in 1925 to the present time. Two children who are 31 and 22. Past history was noncontributory

except for some arthritis and the multiple spontaneous fractures from 1944 to the present. X-rays taken in 1958 showed marked radiation osteitis.

(R.Os.) Born in 1909. Living and well. Luminous dial painter for 20 months 1925-1927 starting at age 16. Body burden Ra 0.009 μc in 1958. No demonstrable effect from radiation 33 years after exposure.

All teeth gone at 34, starting at 16. Married 30 years from 1928 to present. Four children and three grandchildren. Some pointing of brush in mouth. Past medical history was negative. Present physical examination, skeletal x-rays, and laboratory tests were all normal.

(G.Pa.) Born in 1910. Living and well. Luminous dial painter for 4 months in 1927, at age 16. Body burden Ra 0.002 μc in 1958. No demonstrable effect from radiation 31 years after exposure.

Teeth are in good condition. Married 26 years from 1932 to present. Two children, who are 25 and 13. No definite pointing brush in mouth. Medical history shows possible disc injury to back. Physical examination now, skeletal x-rays, and laboratory tests were all normal except for mild hypertension.

(D.Ra.) Born 1899. Living and in fair health. Luminous dial painter 3 months 1920-1921, at age 21. Body burden Ra 0.005 μc. No demonstrable effect from radiation 38 years after exposure.

Teeth deteriorated. Lost three in 1923, eventually all removed in 1952. Married about 1926 to present. One child only. Past medical history shows hypertension. Denies pointing brush in mouth. Present physical examination, skeletal x-rays, and laboratory work all negative, except for hypertension, 170/110, and 1+ albuminuria.

(L.St.) Born in 1874. Living and in poor health. A lot of exposure to radium and x-ray externally 1905-1915 at age 30 to 40. Body burden Ra 0.03 μc in 1958. He had considerable trouble with skin lesions on hands resulting in loss of one finger and skin grafting approximately 20 years ago. Some atrophy of skin at present time on hands.

(P.Te.) Born 1910. Living and well. Luminous dial painter 15 months starting 1926 at age 15. Body burden Ra 0.013 μc. No demonstrable effect from radiation 32 years after exposure.

Teeth affected by pyorrhea since age 16, but has lost only six up to present date. Married 1935 to 1950 when husband died. One child only. Past medical history entirely negative. Did some pointing of brush in mouth. Present physical examination, skeletal x-rays, and laboratory tests negative, except for mild hypertension and pyorrhea.

(J.Un.) For previous history see Medicine 31, 289 (1952). Chemist 1912-1932. Body burden Ra 0.4 μc in 1958.

Patient died in 1957 of ca. of lung.

(K.Wd.) For previous history see Medicine 31, 273 (1952). Luminous dial painter 1921-1925. Body burden Ra 1.9 μc in 1958.

Physical exam 1957 by Dr. E. Richmond Ware showed patient to be in good condition.

(K.Wds.) Born 1901. Living and in fairly good health. Luminous dial painter starting 1920 at age 19, continuing intermittently until 1936. Body burden Ra 0.000 ± 0.005 μc. No demonstrable effect from radiation 38 years after beginning of exposure.

Teeth moderately carious and has lost several to present date. Patient unmarried. Past medical history

shows obesity and panhysterectomy in 1948. Pointed brush in mouth for three-week period in 1923. Remainder of time worked on clocks where no brush tipping was done. Present physical examination shows obesity and pyorrhea. Skeletal x-rays and laboratory findings negative.

Special thanks are due to Dr. R. Harrison Ryder for making one of the major contributions to our study of the luminous dial painting industry in Waterbury, Conn. He has been most cooperative in helping us to make contact with former employees, in providing us with medical data on both living and deceased dial painters, and in arranging for us to carry out medical and radioactivity evaluations at the Waterbury Hospital on several occasions during this past year.

We are also much indebted to Mr. Patrick J. McFadden, Director of Industrial Relations at U. S. Time Co., who has been equally helpful, and who has made available to us the complete employment records of both the Waterbury Clock Co. and the New England Watch Co.

(W.H. Baker, M.D., S.D. Clark, M.D., R.A. Dudley, D.R. Kuchta, M.M. Shanahan, and M. Tavla)

5. Central Catalog

Data on all cases of chronic irradiation in human beings by certain internally deposited α-emitters (e.g., Ra, MsTh, RdTh, ThX, ThO_2) are being compiled in this laboratory in cooperation with the groups listed below. Individuals with an estimated body burden of at least 0.001 μc of an α-emitter are to be included in the compilation. All the information in this field will then be available in one location for future study and correlation of such items as amount of internally deposited radioactivity, shortening of life span, susceptibility to other diseases, and incidence of bone changes and tumors.

Punched cards containing the data on these cases are being made up and sets of cards will be sent to

Argonne Cancer Research Hospital
Dr. Robert J. Hasterlik

Argonne National Laboratory
Dr. Austin M. Brues
Mr. L. D. Marinelli

New Jersey State Dept. of Health
Mr. Lester A. Barrer

Royal Cancer Hospital
Prof. W. V. Mayneord

An annual follow-up of living cases will be carried out with the cooperation of the participating groups. (Follow-up is defined as any actual contact such as visit, telephone call, or correspondence, but not necessarily a complete reevaluation of the patient.)

a. Punched card code

Data on all cases included in the central catalog will be put on McBee Keysort punched cards. A punched card code has been drawn up which covers the following categories:

1. Name - filed under present name with all other names (maiden, married, initials, etc.) being cross-indexed.
2. Sex
3. Year of birth - in decades starting with 1890. Individuals born before 1890 in one group.
4. Year of death - in 5-year periods starting with 1920. All deaths prior to 1920 grouped together.
5. National identification number - U. S. social security number, British national health number, Canadian old age security tax number, etc.
6. Last known status - condition of patient as of last follow-up.
7. Group making study - the groups listed above, as well as the late Dr. Harrison Martland, and Health and Safety Laboratory, A. E. C.
8. Means of discovery of case - patient first seen because of signs or symptoms, or located as a result of a search.
9. Case known only through literature - those cases in the literature where original records are no longer available.

10. Place of exposure - a list of dial painting establishments, hospitals, spas, laboratories, and names of physicians who injected or prescribed radioactive materials.
11. Method of exposure - occupational, or therapeutic administration. These categories are subdivided into dial painting, laboratory or office work, mining, oral or injection, and acute exposure including accidents.
12. Quantity of radioactive material at time of exposure - amount of material administered or received known and verified.
13. Identity of radioactive material at time of exposure - Ra^{226} with a MsTh/Ra ratio of less than 0.01, mixture of Ra^{226} and any other radioactive material, radioactive material other than Ra^{226}.
14. Year of first exposure - in 5-year periods starting with 1915. All exposure prior to 1915 is consolidated in one group.
15. Age at first exposure - in 5-year periods from 15-30 years, then in decades. All who were first exposed at ages younger than 15 years are grouped together.
16. Clinical studies - physical examination, hematologic and other laboratory studies, skeletal and dental x-ray surveys, biopsy, autopsy.
17. Diseases, injuries, and causes of death - as listed in the 1955 revision of the International Statistical Classification of Diseases, Injuries, and Causes of Death.

18. Age at death - in 5-year periods starting with 25 years. Those who died at ages younger than 25 years are grouped together.
19. Specific findings - bone damage (six categories as diagnosed by x-ray, varying from no damage apparent to pathologic fracture), abnormal tooth structure, sarcoma, carcinoma, leukemia, anemia.
20. Symptoms present
21. Genealogical study - a study made of at least one relative of the exposed individual.
22. Fertility - live birth, apparent sterility, stillbirth, miscarriage.
23. Radioactivity measurements - breath radon and thoron, external body gamma on radium and mesothorium series, radium and mesothorium determinations on specimens (urine, feces, bone, tooth).
24. Estimated Ra^{226} body burden -

$0.001 \leq Ra < 0.01$ (μc)	$1 \leq Ra < 5$
$0.01 \leq Ra < 0.1$	$5 \leq Ra < 15$
$0.1 \leq Ra < 0.5$	$15 \leq Ra < 50$
$1 \leq Ra < 5$	$50 \leq Ra$

25. MsTh/Ra ratio -

    <0.01 ("pure" Ra case)

    0.01 to 0.5 (initial $\frac{MsTh}{MsTh + Ra} < \frac{1}{3}$)

    0.5 to 2.0 (initial $\frac{MsTh}{MsTh + Ra}$ $\frac{1}{3}$ to $\frac{2}{3}$)

    2.0 and over ("commercial MsTh")
26. Existence of specimen
27. Existence of x-ray films

b. Data on some radium poisoning cases

During the past year a tabulation was made of some of the published cases of radium poisoning. Only those cases were included on which the information, at that time, had been completely published, and where there was good agreement among several reports made on the same patient. The literature covered American, British, and German reports.

A total of 107 cases of Ra poisoning fulfilled these criteria:

1. An estimate had been made of the body burden.
2. In most cases information on bone changes by x-ray was given.*
3. If the patient had died, the cause of death was known.
4. If the patient was living, a follow-up had been carried out within about the last five years.
5. All the information in items 1 through 4 was available in the literature.

Included in this tabulation were dial painters, injection and oral ingestion cases, chemists, physicists, and laboratory assistants. The cases were divided into three categories: those whose dose was from Ra^{226} only, those who received a mixture of Ra^{226} and other radioactive material, and a separate classification for chemists, physicists, and laboratory workers. There were 12 individuals in the classification of chemist, etc. The remainder of the cases was almost equally divided between those receiving only Ra^{226}

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* Nine cases were included in which x-ray results were unknown or where it was known that no x-rays had been taken.

and those receiving a mixture of Ra^{226}, MsTh, RdTh. A little more than half of the cases were still living.

The dose range represented by the materials was

1. Ra^{226}

Dose range (μc)	No. of cases	X-ray changes present	Sarcoma	Carcinoma
0.01 ≤ Ra < 0.1	3	0	0	0
0.1 ≤ Ra < 0.5	2	2	0	0
0.5 ≤ Ra < 1	12	9	1	0
1 ≤ Ra < 5	14*	13	2	0
5 ≤ Ra < 15	13	13	2	0
15 ≤ Ra < 50	1	1	0	0
total	45	38	5	0

* One case had no x-rays taken

2. Mixture of Ra, MsTh, RdTh

0.01 ≤ Ra < 0.1	2	0	0	0
0.1 ≤ Ra < 0.5	5*	0	0	0
0.5 ≤ Ra < 1	7**	6	3	0
1 ≤ Ra < 5	13+	10	5	2
5 ≤ Ra < 15	10++	9	5	1
15 ≤ Ra < 50	7++	6	3	0
50 ≤ Ra	6++	5	1	0
total	50	36	17	3

* Two cases had no x-rays taken

** One case had no x-rays taken

\+ One case had no x-rays taken; in one case x-ray results unknown

++ One case x-ray results unknown

The range of body burden in the chemist group was from 0.2 μc to 14 μc Ra. Eight of these individuals had died and the causes of death were given as carcinoma, aplastic anemia, myeloid leukemia, and lung fibrosis. The interval from initial exposure to death was from 10 years to 34 years, except for two cases of lung fibrosis where death occurred four and five years after first exposure.

The tumor induction time (from initial exposure to diagnosis of tumor) was

	Range	Average
Ra^{226} only	16-28 years	22 years
mixture	10-33 years	19.4 years

In the one published case of a tumor among the chemists the induction time was 11 years.

Special thanks are due to Prof. Robley D. Evans and Dr. Robert A. Dudley of M.I.T., Dr. Robert J. Hasterlik of Argonne Cancer Research Hospital, and Mr. Lester A. Barrer of N. J. State Dept. of Health for their valuable assistance in drawing up the punched card code.

(M. M. Shanahan)

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B. Low-level Studies

1. Controlled Background Facility

a. Further tests on dunite

The investigations of dunite as a shielding material for controlled background facilities (CBF) reported in our 1957 Annual Progress Report were completed. This work has included measurements on raw dunite ore and on especially prepared Forsterite bricks obtained from the Harbison-Walker Co.

As pointed out in the previous report, the 5 percent MgO additive used in the manufacture of Forsterite A bricks was suspected of contributing considerably to the contamination. Tests showed this to be the case, so five tons of bricks were made without the additive. A series of measurements were then made of the background of a 4 x 4-in. low-background NaI crystal surrounded by various thicknesses of brick up to 18 inches. Figure 1 shows the background spectrum recorded by a 256-channel analyzer for two thicknesses of dunite brick , and for comparison, an enclosure of 6 inches of lead. Curve A is the background inside the 12 inches of dunite brick, and curve B is the background inside

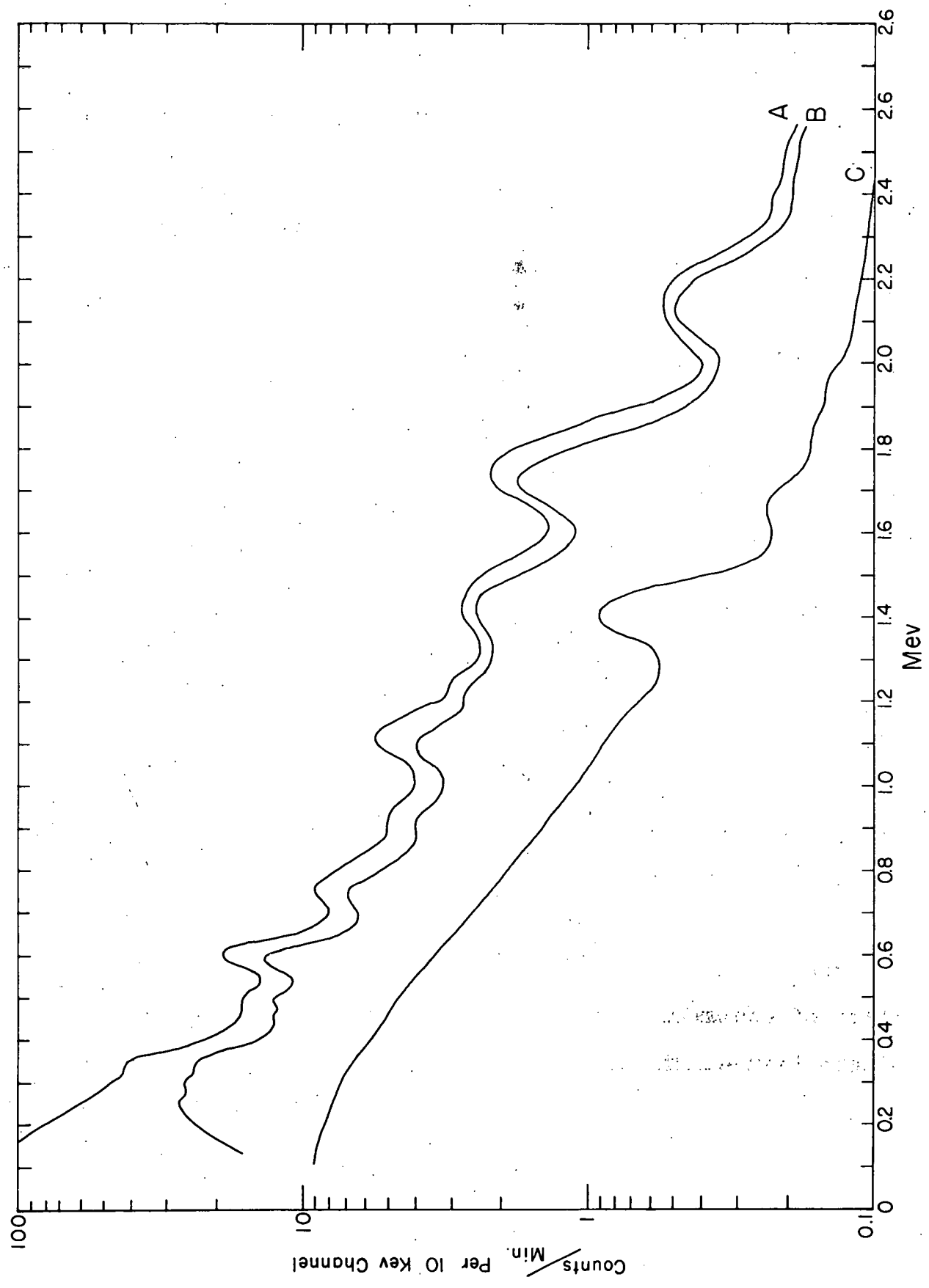

Fig. 1. Background Spectrum Recorded by 256-channel Analyzer

the 18 inches of dunite brick plus 1/8 inch of lead inside the brick. The Ra γ rays are certainly plainly visible. Curve C is the background inside 6 inches of lead and shows only the K^{40} peak which presumably arises from the phototube. A rough calculation indicates a value of $\sim 3 \times 10^{-14}$ g Ra/g brick. This value cannot be tolerated because we desire to measure low-level radium samples. The total background counting rate is about three times that obtained in good steel enclosures or good lead enclosures.

The difference in the low-energy end of curves A and B of Fig. 1 is due to a 1/8-inch lead shield around the detector in the case of curve B. This small amount of lead is very effective in reducing the low-energy background and is especially important when the principal shield is made of relatively low-Z materials.

As one last check, samples of raw dunite ore were obtained directly from the mine and measured at Los Alamos Scientific Laboratory, Argonne National Laboratory, and this laboratory; all laboratories reported results consistent with a Ra concentration of about 3×10^{-14} g/g. Thus the possibility of contamination in the processing of the brick seems to have been eliminated.

b. Interlaboratory comparisons

We are very grateful to the Radiological Physics Division of the Argonne National Laboratory for allowing us to measure the background in two of their shielded facilities with our detection system (phototube and crystal). We have thus been able to eliminate errors due to unknown contamination of the crystals and phototubes which usually make interlaboratory comparisons difficult.

The following table shows the background counting rate in various enclosures. The lead enclosure was made of new bricks borrowed from the M.I.T. reactor for this experiment.

Shield	Background (0.2-2 Mev)
6-in. lead (M.I.T.)	210 cpm
Steel room (Argonne)	293 cpm
18-in. dunite (M.I.T.)	795 cpm

All measurements with M.I.T. 4 x 4-in. crystal.

These lead bricks were from a regular production run from the Edlow Lead Co.

c. Construction plans

Plans are now complete for our CBF. It will be constructed of 5.8-inch armor plate obtained from the Navy. The interior dimensions will be 8 feet long by 5 feet wide by 6.5 feet high. The room will be constructed of six plates plus a door, the sides and roof being welded in place. The door is to be pivoted on a ball thrust bearing and it is hoped will move freely enough to be hand operated. If this proves too difficult a hydraulic mechanism will be provided.

The air in the room will be changed and conditioned to insure the comfort of the patient. Provisions will be made for using aged air when necessary. All the incoming air will pass through an absolute filter to reduce the accumulation of dust inside the room.

d. General conclusions

The detector used in such a facility will always be one of high sensitivity since weak samples are to be measured. In the case of γ rays, this means a scintillation counter. Since the background can be further reduced if the detector has good energy resolution, the use of NaI is indicated for γ-ray detection. At present, facilities can be constructed with backgrounds sufficiently small so that the detecting

system itself gives the principal contribution to the background. This is due primarily to the presence of K^{40} in the photomultiplier and also in the NaI itself. Enclosures that can provide this kind of background must be about 125 g/cm^2 thick, and the shielding material must contain less than 10^{-14} c of γ-ray activity per gram of material. Investigations have so far revealed only steel, water, and lead to have these properties. One should always examine lead with care since Argonne reports some lead seems to be quite active. In general, the activity seems to bear little relation to the age of the lead. Other substances which might possibly meet the above requirement are refined sugar and a form of talc* found in the state of Washington. Of these materials, steel with a 1/8-inch lead lining seems to be the best choice for most applications. Carefully chosen lead might give just as good results but would be much more expensive for large volume enclosures. However, its higher density might make it preferable in low-volume enclosures.

(N. C. Rasmussen, J. L. Bear,
and J. B. Bulkley)

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* Measured by Dr. R. C. McCall, General Electric Co., Richland, Washington.

2. Self-absorption in Distributed γ-ray Sources

Measurements and computations have been continued in the study of self-absorption in γ-ray sources. Measurements have been made on radium sources contained in commercial screw-top 12-ml glass vials. The detector is a copper-screen Geiger-Müller counter with 1/4-in. Al filter, plus lead filters of varying thicknesses.

As previously reported, the ratio of the intensity of radiation that reaches the counter inside the filter to the initial intensity of the source with no self-absorption is described by the semiempirical formula

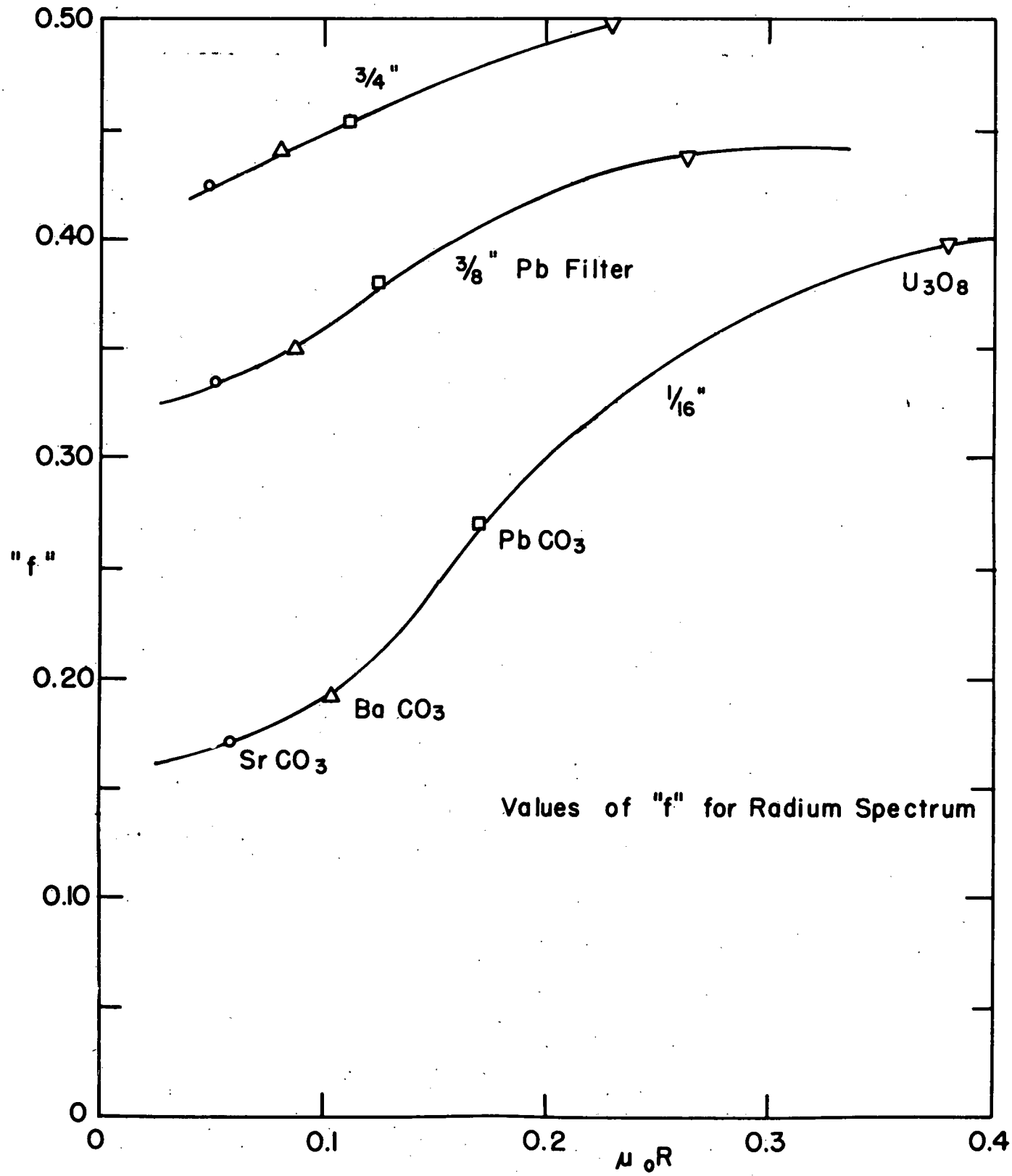
$$\frac{I}{I_o} = 1 - \frac{4+\pi}{3\pi}\mu R + \frac{8}{3}\frac{d_e\sigma_s(90^o)}{d\Omega}NRT + 0.4\mu^2R^2 + \cdots \qquad (1)$$

where R is the radius of the source, $d_e\sigma_s(90^o)/d\Omega$ is the differential Compton scattering cross section per electron at 90^o, N is the number of electrons per cubic centimeter in the source, T is the fraction of radiation scattered at 90^o which reaches the counter, and μ is the effective attenuation coefficient defined as $\mu_a + f\sigma_s$. The value of the fraction f would be zero if all the scattered radiation reached the counter. As mentioned in our 1957 Annual Progress Report, the softer scattered radiation is more strongly absorbed in the filter, so f is greater than zero.

In addition, some of the scattered radiation will be absorbed in the source material as well. For vials of the size used, this effect contributes to the value of f, especially for source material of high atomic number. So the value of f is not a constant but varies with source material as well as lead filter thickness. Graphical calculations have been performed to obtain values of f for the radium spectrum in source materials of interest for various lead filter thicknesses. Figure 2 shows the values of f obtained, plotted against the product of the radius of the 12-ml vial times the absorption coefficient for radium. The product $\mu_o R$ is a parameter related to the absorption in the vials.

Calculations using the new values of f do not give much improvement over the previously reported values. The ratio of observed self-absorption to calculated self-absorption for these radium sources was about 0.95 ± 0.05 at 1/16-in. lead filter, 1.03 ± 0.05 at 3/8-in. lead filter, and 1.20 ± 0.05 at 3/4-in. lead filter.

Finally, it must be emphasized that great care is needed in applying this formula to other situations. Many of the constants used are strongly dependent on the experimental setup used. Especially worth mentioning are: (1) Eq. (1) gives a ratio of intensities. For a copper-screen Geiger tube this is approximately a ratio of counting rates, but for a scintillation counter or ionization chamber, the



μ_o of Radium Spectrum ; R = radius of 12 ml vial

Fig. 2

counting rate is not proportional to intensity; (2) the factor 8/3 in the scattering term is experimentally determined and depends on the fact that the sample vials are about four times as tall as they are wide; (3) the values of f shown are valid only for the radium spectrum and for samples contained in the same type 12-ml vials; (4) the geometry must be such that most of the radiation leaves the source in a path perpendicular to the axis, or the path length factor will change.

(J. L. Bear)

3. Bremsstrahlung from Sr^{90}-Y^{90}

An experimental study has been started to determine the shape and absolute intensity of the continuous x-ray spectrum (bremsstrahlung) produced when the β rays of Sr^{90}-Y^{90} are stopped in various absorbers. Observations are made on a one inch collimated beam incident axially on a 1-3/4 x 2-in. NaI(Tl) crystal. The output of the crystal is observed through a photomultiplier tube and the 256-channel pulse-height analyzer.

In order to do careful studies of spectral shape and intensity, a γ-ray spectrometer such as this must be calibrated as to its response to single-energy γ rays. Resolution of

the photopeak and, in most cases, the shape and intensity of the Compton pulses has been observed for Cs^{137} (0.662 Mev), Hg^{203} (0.279 Mev), Co^{60} (1.17 and 1.33 Mev), Pr^{142} (1.6 Mev), Rb^{86} (1.08 Mev), and Ce^{144} (0.134 Mev). Observations at a few more energies are needed before a response function can be calculated.

The bremsstrahlung measurements are to be made in cylindrical-shaped absorbers. The absorbers will be thick enough to stop all the β rays. This means that some of the bremsstrahlung radiation produced will also be absorbed in the absorbers. This self-absorption must be evaluated if the bremsstrahlung spectrum is to be determined.

Tube-shaped sources of Hg^{203}, Cs^{137}, Co^{60}, and Pr^{142} have been constructed. The changes produced in the spectra from these sources have been observed when carbon, aluminum, steel, and lead absorbers have been placed inside and outside the sources. From this type of study, the spectrum produced in a cylindrical source by photons of various energies can be determined. Thus the self-absorption correction can be made. These measurements also are to be continued for a few more γ-ray energies.

With this information a response function can be calculated with a correction for self-absorption included. Then the pulse-height spectrum observed from the bremsstrahlung of

Sr^{90}-Y^{90} can be converted to the bremsstrahlung spectrum produced in the absorber.

(J. L. Bear)

4. A Low-level Ionization Chamber for Powdered Samples

Work has been completed on the method proposed in our 1956 and 1957 Annual Progress Reports to measure α activity of normal bones. The essentially background-free detector was found adequate for the measurement of gross α activity of low-level samples, but due to a lack of sufficient energy resolution, complete identification of the various radioelements by their characteristic α spectra could not be done. Nevertheless, the ThC' α ray can be identified, leading to a partial identification of most of the elements of the Th decay series.

The low background detector consists of a large ion-pulse chamber having walls made of, or coated with, the radioactive sample. The method of preparing sources suitable for coating the glass walls of the chamber has been described previously in our 1956 Annual Progress Report. The ionization pulses were amplified by a vibrating reed electrometer and recorded with an Esterline-Angus milliammeter. Pulse-height spectra have been obtained by visual measurements of

the recorded pulses for both thick and thin ThB sources. The standard deviation of the ThC' line was found to be approximately 800 kev. Therefore, the energy resolution of the detector is not sufficient to allow identification of all the radioelements from their thick source spectra. Various possible sources of noise have been investigated without success.

In studying the properties of the detector, six different samples (40 to 80 g each) containing activity at the natural level were measured. Except for one sample, analysis of Rn and Tn was not performed, and consequently, the exact source of activity is not known and can only be inferred. Nevertheless, limiting values of activity can be set under appropriate assumptions. Some of the results are given below for the measured samples.

Talc powder: Commercial talc powder (Mallinckrodt Chemical Works, New York, N. Y.) was used. From the absence of any Rn build-up over a period of 13 days, we inferred that the activity was probably due to the Th series. Assuming that the complete series is in secular equilibrium in the sample, and from the counting rate of 520 counts per hour (above a bias energy of 2 Mev) and for 1000 cm^2 of source, we calculated the specific activity as 4.6×10^{-14} c of Th per gram of talc.

Forsterite A (dunite brick): This material was investigated as a possible shielding material for our controlled

background facility. Radon analysis was done by measuring the emanated Rn of a finely powdered sample at 300°C, and indicated a minimum content of 2×10^{-14} c of Ra per gram of brick. From the gross α-activity measurement we can set an upper limit of about 7×10^{-14} c of U per gram of brick.

Pyrex glass: The activity of the uncoated glass wall of the chamber[1] was measured to investigate the possibility of contamination of the sources by Rn emanating from the glass. It was found that the counting rate increased by 17 percent (from 900 to 1053 counts per hour per 1000 cm^2 of glass) in six days. Assuming that the activity in pyrex is due to the uranium series in equilibrium, this increase in counting rate corresponds to a maximum diffusion coefficient of 0.4×10^{-12} cm^2 per sec for Rn in glass. Presumably some of the Rn build-up must be produced by radon recoiling out of the glass following the Ra decay. This build-up should be approximately equal to the ratio of the recoil range to the α range in the glass $(300\ \text{Å}/50\ \mu = 6 \times 10^{-4})^{2}$ which is much too small to account for the detected build-up. Under the same assumption that the uranium series is producing the activity, we calculated the activity as 7×10^{-13} c of U per gram of glass.

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1. Pyrex brand "double-tough" glass pipe, Corning Glass Works, Corning, New York.

2. S. Flügge and K. Zimens, Radioactivity Applied to Chemistry, ed. by A. C. Wahl and W. A. Bonner, John Wiley and Sons, Inc., New York, 1951.

Sugar: Commercial Revere powdered confectioners sugar was measured. From the chemical similarity of Ra with Ca which should promote the assimilation of Ra by plants, and from the absence of any α pulses above 6 Mev, we assumed that the Ra, Rn, RaA ... RaC series was in sugar. The specific activity would then be 1.3×10^{-14} c of Ra per gram. From an increase in counting rate with time, the emanating power of sugar on the chamber walls (the ratio of the Rn activity escaping from the source to the total Ra^{226} activity) was calculated to be about 3 percent. This low emanating power is associated with a high affinity for Rn. Indeed, it was found that more than 50 percent of the Rn introduced in the chamber was absorbed by the sugar.

Ethylenediamine-extracted normal bone: Two different samples were measured. The first was a normal human bone having a maximum of 4.3×10^{-13} c of Ra per gram. The second was a cow bone sample (from the Colorado plateau near a uranium mine). Radon and thoron analyses of this second sample showed an activity of 7.4×10^{-14} c of Rn and 8.3×10^{-14} c of Tn per gram[3]. These values are consistent with gross α-activity measurements. The emanating power of each of these two bone samples was measured in the chamber and calculated to be less than 10 percent. Once again, this low Rn emanating

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3. Annual Progress Report, Contract At(30-1)-952, May 1957, p. 49.

bone was found associated with a high absorption of Rn. The absorption was determined by evacuating and refilling the chamber with dry nitrogen gas containing about 0.3 μμc of Rn. The measured counting rate could only account for about 50 percent of the Rn, which indicates that the dry powdered sample absorbed 50 percent of the Rn in the gas. An aliquot of powdered cow bone similar to the one used in the chamber (also kept dry) was dissolved in HNO_3 and its Rn content measured immediately after dissolution and also five days later. Comparing these two values it was found that approximately 45 percent of the Rn is retained in this bone. We must therefore conclude that conditions promoting absorption and consequently low emanation are fulfilled in the chamber. This could be explained, in part, by the fact that the samples in the chamber are thoroughly dried by the repetitive evacuation and refilling of the chamber with the dry counting gas.

From these measurements we conclude that the detector is highly suited for the measurement of gross α activity of samples containing less than 10^{-12} c per gram. With proper care the source contamination should be small, and furthermore, the powdered source is still available after the measurements for any further test.

(R. A. Beique)

C. Calcium Metabolism

The Dynamics of Strontium and Calcium Metabolism and Radioelement Removal

Perfusion of the blood of dogs *in vivo* through the artificial kidney or ion exchange column was found to be an effective method for removal of calcium from the plasma.

The maximal rate of removal of calcium during the first 30 minutes was usually between 2.5 and 6 mg per minute. After this, the rate of removal was of the order of 0.5-2 mg per minute in most dogs.

The mean amount of radiostrontium and radiocalcium removed by perfusion in seven dogs, one hour after administration, was 33.9 ± 6.5 percent of the injected dose (see Table 7). The amount of the radioisotope which could be removed by the ion exchange perfusion rapidly decreased with increasing intervals between isotope administration and perfusion. The mean removal of radiostrontium and radiocalcium in nine dogs from 12 hours to 3 days after administration was only 6.5 ± 3.1 percent of the injected dose.

The Ca^{45}, Sr^{85}, and Sr^{89} data indicate that calcium is being removed from at least two hypothetical body compartments. Twelve percent of the dose was removed from the first

Table 7

Removal of Radiocalcium and Radiostrontium from Two Hypothetical Compartments Approximately One Hour After Injection

(Seven Dogs)

Dog	Isotope	Percent dose removed from compartment 1	Percent dose removed from compartments 1 and 2	Percent dose removed from compartments 1 and 2 minus percent dose removed from compartment 1	Half-time of removal from compartment 1 (minutes)	Half-time of removal from compartment 2 (hours)
ck121	Ca^{45}	12	40.7	28.7	18	8
ck124	Ca^{45}	6	32.2	26.2	15	17.5
ck130	Sr^{85}	14	32.2	18.2	20	13
ck131	Sr^{85}	20	31.1	11.1	20	7
ck132	Ca^{45}	9.5	22.5	13.1	35	20
ck134	Sr^{85}	13	40.0	27.0	15	7
ck135	Sr^{85}	10	39.0	29.0	20	7
Mean		12 $\pm$ 4.8*	33.9 $\pm$ 6.5	21.9 $\pm$ 7.6	20 $\pm$ 6.8	11 $\pm$ 5.6

* Standard deviation of the mean.

compartment with a half-time of 20 minutes. The remainder of the injected dose removed came from a hypothetical compartment with a half-time of removal of 11 hours.

The removal of Sr^{85} following parathyroid hormone administration was studied in dog ck137. Twelve hours prior to removal the dog was injected with Sr^{85} and 2000 units of parathyroid hormone extract. The total removal of Sr^{85} was 2.5 percent, which is in the lower range of the removal compared to the other dogs in which parathyroid hormone was not injected.

Excretion studies were carried out on four dogs (ck127, ck131, ck132, ck138) in which two isotopes of strontium (Sr^{85} and Sr^{89}) and one of calcium (Ca^{45}) were injected intravenously. One or more of the isotopes were injected either 12 or 24 hours or 3 days prior to the removal period. One isotope was injected one hour prior to the removal period. Since only 2-9 percent of the isotope injected 3 days prior was removed during the 4- to 6-hour period of removal, these dogs acted as their own controls for the excretion studies. Renal clearance studies were made before, during, and after the period of removal.

One of the major questions concerning the removal of radiocalcium and radiostrontium by the ion exchange column was the question of alteration of the normal elimination of the radioisotope in the excreta. The practical value of the

radioelement removal in man will depend to a large extent upon the removal of a significant fraction of the radioelement by the artificial kidney and ion exchange column which would normally not be eliminated in the excreta. Results from excretion studies in four dogs over a 7- to 10-day period have shown that radioisotopes removed by the ion exchange column would have been eliminated eventually in the excreta. This is illustrated by the results of the study on dog ck127 (see Fig. 3). During the 3-day period before connecting the dog to the ion exchange column, about 45 percent of the injected dose of Sr^{89} had been excreted, and only 1.9 percent was removed by the ion exchange column. Thirty percent of the Sr^{85} injected 69 minutes before the dog was connected to the ion exchange column was removed. However, the total amount of both Sr^{85} and Sr^{89} remaining in the dog at the end of the experiment was approximately the same.

There was wide fluctuation in the ratio between clearance of Ca^{40} and clearance of Ca^{45}. The renal clearance of Ca^{45} was less than the clearance of Ca^{40} in two dogs. The most unexpected finding was the marked reduction in the renal clearance of radiostrontium compared to Ca^{40} and Ca^{45}. The reduction in radiostrontium clearance was by a factor of 20 to 30, while the reduction in Ca^{40} and Ca^{45} clearance was usually by a factor of about 5. During the period of perfusion

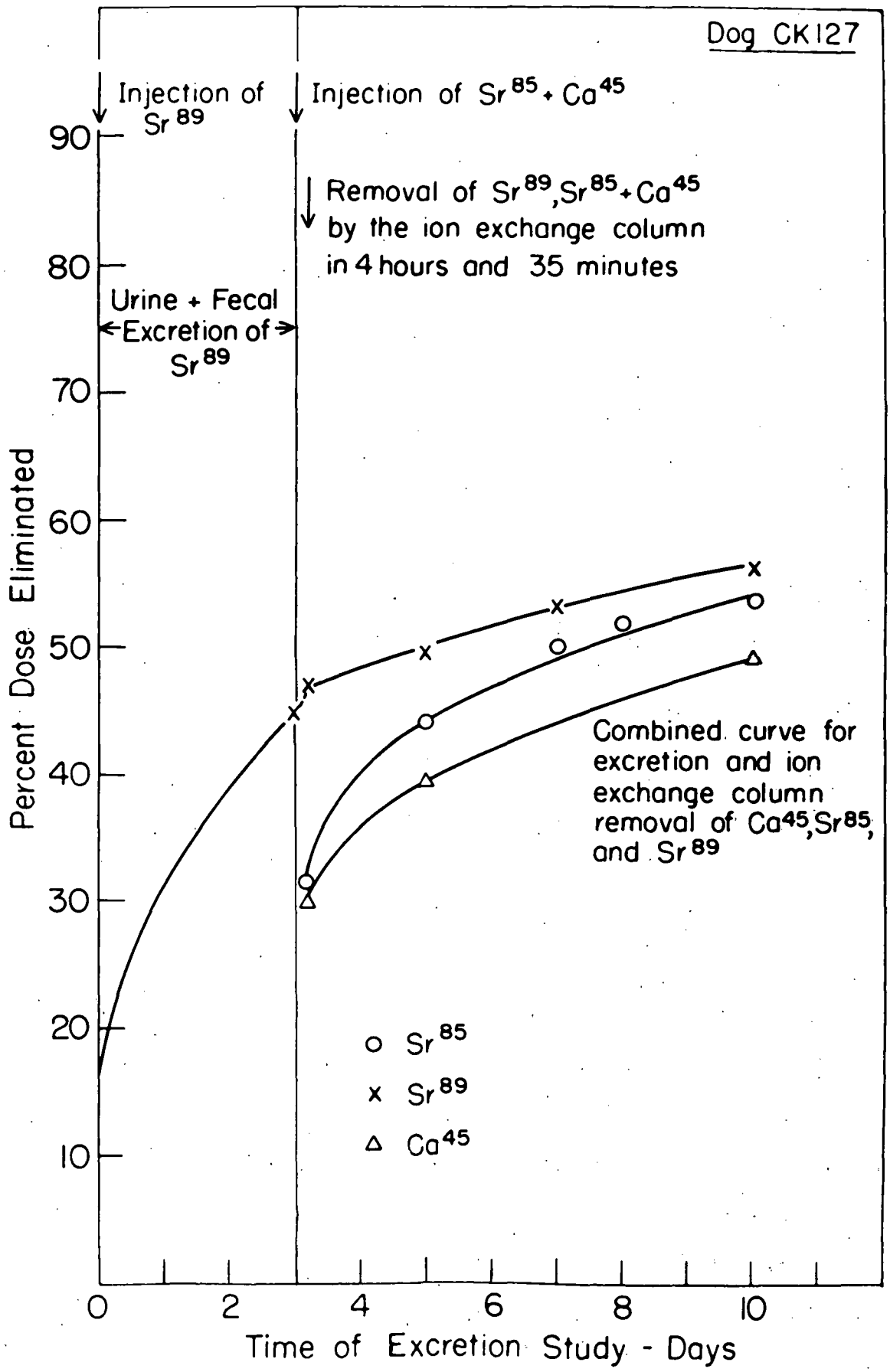
Dog CK127
Injection of Sr 89
Injection of Sr 85 + Ca 45
Removal of Sr 89, Sr 85 + Ca 45 by the ion exchange column in 4 hours and 35 minutes
Urine + Fecal Excretion of Sr 89
Combined curve for excretion and ion exchange column removal of Ca 45, Sr 85, and Sr 89
o Sr 85
x Sr 89
Δ Ca 45
Percent Dose Eliminated
90
80
70
60
50
40
30
20
10
0
2
4
6
8
10
Time of Excretion Study - Days

Fig. 3

the serum calcium level is depressed so the relative renal clearance of strontium vs. that of calcium might not be a true measure of relative reabsorption of strontium and calcium when the serum calcium level was normal.

The changes in the renal clearance of Na, K, P, Ca^{40}, Ca^{45}, Sr^{85}, and Sr^{89} have given results which warrant further study. There was, in general, a reduction in renal clearance of both stable and radioactive cations during the period of removal.

Publication of this work will follow in the near future. In addition, it will be presented at the Geneva Conference.

This project has been completed in collaboration with the Kidney Laboratory at the Peter Bent Brigham Hospital and the John Collins Warren Laboratories of the Huntington Memorial Hospital of Harvard University, Massachusetts General Hospital, Boston, Massachusetts.

(W. B. Looney, C. J. Maletskos, J. Cohen,
F. I. Visalli, W. Guild)

D. Nuclear Data

The Half-period of Th^{232}

The gridded plane parallel plate ion chamber described in previous reports has been redesigned to operate with the electron-collecting electrode at ground potential, and the sample at negative high voltage. The grid has been rebuilt, and consists of 0.006-in. tungsten wires spaced at 1/8-in. intervals. The chamber is operated with the source at -3000 volts and the grid at -1500 volts. The signal-to-noise ratio has been improved, and the Th^{232} α-particle peak from 2π sources now has a full width at half maximum of about 80 kev, including the 25 percent abundant fine-structure peak at 3.93 Mev and the 75 percent abundant peak at 3.98 Mev. The low-energy α decays are subsequently followed in most cases by conversion electrons, about half of which are captured in the ion chamber, thus shifting the lower energy peak toward the higher one. The two peaks cannot be resolved.

It has been observed using a 10 percent methane-90 percent argon counting gas that the pulse-height spectrum is linear with an intercept of about -250 kev. This effect has not been observed by workers using highly purified argon, and indicates that at low energies approximately 250 kev of

α-particle energy is lost in exciting molecular states in the methane molecules.

The apparatus is considered satisfactory in all respects in order to make the measurements for the half-period. New sources must be prepared by evaporation for the measurement, and it has been decided to evaporate ThF_4 as well as thorium metal. ThF_4 melts at 1100°C, a conveniently low temperature, and the thorium weight on the sample can perhaps be determined by weighing the sample disc before and after the evaporation. ThF_4 is evidently stable even at relatively high temperatures. Since the total weight of thorium will be about 1 mg, a microbalance must be used to obtain the weight; but this technique, if successful, will circumvent a difficult chemical thorium determination.

When a spectrum has been obtained from the new sources, a small (less than 2 percent) theoretical correction to the peak intensity for backscattering and source absorption will be made, and the half-period calculated.

It is hoped that this work can be completed by the end of the summer.

(T. A. Farley)

E. Dosimetry and Instrumentation Techniques

1. Fast Neutron Dosimeter

A neutron detector was described in our 1957 annual report which is expected to have a response to absorbed energy which is proportional to tissue dose. Based on the Bragg-Gray cavity principle, the detector employs a thin monogranular layer of zinc sulfide scintillator as the cavity, sandwiched between two plexiglas slabs. The detector is viewed by a photomultiplier tube. The neutron dose to the cavity (rads) is determined by adding the number of pulses multiplied by their pulse height and applying several correction factors which are to be discussed. The instrumentation associated with the readout of this quantity, dose, is discussed in another section of this report.

An experiment was proposed[1] in which this detector was to be used with monoenergetic neutrons for the following reasons:

1. Calculation of absorbed dose depends on accurate conversion of the output pulses of the electronic system (in volts) to their equivalent energy in electron volts, which

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1. E. Tochilin, S. W. Ross, B. W. Shumway, G. D. Kohler, and R. Golden, Radiation Res. 4, 158 (1956).

allows a direct conversion to the unit of dose, the rad. A very approximate calculation of the expected pulse-height spectrum from monoenergetic neutrons suggested that there might be some pronounced structure to this spectrum which, if observed, could provide a reference back to the theory, where the energy scale is known.

2. Calculations of the first collision dose to tissue (as well as plexiglas) as a function of neutron energy have been made[1]. The results of these measurements at several different energies may be compared with this theory.

At the suggestion of Professor R. D. Evans and with the cooperation and help of Dr. W. L. Langham and Dr. J. A. Sayeg of the Health Physics Division at Los Alamos Scientific Laboratory, arrangements were made to use the facilities of that laboratory to obtain monoenergetic neutrons. The author wishes to express his sincere appreciation to these gentlemen for making these measurements possible.

Runs at 4, 6, and 8 Mev were attempted using the (d,d) reaction at the large (10 Mev) Van de Graaff generator. Electronic difficulties largely invalidated this work. Measurements were made with 2.5- and 14-Mev neutrons at the Cockroft-Walton machine. The neutron flux at this machine is considered well known. Two single-layer detectors were used at

these energies, one having a diameter of 2 in. using a 6342 photomultiplier tube, and the other with a diameter of 5 in. using a 6364 photomultiplier tube. The 2-in. detector was used, as well as the 5-in. detector, to prevent the possibility that photocathode nonuniformity in the 5-in. phototube might cause poor resolution.

The pulse-height spectra obtained at these energies did show some structure, that is, some peaks and breaks, but not of the form which was expected. At 2.5 Mev, the spectra from both detectors showed a large double peak at the high-energy end of the spectrum which was several times larger than the distribution at intermediate energies. A single large peak (due to proton recoils in the forward direction) was expected with several smaller peaks on the high-energy tail of the large peak, but in general the observed spectra bore little resemblance to the calculated spectrum. This large double peak did not appear as pronounced at 14 Mev; however, two smaller peaks at very nearly the same energy indicated the phenomenon producing these peaks was still present. The complete interpretation of this spectrum is not fully understood; consequently, the conversion from volts to electron volts and calibration of the energy scale using this information cannot be relied upon.

If, however, an estimate of this energy conversion and calibration is made such that 300 kev (approximately the

energy lost by a recoil proton traversing 10 μ of ZnS with a specific ionization[2], dT/dS, corresponding to the flat portion of the Bragg curve) lies at about 30 volts on a 0- to 100-volt scale of the pulse-height spectrum, a calculation of the dose at these energies can be made. With this assumption, the large double peaks in the 2.5-Mev runs appear at about 650 kev, representing, possibly, the energy lost by a recoil proton traversing 20 μ of ZnS with a somewhat larger specific ionization.

Corrections to the calculation of dose necessary with this detector are:

1. The cavity is ZnS and is not tissue-equivalent. The energy lost in the ZnS is proportional to the specific ionization of ZnS, whereas if the cavity were tissue the energy loss would be proportional to the specific ionization in tissue. The ratio of the average specific ionization in ZnS (averaged over energy) to that of tissue is about 1.75. The measured dose is thus reduced by this factor.

2. Dose measurements in rads represent energy lost (ergs) per gram of the cavity. The density of ZnS is 4.1 g/cc and that of plexiglas is 1.18 g/cc. If this cavity were plexiglas of the same volume, the energy lost as corrected by the specific ionization factor would contribute to a larger dose since the mass of the cavity is less by a factor of about 3.5. The measured dose is thus enhanced by this factor.

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2. M. Rich and R. Madey, UCRL 2301 (1954).

3. Zinc sulfide is somewhat absorbent to its own light and a mono-granular screen can be called, at best, translucent. Therefore, some scintillations from the ZnS can be either reabsorbed in the ZnS or trapped in the plexiglas and eventually lost to the photomultiplier. Some light pulses will be seen that have been considerably degraded in intensity, and contribute erroneous pulses to the low-energy region. To correct for these losses, one can compare the total number of counts observed, N_o, to the number, N', that should have been counted and may be calculated. If it is assumed that it is just as likely for a large light pulse as it is for a small light pulse to be lost to the photomultiplier, the observed dose will be increased by the factor N'/N_o. To calculate the number of pulses that should have been counted, the detection efficiency, one needs only to make the approximation based on the range-energy relations that the range of a recoil proton, R_p, can be written

$$R_p = KE_p^n$$

where K and n are empirical factors determined from proton ranges in plexiglas in the Mev region of energy. An integration over the angular distribution of proton recoils may be carried out, and one finds

$$N' = L\sigma(E)A\varphi\,\xi\,\eta R_{p_o}$$

where

L = number of hydrogen atoms/cc

$\sigma(E)$ = n-p elastic scattering cross section ~ the total cross section of hydrogen

A = area of ZnS layer or screen

ξ = detection efficiency for ZnS to be put equal to one

η = 0.314 for K and n as chosen to fit the range-energy relation

R_{p_o} = range of proton recoils in the forward direction carrying the full neutron energy

φ = neutron flux

so that

$$N' = L\sigma\varphi A(0.314)R_{p_o}$$

It is seen that about one-third of the protons originating from the volume adjacent to the ZnS layer of area A and thickness R_{p_o} will be counted. Note that this correction factor is energy-dependent through the scattering cross section $\sigma(E)$.

With these considerations, the dose per flux (rads/10^9 n per cm^2) at 2.5 and 14 Mev are computed and compared with the theoretical calculation for both tissue[2] and plexiglas. The

results are tabulated below:

Neutron energy	Observed dose (rad/10^9 n/cm^2)	Calculated dose in plexiglas (rad/10^9 n/cm^2)	Calculated dose in tissue (rad/10^9 n/cm^2)
2.5 Mev	0.98	2.75	3.25
14 Mev	2.4	5.5	6.1

The observed values of dose are considered accurate to about 25 percent if the energy scale calibration of the pulse-height spectrum is not completely erroneous and is assigned an (arbitrary) error of 10 percent. The calculated or theoretical values are considered accurate to 5 percent, the errors attributed to the measurement of cross sections used in these calculations.

The discrepancies between observed and calculated neutron dose shown in the above table are about a factor of three and may be attributed to several phenomena not yet fully analyzed. First, the calibration of the energy scale in electron volts cannot be considered to be any more than a judicious estimate. Herein can be perhaps as much as a factor of two of error. Secondly, the correction for counting efficiency of the detector does not include the cases where only a portion of the light pulse from the ZnS is not detected. The high-energy end of the spectrum is thus degraded in a manner that is not taken into account by the counter efficiency correction. Perhaps another

factor of two in the value of dose can arise from this effect. Another source of error may lie in the assumption that the detection efficiency of ZnS is one, or that every recoil proton will produce a light pulse (of some magnitude) while traversing the ZnS cavity.

An experiment which may provide information about the first and second of the above factors of error is being considered. A bare mono-granular layer of ZnS covered, not by plexiglas but by a thin aluminum film, might be bombarded with protons of a few Mev. The resulting spectrum should be very nearly a line corresponding to the specific ionization in the flat portion of the Bragg curve times the thickness of the layer. The spread of this line may yield an estimate of the energy degradation of the pulse-height spectrum by light absorption in the ZnS. The position of this line in volts may enable at least one point on the volts-to-electron-volts conversion to be found.

Another phase of this work involves the development of the "γ-ray analog" of this detector. It may be noted that the energy spectrum of recoil electrons of γ rays from Compton interactions bears some similarity to the recoil proton spectrum from neutron-proton elastic scattering. The path length of these recoil electrons may be considered, on the average, to be directed on a straight line, as are the recoil protons. The cavity principle may be applied to a scintillation detector

if the dimensions of the cavity are small compared with the range of the recoils in the absorbing medium. To produce primarily only the Compton interaction, one needs only a low-Z material such as plexiglas which is, for these purposes, tissue-equivalent. The cavity material is a thin (4 mils) sheet of Pilot B plastic scintillator. This detector has been constructed for the following reason: measurements of γ-ray dose using a similar geometry to the neutron detector should provide a cross check on the methods and calculations used with the neutron counter. The energy scale may be more accurately calibrated by using a thick plastic scintillator such that the Compton electrons are completely absorbed. The calibration can then be determined by measuring the position of the Compton edge of γ rays at several energies. It is also true that sources of monoenergetic γ rays are more easily found than sources of monoenergetic neutrons. The main difficulty with this detector lies in the fact that for plastic scintillator cavities obeying the Bragg-Gray cavity principle, the thickness must necessarily be very thin, permitting very little energy loss in the cavity. The light output of plastic scintillators is relatively weak so that one is faced with the problem of making a very low-energy measurement. It has been considered that the detector should be able to resolve pulses corresponding to energy losses in the plastic down to about

20 kev. The 38-kev Compton edge of the Co^{57} 123-kev γ ray has been resolved. Many problems involving noise and amplifier gains, etc., have been alleviated by two detection procedures:

1. The use of a high gain, 14-stage, 6810 photomultiplier tube. With a high voltage of 2650 volts, pulses of about 50 volts, corresponding to 100-kev energy loss in the plastic, may be obtained directly from the preamplifier. No further amplifier is necessary; consequently, amplifier noise is eliminated.

2. The photomultiplier is cooled by contact with copper coils carrying a mixture of dry ice and acetone. Cooling the tube reduces random emission from the photocathode, thus reducing low-energy noise by perhaps as much as a factor of five.

Work is continuing on this counter. With the accurate calibration of the energy scale possible in this instance and with the advantage of standard γ-ray sources, the procedures of relating the measured and theoretical doses tc the detector should undergo a serious appraisal.

(H. W. Kraner)

2. Neutron Dosimetry Instrumentation

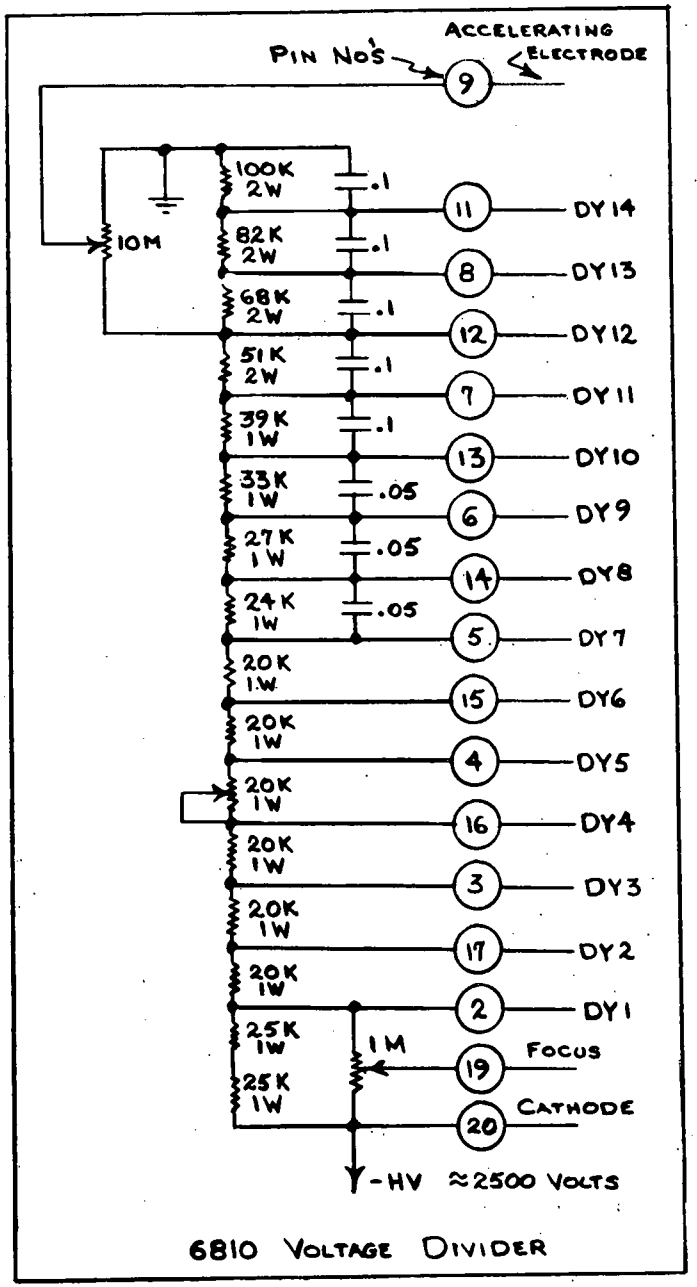
Part I

Measurement of energy loss down to about 20 kev in a plastic scintillator requires a high gain, low noise system. The RCA 6810 14-dynode photomultiplier tube was investigated for this application.

A single-stage capacitive feedback amplifier was designed to replace the usual cathode follower preamplifier and pulse amplifier combination. Adequate gain was obtained with this arrangement so that a pulse amplifier as such was not required.

The complete circuit diagram is shown in Fig. 4. The 6AH6 pentode was chosen because of its relatively low output capacity and high transconductance. The first cathode follower provides a low impedance source of feedback voltage. The second cathode follower, although not necessary to derive a low impedance output signal, is used to isolate the external load from the feedback network. The amplifier output voltage, as a function of charge Q developed at the photomultiplier anode, may be shown to be

$$e_o = - \left(\frac{A}{1 + A}\right)\left[\frac{Q}{(C_s/1 + A) + C_f}\right]$$



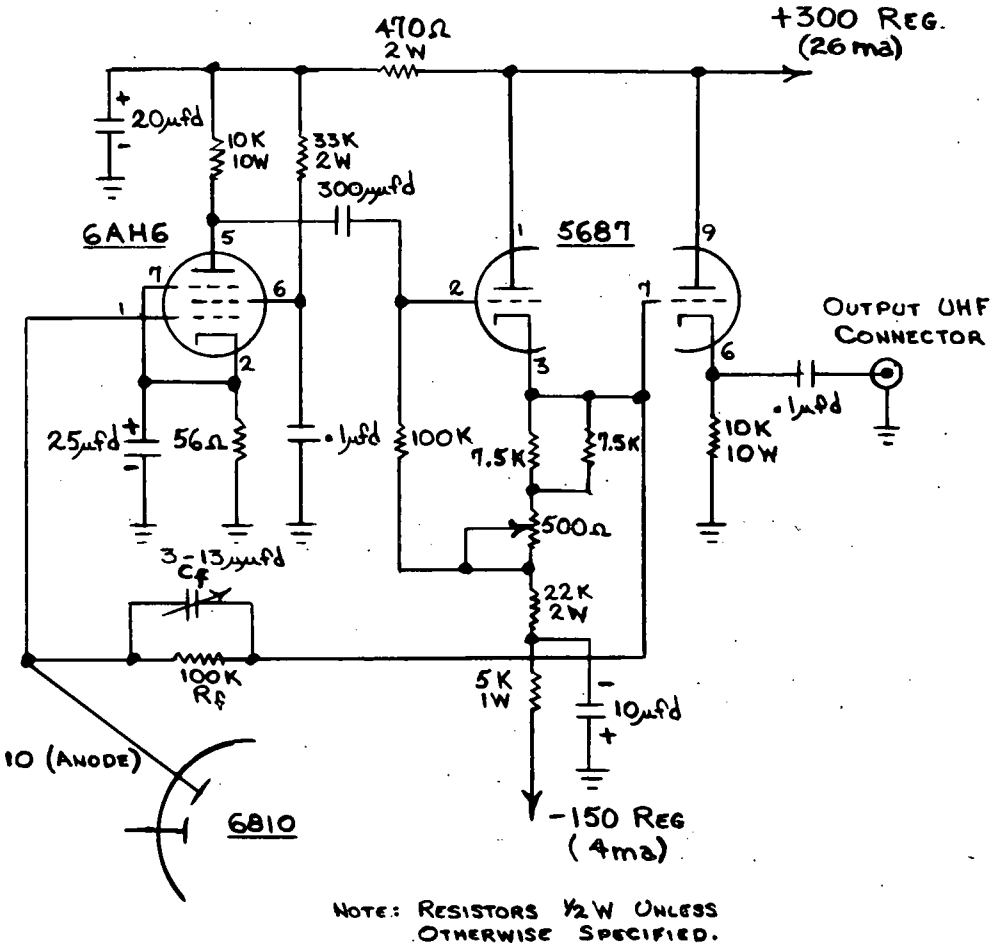


Fig. 4. Amplifier and Dynode Voltage Divider for RCA 6810 Photomultiplier

where A = unfedback amplifier gain

C_s = sum of all shunt capacities to ground at the amplifier input ($\sim$15 $\mu\mu$f)

C_f = series capacity in feedback loop ($\sim$3 $\mu\mu$f)

Since A is large (>100) and therefore $(C_s/1+A)$ is small compared to C_f, this expression reduces, with good approximation, to

$$e_o = - \frac{Q}{C_f}$$

Thus, the output pulse rise time and pulse height is determined principally by the capacity C_f which may be adjusted to a value several times smaller than C_s. Rise time is decreased and pulse height is increased by the same factor (5 or more) that the effective capacity (charged by Q) is reduced. The feedback resistor R_f controls the pulse decay time constant and may be adjusted to provide a pulse decay time over the range of about 1-15 μsec. The 100K resistor shown sets the decay time to about 1.5 μsec. The value chosen for R_f must be large compared to the cathode follower output impedance (about 200 ohms), and small compared to the amplifier input shunt resistance (very high leakage resistance in this case).

This effective amplifier gain of about 5 combined with the maximum gain of the 6810 photomultiplier (high voltage

set at about 2600 volts) provides an over-all gain of approximately 10^8. Output pulses from a 5-kev Fe^{55} x-ray source, for example, are easily seen on an oscilloscope connected to the amplifier output. This x-ray cannot be resolved, however, since the 5-kev line appears to be down in the two, three, or four electron pulse (originating at the photocathode) range where the lower edge of normal pulse-height distribution is cut off. Sources in the 10-30-kev range are not available to determine the lower energy resolution of this system. With the plastic scintillator used (Pilot B), the 38-kev Compton edge of the 123-kev γ ray from Co^{57} has been clearly identified.*

Linearity is good up to about 200 kev, the range of interest, which is adjusted to correspond to an output pulse-height range of from 0 to about 60 volts. Overload properties are excellent, overload occurring at a pulse height of about 150 volts with negligible undershoot.

Further work is scheduled with this RCA 6810 and the newly marketed 6810-A (curved photocathode in flat-faced envelope) photomultiplier with similar amplifier circuitry for possible use in other spectroscopy applications.

(R. A. Beique** and J. F. Frazer)

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* See Fast Neutron Dosimeter, H. W. Kraner, this report.

** Now at the Montreal General Hospital, Montreal, Canada.

Neutron Dosimetry Instrumentation

Part II

A Vorate meter (voltage times counting rate) is in the process of design at the present time. This instrument is to be used to measure the output of a neutron detector in rads. This instrument measures the time average of the sum of the number of pulses times the voltage of each pulse, and thus integrates the area under the pulses. A circuit is being designed that will convert the output pulses from a scintillation counter into a constant width pulse whose height is proportional to the height of the input pulse. This pulse is then used to drive a counting-rate-meter circuit to derive a dc output voltage measured with a vacuum-tube voltmeter. This may then be calibrated in units of counting rate times energy.

With reference to the block diagram of Fig. 5, the circuit operates as follows: incoming pulses from the output of an amplifier are simultaneously fed to a cathode follower and a discriminator. Pulses which do not trigger the discriminator pass through to the pulse stretcher which is disabled, since the discharge diode which is normally conducting shunts these pulses to ground through the low impedance of the cathode follower. When the discriminator is triggered,

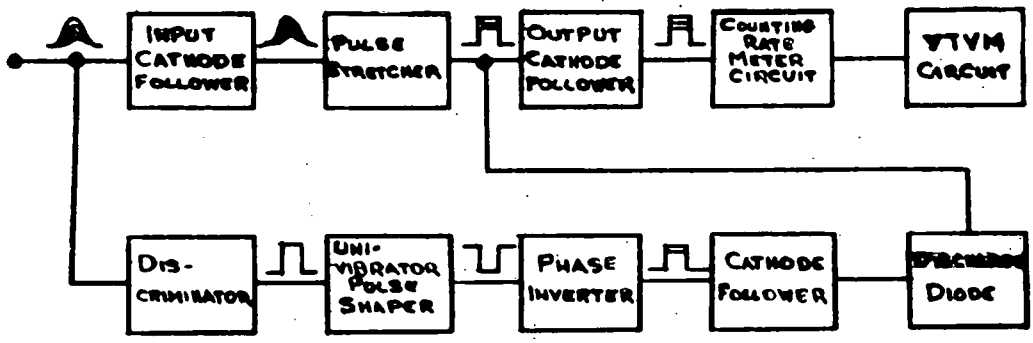


Fig. 5. Vorate Meter Block Diagram

a constant width pulse from the univibrator, with amplitude greater than the maximum input pulse, passes through the phase inverter and opens the discharge diode, thus allowing an incoming pulse to be stretched. When the diode closes again at the end of the univibrator pulse, the pulse stretcher is discharged. The output pulse is therefore of constant width and its pulse height is proportional to the input pulse height. This output pulse is then fed into a standard counting-rate-meter circuit and vacuum-tube voltmeter.

Some difficulty has been experienced with pulse feed through at pulse heights below the discriminator triggering level. This problem will be solved with some form of input gating proportional to discriminator level setting.

(J. F. Frazer and J. P. Morris)

3. Multichannel Analyzer

Since the last Annual Progress Report (May 1957) work has continued on improving the design and simplifying the electronics of the multichannel analyzer. Nearly all of the necessary circuitry is now in operation.

The major design changes include the following:

1. The preliminary storage circuitry, built around a dual-beam oscilloscope, has been redesigned for further

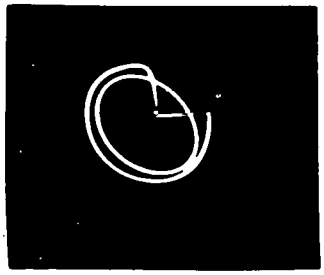
simplicity and improved foil output. In particular, the modulation of the one-shot circular sweep has been completely redesigned.

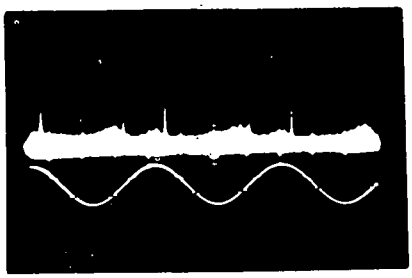
2. The sawtooth sweep of the television-type raster in the permanent electrostatic storage has been replaced by a staircase waveform to reduce jitter.

3. A dual-clock arrangement has replaced the originally proposed single pulse train clock. The use of two synchronized pulse trains in the clock has simplified the binary adder and other periphery circuitry of the permanent storage system.

These design changes do not affect the basic premise of using electrostatic storage to perform pulse-height discrimination. Pulse-height-to-time conversion is accomplished in the front-end circuitry. Time is then converted to angular position on a one-shot circular trace on the face of the dual-beam cathode-ray tube. We have abandoned the idea of modulating the one-shot circular trace with a spike extending from a point on the circumference of the trace toward its center. This proved difficult to realize circuitwise, and left no room to adjust dwell time of the writing beam for optimum signal-to-noise ratio at the foil output. Present circuitry causes the comparator output pulse (a square pulse with its leading edge occurring at a time t, elapsed from the start of the one-shot circular trace, which time is

proportional to pulse height) to collapse both the sine and cosine waveforms to their respective base lines with an adjustable time constant of the order of 1 or 2 μsec. The collapse thus occurs at an angular position on the sweep proportional to input pulse height. The resulting trace resembles the outline of a piece of pie or a pie with one or more pieces removed depending on the height of the input pulse. The oscilloscope photographs in Fig. 6 indicate this relationship. The pie-shaped trace in Fig. 6A shows the result of the writing beam storing a 70-volt pulse derived from a pulse generator. Time starts at the center of the trace and runs counterclockwise. The collapse occurs about three-fourths of the way around the one-shot circular sweep. Total time for this sweep, including the collapse time, is about 38 μsec. The repetition rate of the 70-volt input pulse was made approximately equal to the reciprocal of the period of the reading beam trace which appears as an ellipsoid inside the one-shot trace. Figure 6B shows the resulting foil output together with the sine component of the circular (ellipsoid shown) reading trace. Time proceeds from right to left. The foil output representing detection of the temporarily stored 70-volt input pulse is the large positive blip appearing once each cycle of the reading trace. The signal-to-noise ratio here is better than 2 to 1. It is expected that this may be further improved through the use





5v/cm.

3200 usec. period

Fig. 6

A. Reading and Writing Sweeps B. Foil Output Signal

of a band-pass rather than a wide-band foil signal amplifier. For the purpose of detecting a usable foil output signal, no effort was made to improve the ellipsoid reading trace to a true circle. This will have to be done at a later stage.

A circuit diagram of the analyzer writing circuitry is shown in Fig. 7 , and is complete with the exception of an input gate which must be added to prevent input pulses from altering the pulse stretcher output during pulse writing time. This gate will be constant in time width and will be equal to about 50 μsec or the period of the one-shot sweep. At first glance this would indicate a fixed resolving time of 50 μsec. This is approximate, but not strictly true. A discussion of the statistics involved here is in App. 2 at the end of this report. The circuit diagram closely follows the block diagram shown in the last report. The circuits are designed to accommodate a spectrum from about 0-100 volts. However, it is possible to use all 100 channels over any continuous range of the spectrum. The baseline is set by adjusting the dc level control on the sweep generator (P3). The comparator will not function and no angular modulation will exist unless the stretched input pulse exceeds the dc level of the baseline control. Once the baseline pulse height is established, the upper limit of pulse height analyzed may be set by adjusting the sweep amplitude. Any pulse exceeding this upper height limit will also fail to operate the

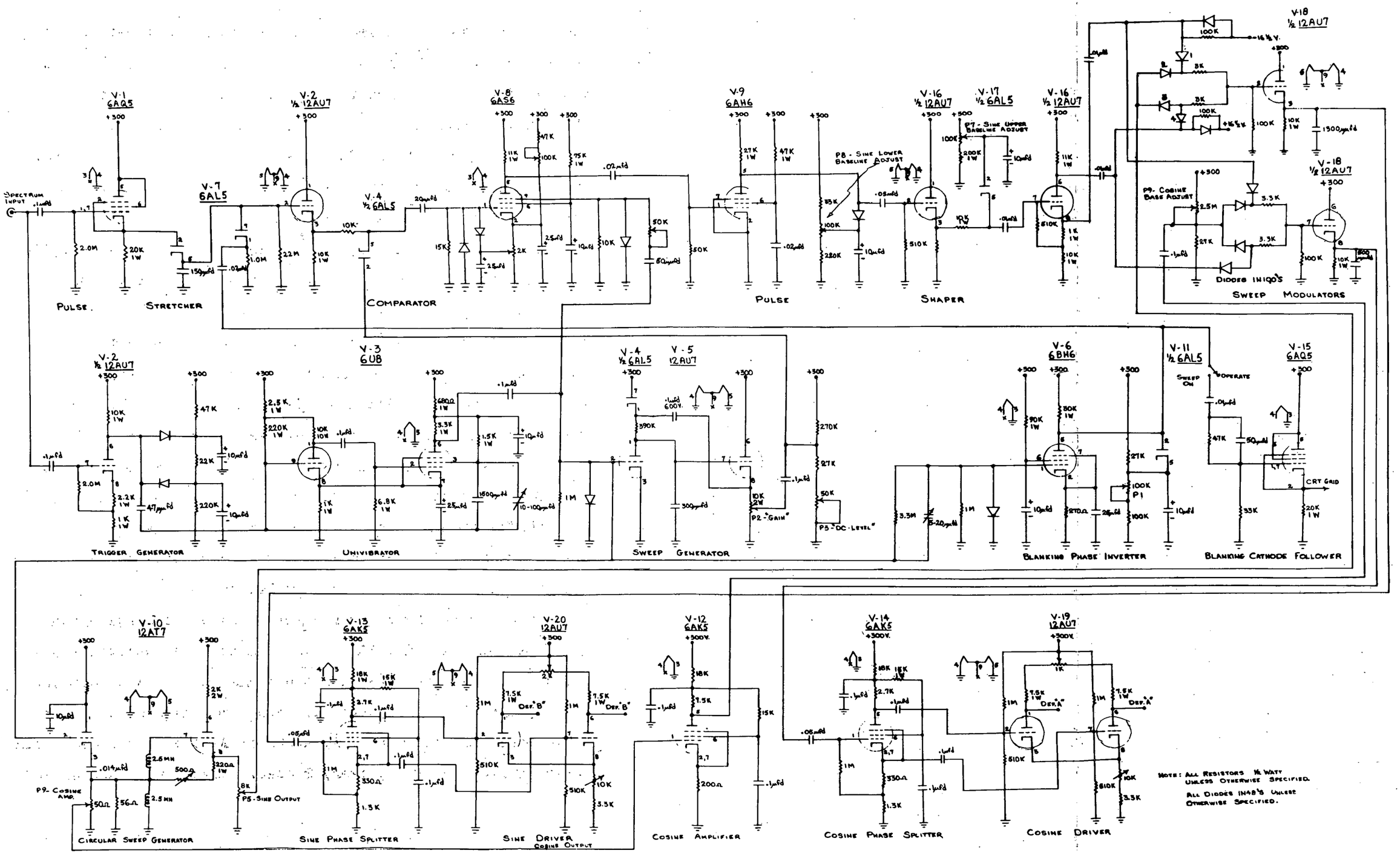


Fig. 7. Analyzer Writing Circuitry

comparator. For small sweep heights it may be necessary to adjust the threshold level of the trigger shaper (P5). The front-end circuitry also includes provision for adjusting the writing beam current by controlling the height of the Z-axis modulator pulse. It is necessary to adjust this beam current for optimum signal from the foil and for proper erasure as the information is read out.

The writing circuitry also contains the necessary amplification to drive the deflection plates of the dual-beam scope directly. The reading and writing circuitry consists of about 22 tube envelopes, of which the 18-tube writing circuitry is shown in the schematic. The reading sweep (not shown) is generated with a simple Wein-Bridge oscillator driven by the synchronizing pulse derived from the clock. All of the writing circuitry of the analyzer is in operation.

Some debugging is necessary first to prevent the baseline shifts with random inputs currently experienced, and second, to provide finer adjustments for removal of the slight eccentricity of the one-shot circular trace.

Much of the circuitry for the permanent storage system is completed. A 3-in. RCA 6571 computer electrostatic storage cathode-ray tube provides the permanent storage surface. A 1-megacycle crystal-controlled clock has been constructed to generate two pulse trains, each consisting of 0.5-μsec-wide square pulses occurring every 2 μsec. These pulse trains are

of opposite polarity, and one is delayed from the other by one pulse width. This form of clock has permitted simplification of the binary adder circuitry and the design of the reading and foil pick-off circuitry to provide the "add-one" pulse at the proper time for permanent storage. A circuit diagram of the binary adder is shown in Fig. 8. The clock pulse inputs are indicated with their proper phase relationship, together with the inputs derived from the permanent storage foil and the "add-one" address from the temporary storage system. The output drives the Z-axis (intensity modulation) of the cathode-ray tube through an appropriate driver circuit. This Z-axis driver has not yet been built, nor has the circuitry for reading and pick-off from temporary storage been finalized in design. The binary adder has been checked out with the clock inputs as indicated and with a laboratory pulse generator providing the other inputs. Transistors are used here because they lend themselves so well to this switching application in a digital circuit. Batteries are presently used to power the transistors, but they will probably be replaced by an appropriate low voltage power supply in the final design.

The operation of the binary adder satisfies, in all respects, the demands of the block diagram shown as Fig. 9 on page 80 of our 1957 annual report. The reader is referred to this diagram and the discussion with it for details of the

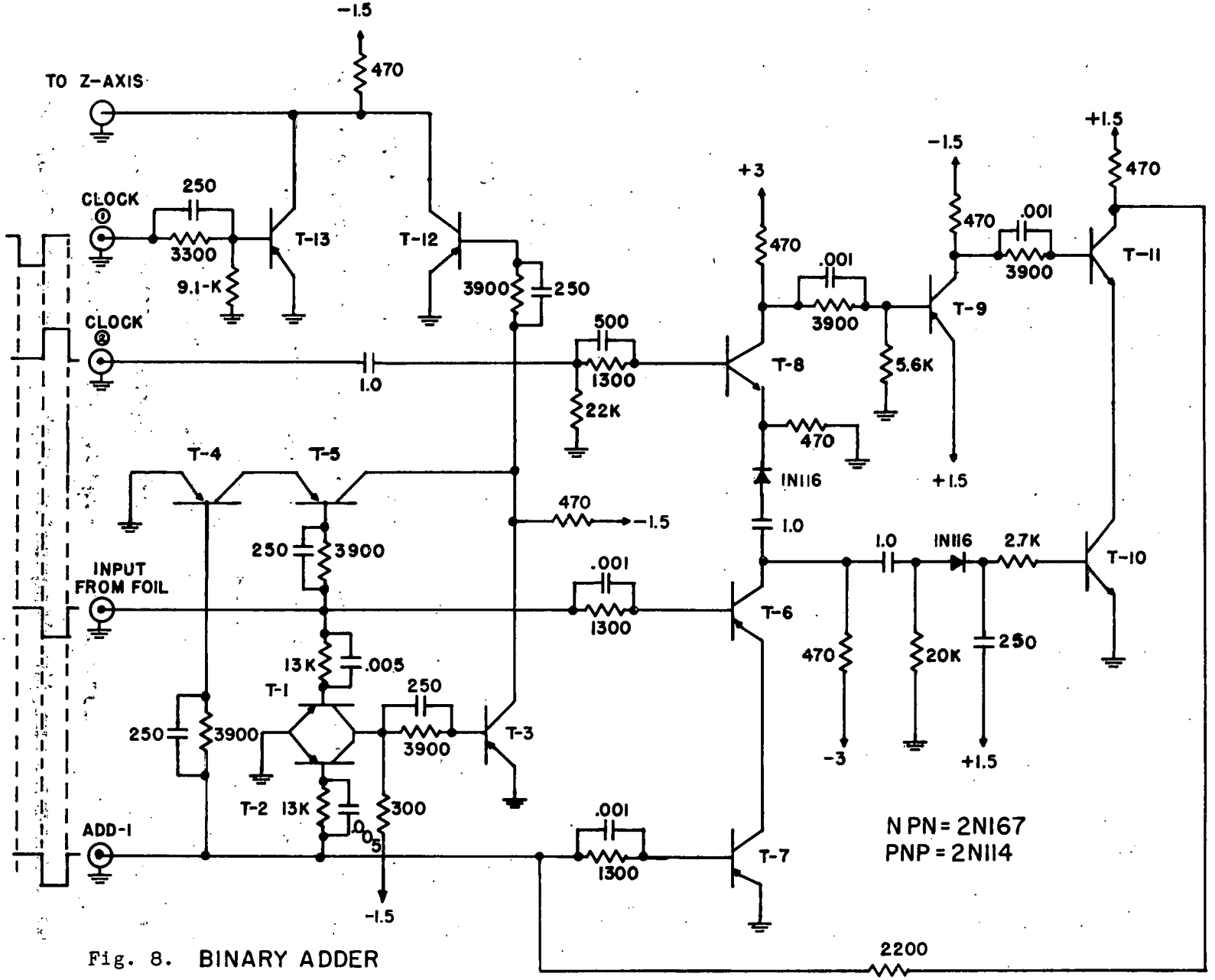


Fig. 8. BINARY ADDER

operation of the binary adder as a part of the storage system, and for the following circuit details. All transistors are used in the grounded emitter configuration. Transistors T-1, T-2, T-3, T-4, and T-5 comprise the exclusive OR gate. T-12 and T-13 are the mixer. The AND gate consists of T-6 and T-7. The 2-μsec delay is accomplished with T-8, T-9, T-10, and T-11. The mixer is simply a standard OR gate which produces an output for either or both inputs. Thus clock ① always passes through T-13 to produce dots on the face of the storage cathode-ray tube. A dot is changed to a dash when T-12 passes a pulse synchronized with clock ② which when combined with a clock ① pulse forms a dash. The exclusive OR gate consists of an OR gate (T-1 and T-2) driving a phase inverter (T-3), which in turn provides an input to T-12 unless an AND gate (T-4 and T-5) cancels it. To achieve the 2-μsec delay, the carry demand pulse (appearing at the output of the T-6 and T-7 AND gate) is stretched and applied to the input of T-10 which together with T-11 forms another AND gate. In the absence of an output from T-6 (the carry demand pulse), T-8 passes the clock ② pulse to phase inverter T-9 and hence to the input of T-11, but no carry pulse is generated since T-10 has no input. A carry demand pulse output from T-6, which is always coincident with clock ②, inhibits the corresponding clock ② pulse preventing excitation of T-11 at that time. The next occurring clock ② pulse, however, will

excite T-11; and since T-10 is held on by the stretched carry demand pulse, a carry output pulse will be derived at the collector of T-11. The pulse stretcher is discharged (during the formation of the carry pulse) by the base current of T-10 to arm the circuit for the next carry demand pulse. The carry pulse is fed back to the "add-one" input as shown.

The system has not been completely interconnected as yet. For this reason it has not been possible to make a closed loop test with the permanent storage system. With the completion of the interconnecting circuitry, over-all system performance will be evaluated.

(J. F. Frazer and R. J. Massa)

4. Geiger-Müller Counter with Known Dead Time

A univibrator preamplifier has been designed for the purpose of giving a known dead time with a GM counter.

In counting or measuring a radioactive source, a GM counter is generally used with a cathode follower preamplifier, an amplifier (if necessary), a discriminator, and some type of scaler or register. It is recognized that the calculation of dead time may present somewhat of a problem because of its tendency to change from day to day. This is due to the characteristics of the GM counter which change with age.

The circuit uses an amplifier with an approximate gain of ten, the output of which is fed into the univibrator. Amplified GM counter pulses thus trigger the univibrator. The univibrator pulse width is set to a value which exceeds the dead time of the counter. Subsequent pulses from the counter will not pass through until the univibrator has completed its cycle. The pulse width of the univibrator is variable from 500 to 900 μsec and may be made longer than the dead time of the GM counters commonly in use. A cathode follower was added to provide a low impedance output to the discriminator which it normally feeds into.

The resolving time of this system is not exactly equal to the pulse width of the univibrator since the GM counter can recover before the univibrator gate opens and produce a second counter pulse creating another dead time and recovery time period in the counter which may extend beyond the gate opening time. Thus the resolving time is somewhat longer than the univibrator gate width depending on counting rate. Theoretical consideration of this situation* shows that the effective dead time is increased approximately two percent more than the univibrator pulse width. However, this is insignificant when the resolving time correction is five percent or less.

(J. F. Frazer and J. P. Morris)

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* The calculations from which these conclusions were drawn were made by J. L. Bear.

5. Tape Recording of Nuclear Detector Pulses

This laboratory currently has at its disposal an RCL 256-channel analyzer capable of operating at counting rates up to 100 counts per second while maintaining an average live time of 99 percent. Quite frequently it is necessary to use the analyzer to measure less active sources which produce counting rates of a few hundred counts per minute. This involves the use of the analyzer for one to two hours to measure a single spectrum. Since the analyzer is not being used efficiently under such circumstances, the laboratory has felt a real need for some system that will analyze the given input spectrum, and which will permanently store the data in such a manner that when properly delivered to the RCL analyzer the spectrum can easily be constructed or established in its magnetic-core memory.

Properties imposed upon the proposed system are as follows:

1. Input pulse heights must be measured to within 0.5 percent and the analysis must be performed in approximately 100 μsec.

2. Data stored must be in binary-coded form since this is most efficiently and reliably read into the memory of the RCL analyzer.

3. The storage unit, in order to record an experiment permanently, must be compact, easily installed and removed from the system, and relatively inexpensive.

A storage unit which satisfies the imposed conditions is magnetic tape. Figure 9 represents a system proposed to yield the given specifications.

The function of each block is as follows:

Analog to binary converter: This operates in a fashion similar to that of the ADC and address scaler of the RCL analyzer. The incoming pulses, when accepted for analysis, are stretched and compared with a linear ramp. A two-megacycle clock delivers a sequence of pulses to an eight-stage binary scaler as long as the ramp voltage is less than the stretched input pulse. At the time the ramp and input voltages coincide, the clock is stopped and a data storage pulse is obtained which reads out the eight stages of the scaler in parallel to the tape address and writing circuits. During the time of analysis and read-out, all pulses that appear at the input are rejected. The output of the ABC consists of eight separate channels of information delivered in parallel. According to whether or not 1's or 0's are delivered at each output of the binary, the states of an eight-bit binary number are determined such that it is the equivalent of the channel to which the analyzed pulse belongs.

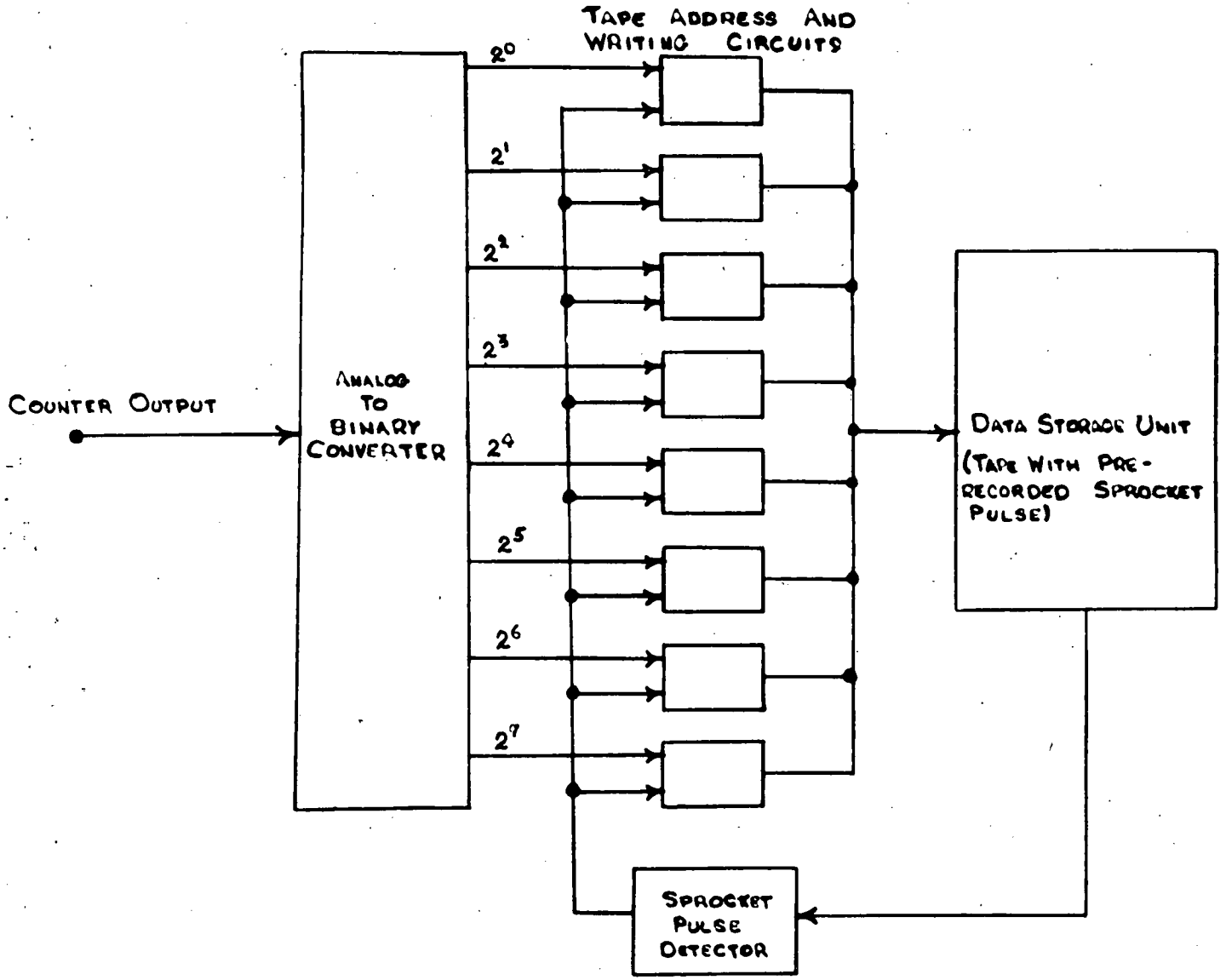

Fig. 9. Proposed Permanent Data Storage System for Multichannel Analysis

Tape address and writing circuits: There are eight of these in parallel and their purpose is to accept the 1's and 0's from the binary output whenever they occur, and then record them simultaneously on the next appropriate portion of the clock pulse.

Sprocket pulse detector: The function of this single circuit is to ensure that there will be a minimum spacing between bits recorded on the tape. It will also ensure that each bit is recorded for a fixed length of time so that all data recorded on the tape will be uniformly and reliably recorded.

Data storage unit: This is no more than a short, continuously running closed loop of magnetic tape. The tape is 0.5 in. wide, digital recording, high output type of tape. The speed of the tape is to be 30 in. per sec while recording, and a bit density of 555 bits per inch per channel has been determined to be a satisfactorily and reliably achieved tape storage density. There are nine parallel channels on the tape, eight for binary recording, and one for a prerecorded sprocket pulse. This sprocket pulse is to be used to ensure that data are read into specific positions on the tape. The density requires a 60 μsec (30 μsec ON, 30 μsec OFF) sprocket pulse if the tape is operated at 30 in. per sec. All of these specifications can be realized with commercially available recording heads, tape, and tape decks.

Due to the method of storage, some previously analyzed and recorded data are going to be destroyed by over-recording of data on subsequent cycles of the tape. Since 1's and 0's are to be recorded uniquely on the tape, over-recording merely replaces the binary number previously stored in that spot with another. Thus, the spectrum ultimately recorded on the tape is a random selection from a large number of events and constitutes a statistical sample of the spectrum. As such, it will not be related to the activity of the source, and steps will need to be taken to determine source activity and percent dead time. These can be determined by counting sample pulses at the input up to a desired count and by counting the total number of data record pulses at the output of the ABC. The measured spectrum can then be related to the source activity since the total number of pulses analyzed will be known and a live time count has been established.

There are numerous advantages to having the data stored in binary form. By means of relatively simple electronic combinational circuits, the data stored on the tape may be analyzed channel by channel, or in groups of adjacent channels independent of the RCL analyzer even though the data are stored such that they can be put into the RCL analyzer.

It is expected that actual construction of an experimental model will begin immediately. Factors that will be

investigated in addition to those that are relative to Fig. 9 are as follows:

1. Consideration of the advantages of temporary storage to eliminate over-recording and subsequent loss of analyzed data.

2. The possibilities of converting this system to a constant dead time, statistical sampling device where the dead time per analyzed sample is to be as small as possible.

(J. F. Frazer and F. H. Irons)

Appendix 1

Medical Protocols

All available medical data on persons whose body burden has been determined in this laboratory during the past year are presented here.

A list of the laboratory tests performed, together with their normal limits, are given below.

Hematology: hemoglobin (hgb) 12-14 g/100 cc
erythrocytes (rbc) 4.5-5 million/mm^3
leukocytes (wbc) 4-9000 mm^3
differential - P65, L29, M4, E1, B1
hematocrit (hct) 36-47 percent
sedimentation rate 0-20 mm(in first hour)

Blood Chemistry: alkaline phosphatase 1-4 units (Bodansky)
calcium 9.5-11.5 mg
nonprotein nitrogen (NPN) 25-38 mg
phosphorus 2.5-3.5 mg
sugar 80-120 mg
urea nitrogen (BUN) 8-20 mg percent

Electrophoresis: (in g percent) total protein 6-8
total globulins 2.5-3.5 albumin 3.5-4.5
alpha 1 0.3-0.5 beta 0.8-1.0
alpha 2 0.5-0.7 gamma 0.8-1.2

Urinalysis: specific gravity 1.005-1.022

(L. Ar.) Clinical information on this patient was reported by Aub, Evans, Hempelmann, and Martland in Medicine 31, 221 (1952). The bone sample was provided by Dr. Robert J. Hasterlik, and further details may be obtained from him at Argonne Cancer Research Hospital, 950 East 59th Street, Chicago 37, Ill.

(R. Ba.) Born 21 May 1901. Present Health: Patient states that at the present time she is in good health and has been since her operation for thyroid four years ago. She also had a removal of the umbilicus eight months ago because of a chronic infection. Systems Review: Ears: tendency to ringing in the right ear off and on for the last ten years associated with some diminution in hearing. No obvious cause for this has been found. Eyes: wears glasses for close work; otherwise, no difficulty. Nose: no nosebleeds or other disorders of the nose. Throat: normal. No great number of colds or sore throats. Neck: thyroid was operated on four years ago because of enlargement with lumps in the thyroid. As far as she knows, she had no evidence of thyrotoxicosis prior to this operation. In recent months, she wonders whether or not there may be some recurrence of the enlargement. Cardiorespiratory: some dyspnea on exertion but no evident palpitation, chest pain, or cough. GI: patient is subject to a lot of gas and heartburn but no actual nausea or vomiting. No history of any melena or blood in the stools. No great difficulty with the bowels. GU: shows nothing abnormal except for possible tendency to nocturia. Catamenia: menarche at 13 very regular until it stopped two years ago. She had some hot flashes which are now diminishing in severity and frequency. Neuromuscular: some tendency to

numbness of the hands at night but no other difficulties. No history of fractures or arthritis at any time. No history of any skin disorders.

Habits: Appetite too good if anything. Tendency to gain weight in the last five or six years. She sleeps soundly at night. Tobacco averages one to two cigarettes daily. Alcohol very slight, possibly one to two drinks per month. She get a minimal amount of exercise.

Past History: Shows history of usual childhood diseases with severe case of whooping cough. No specific history of diphtheria, scarlet fever, or rheumatic fever. Operations consist of tonsillectomy in childhood, partial thyroidectomy, and removal of the umbilicus as noted above. Aside from these, no other hospitalizations or severe illnesses. No history of any fractures.

Family History: Father died at 26 of pneumonia, and mother died at 56 of cerebral hemorrhage. There were no siblings. No familial history of cancer, diabetes, or tuberculosis. One gathers that there has been a tendency to cardiovascular disease in the family. No history of any mental illness, allergic disorders, or epilepsy.

Marital History: Patient is and has been unmarried all her life.

Occupational History: She went to work at the age of 17 in a brass company and from there went to the Waterbury Clock Co. at the age of 18 where she painted dials with radium paint for a period of four to five months. She freely admits that she

tipped the brush with her tongue and lips during this time. She was taken off this job at the end of three months and for the last 34 years has worked for either the Waterbury Clock Co. or its successor, U. S. Time Corp.; for the past 34 years, most of it as a timekeeper.

Dental History: She had many cavities as a school child but had little dental difficulty for many years after her dial painting job. She lost approximately four teeth about six years ago. Her dentist is Dr. Bergen in Waterbury, Conn.

Physical Examination: Shows a well-developed and rather overweight woman in no distress and apparent good health. Weight, 179. Blood pressure, 132/78. Pulse, 80 at rest. Examination of the eyes shows no abnormalities. Ears: negative. Hearing not tested. Nose: normal. Throat: normal. Teeth are in fair state of repair but seemed to show some evidence of pyorrhea at this time. Neck shows old, well-healed though prominent scar from previous thyroidectomy. A mass can be felt in this region, more particularly on the left than on the right, part of which moves with swallowing and probably representing a recurrence of the thyroid enlargement. No nodules were felt. Heart and lungs: normal to auscultation and percussion. Breasts: Normal. No evidence of any masses. No sign of any adenopathy. Abdomen: liver and spleen not felt. No other masses felt. Pelvic and rectal examination not done. Reflexes equal and active. Extremities: normal without any limitation of motion of any joint. A marked lordosis in the lumbar region but otherwise no abnormalities.

Laboratory Findings: Urinalysis: sp. gr. 1.007, albumin neg., sugar neg.; occasional rbc. Hematology: wbc 5200; hgb 13.8 g, 88 percent; differential P49, L51; normocytic rbc; hematocrit 47 percent; sedimentation rate 46 mm/hr.

Blood chemistry:	urea nitrogen	13.5 mg percent
	sugar	86 mg percent
	alkaline phosphatase	12.5 units
	Hinton	negative
Electrophoresis:	total protein	6.9 g/100 cc
	albumin	3.98
	total globulins	2.92
	alpha 1	0.36
	alpha 2	0.52
	beta	0.80
	gamma	1.24

X-ray Findings: Skull, lumbar spine, and pelvis show marked changes in bone consistent with moderately advanced Paget's disease of bone. Routine chest plate showed displacement of trachea to the right by a probable mass in the neck. This would tend to confirm the finding of thyroid enlargement on the physical examination.

(J. Br.) Date of birth: April 26, 1924. Present Health: Patient states that his health has been good except for the following: in July 1957 he had a so-called virus infection characterized by aches in the back of the head, sore throat, fever of 104 or 105, general weakness, muscular aches,

diarrhea, and vomiting. Symptoms lasted intermittently for about ten days to two weeks and then gradually subsided. Since that episode, he has felt perfectly well. He has also been subject to periodic attacks of digestive upsets characterized by disturbance of bowels and accompanied by headaches. He used to have these attacks about once a month, but now they are less frequent, coming on every three or four months and often associated with times of being emotionally upset.

Systems Review: Not completely given. One gathers he has had no particular difficulty with the eyes, ears, nose, or throat. Cardiorespiratory: negative in recent years. GI: see present illness which is given above. GU: not stated. Neuromuscular: normal. Skin: normal.

Past History: Patient had the usual childhood diseases. He also had pneumonia twice and a tendency to rheumatism. No specific history of scarlet fever, diphtheria, or rheumatic fever. He had a small neck tumor removed in 1950 without any trouble thereafter. Multiple fractures of the left arm in 1938 with complete recovery. He had a fracture of the navicular bone in the left wrist in 1949 with good recovery.

Family History: Father and mother are both living. Father has a tendency to heart disease. Mother has high blood pressure. Nothing known of any other familial diseases.

Marital History: Patient is single.

Occupational History: Patient was a prisoner from 1949-1950 working in the uranium mines of Joachmisthal as a common laborer. Four months he worked on surface digging and shoveling

stones and soil containing negligible amounts of uranium, and then for four months he was in the deep part of the mine digging and loading wagons. No protection for face. No great amount of dust. Water poured through the porous rocks. The rest of his stay was in the refinery plant carrying containers of ore and water. Dust not important. While under ground, skin turned a pale green color similar to what happened to other workers. This is definitely not yellow. He felt well during this period. He had paratyphoid for five or six days characterized by diarrhea, vomiting, and fever.

Dental History: He has had a fair number of fillings, but otherwise has had very little difficulty with teeth.

Physical Examination: Shows a well-developed and nourished man of 33 weighing 140 pounds. Blood pressure, 120/75. Pulse, 88 at rest. Eyes: pupils react normally to light and accommodation. Extraocular movements are normal. Fundi: not examined. Wears glasses for mild myopia. Ears: normal, except for question of some diminution of hearing on right. Nose: normal. Teeth were in good repair. Thyroid not palpable. No cervical adenopathy at this time. Heart and lungs: normal to auscultation and percussion. Abdomen: soft and relaxed. Liver and spleen were not felt. No masses were felt. Inguinal rings: normal. Genitalia: normal. Rectal examination including prostate: negative. Reflexes were equal and active. Extremities: normal.

Laboratory and X-ray Findings: No examinations made.

(C. Ca.) Born 30 August 1912. Present Health: Patient states that her present health is good except for a slight stiff neck which developed within the past two or three days.

Systems Review: Shows no abnormalities of the eyes, ears, nose, or throat. Cardiorespiratory system: negative. GI: negative. Bowels are regular without laxatives. No history of any melena or rectal bleeding. GU: negative. Catamenia: menarche at 12 regularly every 28 days. Flow lasting for three days. Occasional cramps. Last period was the first of January. Neuromuscular: occasional cramps in the left thigh, otherwise no disabilities. Skin history: negative.

Habits: Appetite is good. Tendency to gain weight recently. Smokes 15 cigarettes daily. Alcohol averages one to two drinks per week. Sleeps soundly at night. No regular exercise.

Past History: Usual childhood diseases but no specific history of rheumatic fever or diphtheria. No hospitalizations at any time except for tonsillectomy in childhood. No accidents of consequence. No history of any broken bones.

Family History: Father died at age 40. Mother living and well at the age of 79. Five siblings are all living and well. No familial history of cancer, diabetes, or tuberculosis. Four of the five siblings have had children.

Marital History: Patient married at the age of 21 when her husband was 25. Married for eight years. One pregnancy after one year of married life, but this resulted in a miscarriage at approximately six months. No birth control or other preventive measures were taken during her eight years of married life.

Marriage broke up at the end of this time essentially because of the discovery of a positive Hinton test found when she had a physical examination at a place of employment. Following discovery of a positive blood test, patient underwent extensive antiluetic therapy with apparent cure.

Occupational History: This patient worked as a dial painter for a period of two months in 1927 at the age of 15. She states that she did not do any tipping with a brush on her tongue.

Dental History: Patient began to have trouble with her teeth because of cavities about 15 years ago resulting in a complete upper denture four years ago. The dentist at that time was Dr. May of Waterbury. She has two very poor teeth at the present time which she expects to have removed in the near future.

Physical Examination: Patient is a well-developed and nourished woman of 46 weighing 128 pounds. Blood pressure, 128/78. Pulse, 84 at rest. Height is 60". Head and scalp: normal. Eyes show normal pupils which react equally to light and accommodation. Fundi not examined at this time. Extraocular movements are normal. Ears: normal. Drums: intact. Nose: normal. Throat: normal. Teeth: those remaining in poor state of repair. Upper teeth all absent. Neck shows no evidence of cervical glands. Thyroid was not palpable. Heart and lungs: normal to auscultation and percussion. Breasts: normal female. No masses were felt. Abdomen: soft and relaxed. Liver and spleen: not felt. Pelvic examination

shows no evidence of cervical erosion. Uterus in good position. Ovaries were not palpable. Rectal examination was not done. Extremities: normal. Reflexes were equal and active. Romberg was negative.

Laboratory Findings: Urinalysis: sp. gr. 1.029, albumin neg., sugar neg.; bacteria, amorphous material, 1-2 epith. cells and wbc/hpf, rare rbc. Hematology: rbc 4,680,000, wbc 4800; hgb 13.8 g, 88 percent; differential P31, L66, E1, M1; platelets appear greatly reduced; hct 39 percent; sed. rate 2 mm/hr.

Blood chemistry:	urea nitrogen	11.7 mg percent
	sugar	90 mg percent
	alkaline phosphatase	4.6 units
	Hinton	negative
Electrophoresis:	total protein	6.0 g/100 cc
	albumin	3.6
	total globulins	2.38
	alpha 1	0.38
	alpha 2	0.52
	beta	0.68
	gamma	0.80

X-ray Findings: Skeletal survey shows no evidence of radium poisoning. There are no significant abnormalities in the bones, and the heart and lungs are normal in appearance.

(F.Co.) A watch dial painter at the Waterbury Clock Co. starting in 1920 at the age of 17. She worked for about thirteen years. X-rays of skull, shoulder, pelvis, and hips taken in 1931, 1934, and 1935 showed patchy areas of decalcification and the mottled appearance considered to be typical of radium poisoning. She died in 1943 of osteogenic sarcoma, right leg, due to radium poisoning.

(M.Da.) Date of birth: February 16, 1900. This 57-yr. old white single female was examined by Dr. William H. Baker at the Waterbury Hospital on June 25, 1957 for purposes of analysis regarding her radium-mesothorium ingestion which occurred in the 1920's at the Waterbury Clock Co. radium dial painting room. The patient has been perfectly well all of her life. She was employed at the Waterbury Clock Co. from March 10, 1920 to April 1, 1927. During that time, she worked in room 31r, and in 1927 she stopped work because of difficulties in New Jersey plant, and transferred to another section where she worked until 1937. Since 1937 she has not worked. She painted watch dials with a mixture of radium and mesothorium. She pointed the brush with her teeth and noticed at times that her hair glowed at night and also that there were speckled areas over her dress at night. The speckled areas were remnants of the radium which she rubbed off when she made a mistake on the dials. She has had very little difficulty regarding medical or surgical illnesses. She began having trouble with her teeth in 1937 and had them removed intermittently from 1937 to 1939.

They gradually loosened, some fell out, and others were taken out. A few developed abscesses but she had no difficulty with the extractions. There have been no fractures that have needed surgical intervention and only a possible fractured rib in January 1950. At that time, she was hospitalized because of pain in the chest of a pleuritic nature, and x-rays showed a possible fracture of her ribs. Present Health: She has had pain in her back for about ten years and she also has intermittent pain in the ribs, otherwise is perfectly all right. She has no complaints at the present time, is ambulatory and keeps house, living by herself in her own home.

Systems Review: Entirely negative, except for occasional sinus difficulties. Her menses began at age 15. She flowed every 28-30 days, 3-4 days. No irregularity. Occasional pain with her menses. They ceased spontaneously about seven years ago. Head: not remarkable. Hair: gray, no defects. Ears: negative. Eyes: pupils round, regular, equal; react equally to light and accommodation. Fundoscopic, not remarkable. Mouth: upper and lower dentures. No irritation of the gums. Tonsils: present with one small follicular patch in the lt. tonsil and one in the rt. tonsil. No other abnormalities noted. Neck: no adenopathy. Thyroid in midline. No nodules. Chest: clear to P and A. Heart: PMI in 5th interspace within midclavicular line, normal sinus rhythm. A2 greater than P2. Blood pressure, 140/85. No murmurs. Breasts: negative, except for a small cystic nodule at about 11 o'clock in the outer quadrant of the rt. breast. Axillae: free of disease. Abdomen:

covered with small melanomatous nevi. Liver and spleen: not felt. Peristalsis normal. Pelvic and rectal: refused. Neurological: deep tendon reflexes, equal and active bilaterally. Extremities: hypertrophic Heberden node changes in both hands, most marked in the rt. hand and most marked in the 4th and 5th fingers.

Habits: She does not drink, nor does she smoke. At present is unemployed and has been such for 20 years.

Past History: She has had a tumor of the rt. breast for about nine years which did not grow in size but has been noted by Dr. Ryder. There have been no previous hospitalizations for surgery or medical illnesses. Usual childhood diseases. In the last two years she has had intermittent trouble with her sinuses with pain underneath her eyes.

Family History: Mother died at 73 of heart condition. Father died at 77 of heart condition. One brother died at 16, accidentally. No sisters.

Physical Examination: Well-developed, well-nourished white female, who looks her stated age in no acute distress. Has obvious hypertrophic Heberden node changes of both fingers, affecting primarily the terminal phalanges of both hands with the 4th and 5th fingers of the rt. hand most affected.

Impression: Except for the history and occasional pain in the back and rib area, this lady has very little evidence of radium intoxication.

Discharge diagnosis: Radium-mesothorium intoxication, minimal.

Laboratory Findings: Urinalysis: sp. gr. 1.006, albumin, sugar and acetone negative; rare epithelial cells. Hematology: wbc 9400, hgb 13.2 g; differential P68, L24, M3, E2, B1, platelets normal; hematocrit 38 percent.
Blood Chemistry: nonprotein nitrogen 63 mg/100 cc, alkaline phosphatase 1.7 units, calcium 10.0, phosphorus 3.06, protein electrophoresis normal.
X-ray Findings: Skeletal survey exhibits relatively mild bone changes in the long bones and calvarium due to radiation osteitis.

(I. Da.) This patient was reported on by Hasterlik in ANL-4932 in 1952 and by Norris, Gustafson, and Speckman in Am. J. Roentgenol. 73, 785 (1955). The bone sample was provided by Dr. William P. Norris, Argonne National Laboratory, P. O. Box 299, Lemont, Ill.

(E. Da.) Watch dial painter at the Waterbury Clock Co. starting when she was 16, in 1920. The company doctor states that she painted dials for only five days. In 1928 she developed osteomyelitis of the jaw and died in 1937 of radium poisoning, osteomyelitis of superior and inferior maxillae, otitis media, and anemia.

(C. Da.) Clinical information on this patient was reported by Looney, Hasterlik, Brues, and Skirmont in Am. J. Roentgenol. 73, 1006 (1955) and physical measurements were given by Norris, Speckman, and Gustafson in Am. J. Roentgenol. 73, 785 (1955). The bone sample was provided by Dr. Robert J. Hasterlik and further details may be obtained from him at the Argonne Cancer Research Hospital, 950 East 59th Street, Chicago 37, Ill.

(E.DeB.) This 51-year old white married female, mother of one child, was examined by Dr. William H. Baker at the Waterbury Hospital on June 28, 1957 for purposes of analysis regarding radium-mesothorium ingestion which occurred while working for the Waterbury Clock Co. She has been perfectly well all of her life and was employed by the Waterbury Clock Co. from January 24, 1923 to March 24, 1926. During that time she painted watch dials with a radium-mesothorium mixture. She painted them with a small brush which she tipped with her teeth and lips. She was married in 1926, had a miscarriage in 1927 at two months. A daughter was born two years after the patient stopped work and was nursed for two to three years. In 1928 she was positive by the electroscope by Dr. Flinn, and in 1929 wisdom tooth was extracted. At this time her teeth were x-rayed and patient thinks that they were negative. In 1937, she was having diffuse headaches which many physicians told her were caused by anxiety. In 1941, she was hospitalized in St. Mary's where an appendectomy was performed and her coccyx removed because of fracture previously during birth of her child. A small deformed coccyx was removed which had many fibrous adhesions; no tissue was saved. In 1946, she had a pan-hysterectomy. X-rays were taken at the Waterbury Hospital at that time, and they showed possible decreased areas of density. In 1947, x-rays of her feet showed straggly punched-out areas in shoulder and feet consistent with radium intoxication. She was hospitalized in 1950 at Waterbury Hospital for a troublesome

gallbladder, and a cholecystectomy was performed. She gradually became worse. In 1946, after emotional upset, she attempted suicide, but failed in the attempt. In 1951-1952, she gradually went to bed because of increasing intensity of pain in her back; since that time she has been bedridden. This has been getting worse and worse and she was ambulatory only when going to the bathroom. She sits up very little and lies in bed most of the day. She has had no fractures, but has had a few bad falls which have not caused fractures of her legs. Four years prior to this admission and three years after gallbladder was removed, she had nine weeks of nausea, vomiting, and diarrhea. This had gradually subsided. She now comes in for studies pertaining to this exposure to radium and mesothorium. Her appetite is good and she maintains her weight.

Systems Review: Not remarkable, except for a nodule in the region of her neck which she thought was an extra "Adam's apple".

Habits: She does not smoke or drink.

Past History: As outlined in the PI. Initial childhood diseases. Menses began at age 12, flowed every 28-30 days, regular until her marriage, after which her periods became irregular. They ceased after hysterectomy was performed in 1946, and this was followed by a few hot flashes. She takes Bufferin and Alka Seltzer for her pain, and occasional Alophen tablets for constipation.

Family History: Father died at 57 of nephritis and hardening of the arteries. Mother died at 61 of a shock. One sister,

age 50, living and well. One brother, age 41, living and well. One brother died in infancy, and her mother had one stillbirth. Her major difficulty now is that she has constant pain in her back, especially when her bed is jarred, and she has constant pain throughout her bones.

Physical Examination: She is well developed, well nourished, lying in bed in no acute distress, but is frightened and quite emotional. Scalp: not remarkable; hair is grayish with brown tinge. Eyes: pupils are round, regular, equal; react to light and accommodation; EOM normal. Ears: not remarkable. There is a cerumen of lt. ear. Throat: there are 16 remaining teeth as charted by the dental chart. They are in good repair. A number of cavities and many of the molar teeth remain. Tonsils are present. Tongue is in the midline, does not fibrillate. Neck: no cervical adenopathy; thyroid can be felt, and adjacent to it and moving with swallowing is a firm mass which seems to be moving with the thyroid and connected with it; it is linear and extends laterally, measures approximately 6 × 4 cm. This is freely movable and may be a lymph node overlying the thyroid gland, but attached to it by adhesions. Supraclavicular area is free of disease. Chest: clear to P and A. No CVA tenderness. Spine: normal curvature. No tenderness by light palpation. There is a well-healed scar in the region of the gluteal folds overlying the coccyx. Breasts: there is fibrous quality throughout with slight irregularity, but no definite nodules felt. Axillae are free of disease. Heart: PMI with the 5th interspace, NSR at rate of 75. No murmurs. A2

greater than P2. Sounds of fair quality. Abdomen: three well-healed scars, one extending from the umbilicus to the xiphoid, which is the previous scar of cholecystectomy. There is a well-healed appendectomy scar in the RLQ measuring about 8 cm, and there is a well-healed midline scar extending below the umbilicus to the pubis, approximately 12 cm. No herniation in any of these scars. Deep tendon reflexes, equal and one plus active bilaterally. There is no definite atrophy of the muscle groups in the legs. There is definite weakness of extension and flexion of feet, consistent with disuse. There is a similar weakness to the arms, but not as marked. She is able to stand unsupported but not for long periods of time. She can only sit for short periods of time, otherwise gets pain if she does not shift her weight.

Impression: Radium-mesothorium intoxication with osteoporosis of inactivity; possible compression fractures of the lumbar and thoracic spine; calcification of node overlying the thyroid gland and possibly part of the thyroid gland.

Laboratory Findings: Hematology: wbc 7500; hgb 13.5 g; differential P73, L25, M1, B1; platelets normal; hematocrit 42 percent.

Blood chemistry:	alkaline phosphatase	4.5 units
	non-protein nitrogen	42 mg/100 cc
	calcium	9.6
	phosphorus	1.5

Protein electrophoresis normal.

(C. Do.) Born in 1904. This patient was examined by Dr. J. Elser at the Waterbury Hospital in September of 1957. She was employed as a dial painter at the Waterbury Clock Co. for seven years and two months from 1920 to 1928, and pointed the brush with the lips as was customary at that time.

Systems Review: Appetite and strength good, weight stable. Head andneck: denies headache, dizziness, or tinnitus. Ear, nose, throat: no bleeding or ulceration of buccal mucosa, no dysphagia. Eyes: negative. Skin: denies rashes, itching. Respiratory: denies cough, hemoptysis, pain, wheezing, or frequent infections. Cardiovascular: denies angina, ankle edema, orthopnea or dyspnea on exertion. No palpitations. GI: no food intolerance, no indigestion or heartburn. Denies any GI bleeding or pain. GU: denies frequency, nocturia, or dysuria. Extremities: short rt. leg with limp, unable to abduct legs very well.

Past History: Patient denies any illness during childhood of any significance. No rheumatic or scarlet fever. Has two living children, ages 26 and 25, both of normal birth and delivery. During second pregnancy developed a goiterous thyroid which she describes as being mildly toxic. Left lobe removed one year later; no further trouble. Appendectomy many years ago. Fractured rt. femur twice, once in 1941, and once six yrs. ago with shortening and deformity. Menopause six yrs. ago with little difficulty or bleeding since. Denies any knowledge of hypertension, diabetes, or kidney disease.

Family History: Non-contributory.

Physical Examination: Blood pressure 130/80, pulse 84 regular, temperature 98.6°, R 20. Slightly obese white female who is somewhat anxious and wondering about necessity of examination. Color good. Head and neck: supple, no masses, nodes, or organs felt. Veins flat. Lower thyroidectomy scar. Ear, nose,

throat: no evidence of bleeding or ulceration. Teeth in good repair. No inflammation. Eyes: pupils R.R.E. No jaundice. Fundi normal. Skin: no jaundice, cyanosis, or rashes. Breasts: no masses or bleeding. Lungs: clear to P and A. Heart: not enlarged. PMI concealed by breast. NSR, no murmurs. A2 greater than P2. Abdomen: healed lower midline scar, soft, non-tender. No organs or masses felt. Back: spine straight, no tenderness. Patient has to support herself with arms to sit up. Extremities: no edema, cyanosis. Pulses normal and equal. Right leg shorter than left with limitation of motion of both hips and knees, more so on right. Rectal: normal. Pelvic: could not be done due to inability of patient to assume any examining position. Impression: shortened right femur due to old fracture.

X-ray Findings: Chest: infiltrate overlies the extreme left base and merging with the apex of the heart and due to either normal epicardial fat pad or parenchymal infiltration. Lungs otherwise are clear except for accentuated lung vascular markings. Ribs show a slightly scraggly appearance suggesting metallic intoxication. Lumbar spine, pelvis, right and left femurs: bones show scraggly appearance, mainly the right femoral shaft due to metallic intoxication; the left femoral shaft shows smooth periosteal calcification, wavy in character laterally due to chronic benign irritation. Proximal right femur shows smooth bulbous margins and due to old well-healed fracture held in place by a Lane plate and six screws. No absorption is noted about the plate or the screws.

(W.Fa.) Date of birth: January 12, 1912. Present Health: Patient states that right now she is feeling fairly well but is having some trouble with hot and cold feelings which have been present for the past three years. She has also had some difficulty with pains in her feet off and on for the past year which one gathers are due to some disorder of the anterior arch.
Systems Review: Reveals glasses for watching TV only. No difficulty with ears. Nose: normal. No history of epistaxis. Throat: entirely normal except for occasional sore throats with upper respiratory infections which are not frequent. No history of any swollen glands. Cardiorespiratory: entirely negative for dyspnea or chest pain. No history of cough. GI: shows no tendency to indigestion, melena, or grossly bloody stools. GU: shows nocturia once per night, but otherwise no difficulties. Catamenia: menarche at 15. Periods were perfectly regular until salpingectomy and question of hysterectomy 15 years ago for tubal pregnancy. One wonders if the hot and cold feelings which she has been experiencing for the past three years may be menopausal hot flashes. Neuromuscular: Patient gives a history of one episode of bursitis in the rt. shoulder, and pains in the feet during the past year. Right foot bothers more than the lt. No history of any skin disorders or rashes.
Habits: Appetite is somewhat variable and never too good. However, there has been no weight change in the last ten years. She sleeps soundly at night. Smokes approximately ten cigarettes daily. Alcohol consumption is minimal, averaging possibly one drink per month.

Past History: Patient had the usual childhood diseases but no specific history of rheumatic fever, diphtheria, or scarlet fever. No other hospitalizations other than that for the tubal pregnancy in the Waterbury Hospital 15 years ago. Her surgeon at that time was Dr. John Freiheit of Waterbury. No history of any fractures.

Family History: Father died at 30 of pneumonia. Mother, age 73, living and well except for some arthritis. She has two step-brothers, 36 and 35, both of whom are living and well. No familial history of cancer, diabetes, tuberculosis, allergy, epilepsy, or mental disorders.

Marital History: Married 27 years. Husband is 51, living and well. Four children ages 26, 23, 22, and 16. Two children are married and have one child each. All children seem to be normal in development.

Occupational History: Patient started painting dials at 16 in 1927. She painted intermittently for a period of four years, until 1933. She does not remember ever putting the brush in her mouth, but she does remember that her hair, face, and hands often glowed in the dark when she came home at night. She does not remember ever being particularly warned about putting the brush in her mouth, but she does remember that it was supposed to be somewhat dangerous.

Dental History: She began to have trouble with her teeth approximately two years after starting her dial painting when she was about 18 years of age. She lost two teeth at that time, and gradually, over the next 10 or 15 years lost more and more of

them until 16 years ago when all the remaining teeth were removed and she was fitted with complete dentures. Her dentist was Dr. Mayon of Waterbury who has since died. She does not remember any dental x-rays being taken at any time.

Physical Examination: Shows a thin, rather poorly nourished-appearing woman of 46 in no apparent distress. Weight is 107 lbs. Height is 60.5". Pulse 84 at rest. Examination of the eyes shows the extraocular movements to be normal. Pupils react normally and equally to light and accommodation. Fundoscopic examination was normal. Ear canals: normal. Nose: negative. Mouth: shows complete absence of teeth. Throat: normal. Neck: normal. No palpable glands or thyroid made out. Heart and lungs: normal to P and A. Regular rhythm. No murmurs. Breasts: small, somewhat atrophic, and there is no evidence of any masses at this time. Abdomen: soft and relaxed throughout. Liver and spleen were not felt. There was a well-healed scar in the lower midline. Pelvic examination shows either a small atrophied uterus or a cervical stump. Both vaults are clear. Rectal examination including hematest: negative. Extremities: normal. Reflexes: equal and active. No limitation of motion of any joints. No skin abnormalities.

Laboratory Findings: Urinalysis: albumin and sugar neg. Hematology: wbc 8600; hgb 15.4 g, 99 percent; differential P49, L49, M2; normocytic rbc; hct 48 percent; sed. rate 15 mm/hr.

Blood chemistry:	urea nitrogen	12.4 mg percent
	sugar	88 mg percent
	alkaline phosphatase	2.7 units
	Hinton	negative
Electrophoresis:	total protein	6.6 g/100 cc
	albumin	4.1
	globulin	2.47
	alpha 1	0.26
	alpha 2	0.53
	beta	0.61
	gamma	1.07

X-ray Findings: Skeletal survey shows no evidence of radium poisoning. There are no significant abnormalities in the bones, and the heart and lungs are normal in appearance.

(B.Ga.) Date of birth: October 18, 1910. Present Health: Patient states that her present health is good with the following exceptions. She tends to feel tired a lot of the time. She has quite a number of headaches, and she feels that she is going through the change of life. She also has what she calls a tendency to arthritis characterized by pains in some of her joints. Systems Review: Shows some tiredness of the eyes, but no other specific complaints or symptoms. Ears: negative. Nose: normal; no history of epistaxis. Few colds or sore throats, none of them severe. No history of any swollen glands. Cardiorespiratory: entirely negative at this time. GI: some tendency to gas; otherwise her digestion seems to be excellent. She gives a

history of some x-rays of the stomach approximately six yrs. ago which were apparently normal. Bowels are regular without laxatives; no history of any blood in the stools, or melena. GU: normal. Catamenia: menarche at age ten and a half. Periods were always regular until five mos. ago when she skipped once and have been regular since. She has some warm feelings, but no definite hot flashes to date. Neuromuscular: tendency to attacks of pain and possibly some swelling in the lt. ankle and lt. elbow, also the second joints of the fingers of both hands. She notices all of these symptoms more at the time of her periods. Also at the time of her period she has a tendency to headaches; these are relieved by bufferin tablets. Skin: normal, no history of any itches or rashes.

Habits: Appetite is good; there has been some weight gain during the past year. Sleeps soundly at night. Tobacco consumption averages one package of cigarettes daily. Alcohol is minimal. Exercise consists mostly of walking.

Past History: Had the usual childhood diseases, but no specific history of scarlet or rheumatic fevers, or diphtheria. No allergic history or epilepsy or mental illness. Operations and hospitalizations consist of appendectomy in 1936, and a period of hospitalization for postpartum bleeding following the birth of her last child. Otherwise, no accidents, operations, or chronic illnesses.

Family History: Father died at 79 of cirrhosis of liver. Mother died at 65 of leukemia. Two brothers, living and well. Four

other siblings died in infancy, cause unknown. No family history of cancer, diabetes, tuberculosis, epilepsy, mental illness, or allergy.

Marital History: Married 30 yrs.; husband 49, living and well, except for recent story of ulcers of the stomach. Two children, 26 and 15, both living and well. No stillbirths or miscarriages. Birth control was practiced for the first four yrs. of married life and for the nine-yr. interval between the two pregnancies and following the birth of the last child.

Occupational History: She went to work in 1927 at 17 painting watch dials at the Waterbury Clock Company. She is not certain whether she tipped the brushes in her mouth or not. She has no remembrance of any glowing of the hair or hands at night while she was engaged in painting dials. No radium exposure since that time.

Dental History: She has had a moderate amount of dental difficulty during her life, and none at all until the birth of her first child 26 yrs. ago. Since that time, she has lost approximately six or seven teeth; the last one was removed about two or three yrs. ago by Dr. Baxeville of Waterbury who took x-rays.

Physical Examination: Shows a well-developed and slightly overweight woman of 47 weighing 154 lbs. in no apparent distress. Head shows small xanthochromic spot over the lt. upper eyelid; otherwise, eyes appear normal. Extraocular movements appear normal. Pupils react normally to L and A. Ears: negative. Nose and throat: normal. Teeth seem to be in good state of repair.

Neck shows no enlargement of cervical glands. Thyroid not palpable. Heart and lungs: normal to P and A. Blood pressure 106/68. Pulse 78 at rest, regular rhythm. No murmurs. Breasts: normal female; no evidence of masses or cysts. Abdomen: soft and relaxed throughout. Appendectomy scar on rt. lower quadrant well healed. Liver and spleen not felt. Pelvic examination showed fundus to be in good position. Ovaries not enlarged. Vaults clear. Cervix in good condition, no evidence of erosion or bleeding. Rectal examination and hematest were negative. Reflexes equal and active. Extremities: normal at this time. Joints normal without evidence of swelling when examined.

Laboratory Findings: Urinalysis: sp. gr. 1.022; albumin and sugar neg.: occ. wbc, 2-3 rbc, 2-3 epith. cells. Hematology: wbc 8700, hgb 14.5 g, 93 percent; differential P63, L33, E3, M1; normocytic rbc; hct 47 percent; sed. rate 15 mm/hr.

Blood chemistry:	sugar	100 mg percent
	alkaline phosphatase	4.0 units
	urea nitrogen	16 mg percent
	Hinton	negative
Electrophoresis:	total protein	7.2 g/100 cc
	albumin	4.27
	total globulins	2.93
	alpha 1	0.39
	alpha 2	0.58
	beta	0.92
	gamma	1.04

X-ray Findings: Skeletal survey shows no evidence of radium poisoning. There are no significant abnormalities in the bones, and the heart and lungs are normal in appearance.

(J.Ga.) Date of birth: November 4, 1908. Present Health: Patient has no complaints at the present time other than occasional nervousness. Her health has been good in recent years. Systems Review: Shows no abnormalities of the eyes. Vision is good with glasses. Has few colds. No nosebleeds. No disturbances of the ears. Cardiorespiratory: occasional slight swelling of the ankles, in summer only. GI: entirely negative. Bowels are regular without laxatives. One small hemorrhoid, but no bleeding. No melena ever noted. GU: patient used to be subject to attacks of cystitis from time to time in the past, starting at the age of 16. Last time she had such an attack was five or six yrs. ago. At the present time she has no symptoms and no nocturia. Catamenia: menarche at 11. Periods were always regular up to and including the present time, usually every 28 days, lasting four to five days. Flow is moderate-to-heavy the second day. In the last six mos. she thinks she has had some hot flashes. Neuromuscular: no history of any rheumatism, arthritis, or bursitis. No limitation of motion of any joints. No fractures of any bones at any time in the past. No disturbance of gait, field of vision. No numbness or tingling of the hands or feet. Skin: patient was subject to attacks of severe dermatitis beginning about 1934. When suffering from these attacks, both hands would usually be affected. The hands would swell up and

weep copious amounts of fluid. Often when the dermatitis was at its height, there would also be involvement of the groin and scalp. These attacks of dermatitis lasted sometimes for several mos. during the winter and clearing up in the spring. Many treatments were tried, including x-ray. She received x-ray treatment at the office of Dr. Gardney in Waterbury and also at Waterbury Hospital. During the last four yrs., she has little, if any, dermatitis of the hands except for a slight tendency for the skin to crack in the folds at the base of the fingers.

Past History: Patient had usual childhood diseases with no specific history of diphtheria, scarlet fever, or rheumatic fever. Tonsillectomy at 19. Other operations consisted of three admissions for fibrous tumors in both breasts. Last episode was three years ago. She has been assured that these were benign lesions. Ten years ago she had a caesarean section. No accidents or broken bones.

Family History: Father died at 44 of some type of kidney disorder. Mother died at 32 of tuberculosis. Patient was two yrs. old. Three siblings, aged 52, 50, and 55. All are living and well. Two are married, and one has three children and several grandchildren, all of whom are well. The other married sibling has had no children. There is no familial history of cancer or diabetes. No history of tuberculosis other than the patient's mother.

Marital History: Patient was married at 29. Husband was 30 at the time of marriage. After nine yrs. of married life, during which time no birth control was practiced, there were no pregnancies.

At the end of nine yrs., she became pregnant, and because of a large baby and small formation of the pelvis, her doctor advised and did a caesarean section. No birth control has been practiced in the ten yrs. following the caesarean section, and there have been no pregnancies. At the time of the caesarean section, a chocolate cyst from one of the ovaries was found and removed. The one child, a daughter, normal development, both physical and mental. The child's teeth are perfectly normal. At the present time she is in her normal grade, which is grade five, and doing well.

Dental History: Patient states that she had essentially no cavities until she was about 19. During the next ten years she lost only one or two of her teeth aside from the removal of impacted widsom teeth. After the birth of her only child about ten years ago, she began to have more cavities and began to lose more and more of her teeth. Last extraction was eight to nine mos. ago. She contemplates having some more of her poor teeth removed. Her dentist is Dr. McGrath of Watertown.

Physical Examination: Shows a well-developed and nourished woman of middle years weighing 138 lbs. Blood pressure 180/110. Pulse 100 at rest. Examination of the eyes shows some dilation of the pupils which react slightly to L and A. There is a suggestion of a lid lag. Fundi appear normal. Ears are normal. Nose is normal. Mouth shows many teeth missing. Those remaining are in poor state of repair. Tongue shows suggestion of fine tremor. Neck shows barely palpable thyroid. No cervical

adenopathy. Chest: clear. Heart and lungs: normal to P and A. There are multiple scars over both breasts, sites of previous operations. At the present time no masses are felt in the breasts. Abdomen: negative. Liver and spleen were not felt. Pelvic and rectal examination refused. No hernia noted. Extremities: normal except for question of slight tremor of the hands. Reflexes are equal and active. Romberg was negative. No limitation of any bones or joints.

Laboratory Findings: Urinalysis: sp. gr. 1.026; albumin and sugar neg.; 4-5 epith. cells, amorphous phosphates. Hematology: wbc 5300, rbc 4,760,000, hgb 15.1 g, 97 percent; differential P58, L37, E3, M1, B1; normocytic rbc; hct 44 percent.

Blood chemistry:	urea nitrogen	12 mg percent
	sugar	102 mg percent
	alkaline phosphatase	3.9 units
	Hinton	negative
	sed. rate	15 mm/hr.
Electrophoresis:	total protein	6.6 g/100cc
	albumin	4.4
	total globulins	2.20
	alpha 1	0.39
	alpha 2	0.34
	beta	0.63
	gamma	0.84

X-ray Findings: Skeletal survey shows no evidence of radium poisoning. There are no significant abnormalities in the bones, and the heart and lungs are normal in appearance.

(Y. Gi.) Date of birth: Sept. 13, 1900. Dial painter at Waterbury Clock Co. for 10 months in 1921-1922, starting at age 20. She painted about 30-40 dials per day, tipping the brush with her lips. From 1937 to 1938 she had many abscesses around her teeth, and during the extractions there was difficulty with bleeding and infection. In 1947 she had a spontaneous fracture of the left femur, and x-rays were taken at that time which showed areas of destruction in the skull, left femur, pelvis, and chest. Her major complaint in the past 5-10 years has been occasional headaches and intermittent multiple aches throughout her bones. Physical examination at the Waterbury Hospital in June 1957 by Dr. William H. Baker was negative except for cataract of lt. eye, deafness and possible sclerosis of the lt. ear. There was no evident limitation of motion of any joints, including the left leg, other than that due to degenerative osteoarthritis. Skeletal survey showed bone changes consistent with radiation effects from radium. Review of the skull films by Dr. John Reeves of the Mass. General Hospital showed large areas of focal demineralization plus more generalized smudging with rather marked progression in the lesions from 1947 to 1957. Laboratory studies were within normal limits except for an NPN of 49.

(R. Ha.) Age is uncertain. Allegedly mixed radium paint at Waterbury Clock Co. for several years. No demonstrable effect from radiation many years after theoretical exposure.

(I. Ja.) The bone sample from this patient was provided by Dr. R. J. Hasterlik and further details may be obtained from him at Argonne Cancer Research Hospital, 950 E. 59th St., Chicago 37, Ill.

(J. Ja.) Born 1883. Details of previous studies will be found in Medicine 31, 274 (1952) and our Annual Progress Report, May 1954.

Since her last physical examination in 1953 patient has continued to be well symptomatically except for mild angina pectoris, which is well controlled with medication. Physical examination in October 1957 by Dr. John Quinby showed the patient appearing well. Blood pressure was 170/85. The remaining teeth were in adequate repair. The chest showed the previously noted structural scoliosis, with heart and lungs normal to clinical examination. There was no residual disability from the fracture of the left femur (1951). The previously noted hypertrophic arthritis of the fingers was present.

Routine laboratory studies of blood and urine were normal. Blood chemical values (calcium, phosphorus, total protein, non-protein nitrogen) were within normal limits. The serum alkaline phosphatase value was slightly elevated at 5.5 Bodansky units.

X-ray studies were made of the skull, femora, humeri, and upper teeth. These again showed multiple osteolytic areas in all regions examined, with no changes suggestive of malignancy. The films were reviewed by Dr. Laurence L. Robbins at the Mass. General Hospital, and compared with films taken there in 1953. It was felt that no significant x-ray change could be seen over the four-year interval.

(J. Ke.) Date of birth: November 6, 1910. Present Health: Except for slight tendency to nervousness and some stiffness of the joints, patient states that she is and has been essentially well for many years. She has had a recent cold and bronchitis during the past two weeks, but this has now subsided.

Systems Review: Shows no difficulty with the ears. Eyes have given no trouble. She does not wear glasses as yet. No nosebleeds or other disorders of the nose or throat. Ordinarily she is not subject to many colds. She has never suffered from swollen glands. Cardiorespiratory: negative except for slight shortness of breath on exertion. GI: normal. Little if any indigestion. Bowels regular without laxatives. There is no history of melena or obvious blood in the stools. GU: negative. Catamenia: menarche at thirteen, always regular every 28-30 days lasting five to seven days except for one episode about a year ago when she flowed nearly continuously for three weeks. This has straightened out, and there has been no menstrual irregularity since that time. No skin disorders. Neuromuscular: negative except for slight stiffness of the joints, particularly to the knees, noted above.

Habits: Appetite is too good, if anything, with a gradual gain in weight during the past few years. She sleeps soundly at night except on rare occasions when she has something on her mind. She does not smoke. Alcohol consumption averages not more than two drinks per week. The only exercise she gets is around the house.

Past History: Shows the usual childhood diseases but no specific history of scarlet fever, diphtheria, or rheumatic fever. She has

had no hospitalization, operations, accidents, or injuries at any time. There have been no broken bones.

Family History: Father died at age 68 of cancer of the esophagus. Mother is 67, living and well. Two siblings, age 40 and 43, living and well, each with three children. No other familial history of cancer. No history of any tuberculosis, diabetes, mental illness, or epilepsy.

Marital History: Patient has been married 28 years. Husband is now 50, living and well. There was one child born two years after she was married, 26 years ago. There have been no other pregnancies or miscarriages. No birth control has been used at any time.

Occupational History: Her first job at approximately the age of 16 was that of a dial painter at the Waterbury Clock Co. This lasted for about 3 months. She states she did not tip any of the brushes, but she did note that at times her hair would glow in the dark from the dust accumulating at work. After this one job of dial painting, she left the Waterbury Clock Co. and has done some clerical work ever since.

Dental History: She had a few of her front teeth filled before taking the dial painting job and has had occasional fillings from time to time since that time but has lost only four teeth altogether, the last one several years ago.

Physical Examination: Shows a healthy-appearing, rather obese woman of 47 weighing 208 pounds. Blood pressure is 150/100. Pulse is 80 at rest. Examination of the eyes including fundi,

extraocular movements, and pupillary reflexes were all within normal limits. Ears: normal. Nose: normal. Throat: in good condition. Tonsils were not enlarged. Teeth in good state of repair. No gross evidence of pyorrhea. Neck: shows no adenopathy. Thyroid gland shows slight enlargement or at least is fairly palpable. There is no evidence of any thyrotoxicosis such as tremor or undue sweating. Heart and Lungs: normal to A and P. Breasts: normal. No evidence of any masses. Abdomen: obese. Liver and Spleen: not felt. Pelvis examination was not done because patient stated that her own physician did a pelvic examination within the last few weeks and told her there is nothing abnormal. Extremities: normal. Reflexes: equal and active. No limitation of motion in any joints.

Laboratory Findings: Urinalysis: sp. gr. 1.022; albumin and sugar neg; rare crystals. Hematology: wbc 6500, hgb 14.3 g, 91 percent; differential P59, L38, E1, M2; normocytic rbc; hct 47 percent, sed. rate 52 mm/hr.

Blood chemistry:	urea nitrogen	12.9 mg percent
	sugar	100 mg percent
	alkaline phosphatase	5.7 units
	Hinton	negative
Electrophoresis:	total protein	6.8 g/100cc
	albumin	4.3
	total globulins	2.5
	alpha 1	0.29
	alpha 2	0.44
	beta	0.80
	gamma	0.97

X-ray Findings: Skeletal survey shows no evidence of radium poisoning. There are no significant abnormalities in the bones, and the heart and lungs are normal in appearance.

(G. Ki.) Date of birth: October 22, 1909. Present Health: Patient states that her present health is good except for a recent upper respiratory infection of a few days' duration.

Systems Review: Shows an infection in the left ear approximately two weeks ago which has since cleared up. Eyes: normal. She uses glasses for reading. There is no difficulty with the nose and throat. She does not have an abnormal number of colds or sore throats. Cardiorespiratory: entirely negative; question of slight ankle edema, but this occurs in the summer time only. GI: normal. Bowels regular without use of laxatives; no history of any melena at any time. GU: normal except for occasional nocturia. Catamenia: menarche at 14; regular until periods stopped one year ago. There has been no resumption of flow since that time; only rarely has hot flashes. Neuromuscular: entirely normal. There are no skin abnormalities.

Habits: Appetite too good, if anything. There has been a slight weight gain during the past year. She sleeps soundly at night and does not smoke. She does not consume any alcohol. Exercise is minimal except what she does at work and around the house.

Past History: Had the usual childhood diseases but no specific history of scarlet fever, diphtheria, or rheumatic fever. She has been hospitalized for childbirth only; no illnesses of any

consequence except for one episode of temporary loss of vision for a few days before the birth of the last child. She has had no accidents, operations, or injuries.

Family History: Father died at 72, cause undetermined. Mother died at 71 of heart disease. She has three brothers, aged 58, 47, and 43, all living and well. There is no familial history of cancer, diabetes, tuberculosis, epilepsy, or mental illness.

Marital History: Has been married 23 years; husband is 49, living and well. There are two children, aged 19 and 17. There is no history of any stillbirths or miscarriages. There has been no possibility of pregnancy since the birth of the last child as the patient has not cohabited with her husband since that time.

Occupational History: Her first job was that of dial painting at the age of 16 in 1925. She did this work for a period of ten months or more. She did put the brush in her mouth from time to time, but there is no history of any glowing of the hair or hands after work at night. She has had some trouble with her teeth.

Physical Examination: This 48-year-old woman appears to be in good health. She is well developed and nourished. Weight is 127 pounds. Height is 60". Blood pressure is 138/90. Pulse is 80. Head; shows the eyes to be normal. Extraocular movements are normal. Fundi are negative. Ears: show some dullness of the drum but otherwise normal. Hearing appears normal. Nose: neg. Throat: normal. Teeth are in fair state of repair. Neck: shows no evidence of swollen glands. Thyroid is not palpable. Heart and Lungs: normal to A and P. Rhythm is regular; no murmurs were

heard. Breasts: normal female; no masses felt. Abdomen: soft and relaxed. Liver and spleen not felt. Pelvic examination shows question of slight enlargement of the uterus, possibly due to small fibroids. Cervix is normal; no evidence of erosion; no discharge. Rectal examination including hematest: negative. Extremities: normal. Reflexes: equal and active. No limitation of motion of any bones or joints.

Laboratory Findings: urinalysis: albumin and sugar neg. Hematology: wbc 5600; differential P64, L34, M2; normocytic rbc; hct 44 percent, sed. rate 21 mm/hr.

Blood chemistry:	urea nitrogen	14.7 mg percent
	sugar	96 mg percent
	alkaline phosphatase	4.1 units
	Hinton	negative
Electrophoresis:	total protein	7.3 g percent
	albumin	4.87
	globulin	2.43
	alpha 1	0.30
	alpha 2	0.53
	beta	0.80
	gamma	0.80

X-ray Findings: Skeletal series shows no evidence of radium poisoning. There are no significant abnormalities in the bones, and the heart and lungs are normal in appearance.

(M. Kl.) Date of birth: November 9, 1902. Patient was examined by Dr. William H. Baker at the Waterbury Hospital in June 1957. She was admitted to the Waterbury Hospital in 1954 because of fracture of left femur, possibly caused by a weakness in her femur due to deposition of radioactive material. Was hospitalized

about 4-6 months and after a long period the fracture healed. She did not complete weight bearing until about eight months after original fracture. Since then she has been perfectly well and has noticed no particular symptoms, other than occasional palpitation of the heart and feeling of flushing in the head, associated with pounding in her head. She has occasional headaches, which are relieved by aspirin. No pains in other bones. She worked in the Waterbury Clock Co. from January 1921 to January 1924. She painted many, many watches and pointed the brush with her lips. She had numerous dental extractions from 1937 to 1950 with resultant upper and lower dentures.

Past History: Fracture, 1954. Myoma of uterus, age 22, removed at Waterbury Hospital. Hysterectomy, approximately 10 years ago. Hot flashes following hysterectomy. Menses began at 13, flow every 28-30 days. Flowed 3-4 days. She has had no pregnancies or miscarriages or abortions. She was married to one man 14 years. He died about 15 years ago and then she married her present husband.

Family History: Father died at 71 of enlargement of heart. Mother died age 72 of generalized hardening of arteries and a heart attack. She is one of 8 children, of which only 1 brother survived. Six other children died at a very young age.

Systems Review: Not remarkable. Wears glasses, bifocals, has astigmatism and myopia. Bowels move well, does not take cathartics. Appetite good, weight maintained. Occasionally needs removal of wax to aid in hearing but there is no difficulty in hearing afterwards. Hair: brown, with flecks of gray. Scalp loose, not remarkable. Ears: bilateral cerumen but drums appear normal and intact. No

evidence of old perforations. Eyes: pupils round, regular, equal. React to L and A. Fundoscopic did not reveal any abnormalities. EOM normal. Mouth: tonsils absent, removed as a young child. Tongue in midline. Upper and lower dentures. Neck: thyroid in midline, not enlarged. No adenopathy. Chest: clear to P and A. Breasts: virginal in appearance with no pigmentation of nipples. There is a small lymph node in the rt. axilla, measuring about 1.5 cm which is freely movable. No masses in either breast. Heart: PMI in 5th interspace within the midclavicular line, normal sinus rhythm. There is a rate of 78. Blood pressure 120/80. Rt. arm lame. Abdomen: soft, few small pigmented areas on the surface. Liver and spleen not palpable. No masses felt. Peristalsis normal. Abdominal reflexes absent. Pelvic, rectal: not done. No inguinal adenopathy. Neurological: deep tendon reflexes equal and active, 3+. No pathological reflexes present. Extremities: there is some degenerative arthritis of the terminal phalanges and there is deformity of the rt. finger with a swelling on the proximal joint of the 5th finger, rt. hand . Patient says that this is congenital and has been present since birth. Mother also had similar deformity. Impression: Ra-MsTh intoxication, by history.

Laboratory Findings: Urinalysis: sp. gr. 1.020; albumin, sugar, and acetone neg; 2 wbc/hpf, rare epithelial cells. Hematology: wbc 7700, hgb 12.3, hct 41, platelets normal; differential P51, M3, L46.

Blood chemistry:	alkaline phosphatase	3.2 units
	nonprotein nitrogen	41 mg/100 cc
	calcium	10.4
	phosphorus	2.2
	protein electrophoresis	normal

X-ray Findings: special bone survey shows mild radiation osteitis in calvarium, radius and ulna, bilaterally, both femurs.

(M. LaF.) Date of birth: January 10, 1911. Present Health: Stated to be good except for difficulty with her lt. eye, diagnosed as a retinal hemorrhage in January 1958. The vision in this eye is improving. No other complaints.

Systems Review: Shows no other disturbances of the eye, except as noted above. Ears, Nose, and Throat: normal except for tendency to frequent upper respiratory infections. Cardiorespiratory: some cough with colds; otherwise no chest pains or palpitation. No particular dyspnea on exertion. GI: some gas with rich foods; otherwise no nausea or vomiting or bowel disturbances. No melena ever noticed. GU: entirely negative. Catamenia: menarche at age 10 1/2. Periods have always been irregular with very heavy flow until operation in 1949(hysterectomy)- one ovary removed. She has experienced no hot flashes so far. Neuromuscular: entirely negative. No skin disorders.

Past History: Usual childhood diseases plus scarlet fever. No history of scarlet fever or rheumatic fever. She had a proven case of tuberculosis of rt. lung at age 18 and spent 15 months in a sanatorium, treated by pneumothorax therapy for 2.5 years. She has had no recurrence and has had an x-ray nearly every year since. Her only hospitalization and operation was that of the hysterectomy. There is no history of allergy, epilepsy, or mental illness.

Family History: Father died at 42 of pneumonia. Mother is 85, living and well. There are eight siblings, living and well. Two

died in infancy. No other family history of tuberculosis, cancer, or diabetes. One brother has some asthma. No familial history of epilepsy or mental illness or allergy.

Marital History: Married 19 years. Husband is 46, living and well. No pregnancies at any time.

Occupational History: Started work at age of 16 as a dial painter for Waterbury Clock Co. where she worked for 1 year. At no time did she remember putting the paint brush in her mouth. She did notice occasional glowing specks on her hands at home after dark. After 1 year, she was transferred to another department. She has worked at U. S. Time Co. intermittently ever since.

Dental History: Has had trouble with her teeth for many years and started to lose them shortly after she went to work for the Waterbury Clock Co. The last extractions were three years ago.

Physical Examination: Weight 139 lbs. Blood pressure 138/80. Pulse is 80 at rest. Eyes: pupils react normally to light and accommodation. Extraocular movements are normal. Fundi not well visualized at this examination. Ears, Nose, and Throat: normal. Teeth show full upper denture and only a few natural teeth in front still present with partial lower plate. Neck shows no cervical adenopathy. Thyroid not palpable. Lungs: occasional transient rales on the right posteriorly. Heart: normal. Rhythm regular, no murmurs heard. Abdomen: soft and relaxed. Liver and spleen not felt. There is a well-healed lower midline scar. Breasts: normal female. No evidence of masses or cysts. Pelvic and Rectal: not done. Reflexes: equal and active. Extremities: normal.

Laboratory Findings: Urinalysis: sp. gr. 1.021, albumin and sugar negative; occ. rbc and wbc, and 1-2 epithelial cells per hpf. Hematology: wbc 5300; hgb 14.5 g, 93 percent; differential P54, L34, E1, M1, normocytic rbc; hematocrit 45 percent, sed. rate 13 mm/hr.

Blood Chemistry:	urea nitrogen	15 mg percent
	sugar	105 mg percent
	alkaline phosphatase	4.5 units
	Hinton	negative
Electrophoresis:	total protein	6.7 g percent
	albumin	3.84
	total globulins	2.86
	alpha 1	0.31
	alpha 2	0.64
	beta	0.86
	gamma	1.05

X-ray Findings: Skeletal survey shows no evidence of radium poisoning. There are no significant abnormalities in the bones, and the heart and lungs are normal in appearance.

(J. La.) Date of birth: March 11, 1905. Watch dial painter at the Waterbury Clock Co. in 1920, starting at the age of 15 and continuing for 7.5 years. In 1928-9 she was examined by Dr. F. B. Flinn[1] and Dr. S. M. Seidlin who reported that by electroscope she had a body burden of 87 μg of radioactive substance. She has one child, born in 1932 by caesarian section. In the last few years she has developed bilateral cataracts, osteomyelitis of the mandible, ankylosis of the hips. She has had numerous fractures of the ribs and both femurs. X-rays taken

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1. F. B. Flinn, Radiology 23, 331 (1934)

in 1953 showed the medullary cavity to be radiolucent, with alternating sclerotic and radiolucent areas in the head of the femur, acetabulum, and left pubic arch. In October 1957 she was admitted to the Waterbury Hospital for removal of a polyp in the lt. ear canal. Pathological report showed the growth to be a squamous cell carcinoma. She is living but in very poor condition.

(C. La.) For physical and clinical details on this patient see W. P. Norris, T. W. Speckman, and P. F. Gustafson, Am. J. Roentgenol. 73, 785 (1955), and Looney, Hasterlik, Brues, and Skirmont, Am. J. Roentgenol. 73, 1006 (1955). The bone sample was provided by Dr. Robert J. Hasterlik and additional details may be obtained from him at Argonne Cancer Research Hospital, 950 East 59th Street, Chicago 37, Ill.

(A. Le.) Date of birth: January 9, 1910. Present Health: Patient states that she is and has been in good health in recent years. Her last and only hospital stay was for childbirth. Review of systems shows that she wears glasses for reading only and has had no other difficulties with her eyes. Ears are normal. No difficulties with the nose or throat. She has had few upper respiratory infections. Neck: normal. Cardiorespiratory: slight dyspnea only. No substernal pain. No palpitation. She has noticed a minimal amount of edema occasionally towards evening. GI: slight tendency to indigestion with overeating due to questionable gall bladder disease. Bowels are regular without the use of laxatives. There is no history of melena or gross blood in the stools. GU: negative. Catamenia: menarche at 15; always regular and still

regular at the present time. She believes flow to be heavier than it used to be. Neuromuscular: she is subject to occasional pains in the left leg. This has been intermittent during the past year. There have been occasional episodes of low back pain, but these have not been serious. Skin: no abnormalities.

Habits: Appetite is good; no recent weight change. She sleeps soundly at night. Does not smoke. Alcohol averages possibly one drink per day. Exercise consists mostly of housework.

Past History: Usual childhood diseases but no specific history of scarlet fever, diphtheria, or rheumatic fever. No epilepsy, allergy, or mental illness. No history of any severe injuries or fractures. No hospitalizations except as noted above.

Family History: Father died at 90 of accidental death. Mother died at 65. Five siblings. Two are living and well; two were killed in an accident. No familial history of cancer, tuberculosis, allergy, or mental illness. Mother had diabetes at the time of her death, but there is no other family history of this disease.

Marital History: Patient has been married 30 years. Husband is living and well. Three children, aged 28, 24, and 17, living and well. No other pregnancies, stillbirths, or miscarriages.

Occupational History: Began her working career at the age of 17 in 1927 as a dial painter for the Waterbury Clock Co. She continued at this work only for approximately two years because of pregnancy. The pregnancy was uneventful. The children were all normal. She never returned to dial painting. She never put the brush in her mouth. She did occasionally notice some glowing of the hair and hands when she went home at night.

Dental History: In general, her teeth have been good although she did lose one tooth when painting watch dials because of the poor position of the tooth. Whenever she has had to have any teeth extracted, she has never had any difficulty with prompt healing.

Physical Examination: Shows a well-developed, well-nourished woman weighing 139 lbs. Height 5' 4". Blood pressure is 120/80. Pulse is 78 at rest. Examination of the eyes shows extraocular movements to be normal. Pupils react normally to light and accommodation. Fundoscopic examination normal. Ears: show normal canals and drums. Nose: normal. Throat: negative. Teeth: in fair state of repair although one has recently broken off. Neck: shows no enlargement of the thyroid. No glands palpable. Heart and Lungs: normal to A and P. Breasts: normal female. No evidence of any masses. Abdomen: soft and relaxed. Liver and spleen not felt. Pelvic and rectal examinations not done since the patient reports that this was recently done by her own physician. Extremities: normal. Reflexes: equal and active.

Laboratory Findings: Urinalysis: albumin and sugar negative, 10-16 wbc and 3-4 epithelial cells/hpf. Hematology: wbc 8300, hgb 9.7, differential: P69, L27, E1, M3; marked hypochromia; hematocrit 29 percent, sed. rate 0 mm/hr.

Blood Chemistry:	urea nitrogen	16 mg percent		
	sugar	100 mg percent		
	alkaline phosphatase	2.8 units		
	Hinton	negative		
Electrophoresis:	total protein	6.9 g percent		
albumin	4.2 g percent	alpha 2	0.48 g percent	
total glob.	2.7	beta	0.80	
alpha 1	0.26	gamma	1.16	

X-ray Findings: Skeletal survey and routine AP view of the chest revealed no bone pathology with the one possible exception of one area in the left trochanter only, which may represent minimal radiation osteitis. This is probably of no significance and will almost certainly never cause the patient any difficulty.

(H. Ma.) Date of birth: February 19, 1895. For previous history on this patient see R. H. Marshak, R. A. Newburger, and J. Eliasoph, JAMA 160, 41 (1956). Received 24 intravenous injections of radium salts in 1914 at age of 19 for severe arthritis. Teeth were very poor. All had to be removed with great difficulty. Married. Present examination by family physician shows marked changes in the bones, presumably due to radiation osteitis.

(L. Ma.) Born 1909. Luminous dial painter for about three years intermittently between 1927 and 1936, starting at age of 18. No demonstrable effect from radiation 31 years after exposure.

(H. McG.) Date of birth: February 28, 1904. Patient was examined in Waterbury Hospital during June 1957 by Dr. William H. Baker. She was employed by Waterbury Clock Co. for about 1 year from 1924 to 1925 and painted approximately 4-5 trays of watches per day, each tray containing 30-50 watches. She has been perfectlywell all of her life and has had very little difficulty. Her teeth have all been removed at two different intervals, 1948 and 1950. She had no abscesses, now has upper and lower dentures but wears only the upper dentures. Has never been sick. Has never had any fractures or difficulty with her joints. Previously admitted to Waterbury Hospital for an appendectomy.

Habits: Drinks a small amount of beer. Smokes occasionally. Lives at home with two unmarried sisters and keeps house. Is not working at present.

Family History: Mother died, age 57, of tumor of the leg. Has three sisters, all of whom are living and well. Father died at 85 of old age.

Systems Review: Not remarkable. She has a diminution in hearing but otherwise is in very good health. She is constipated and takes Alophen tablets intermittently for this. Her appetite is good and she has maintained her weight consistently.

Physical Examination: Well-developed, well-nourished white female who looks her stated age, in no distress. She was ambulatory and her hair is grayish-white, normal in amount. There is increased venous pattern over the scalp, most prominent in the temporal areas. Eyes: pupils round, regular, equal, react to L and A. Fundoscopic showed increased tortuosity and slight AV nicking. Ears: negative. Throat: tonsils present, small, atrophic. She has upper denture, no difficulty with her gums. Tongue in midline and protrudes without any evidence of fibrillation. Neck: thyroid palpable. There is a small nodule in the rt. lobe of the thyroid which measures about 1 cm. No cervical adenopathy. Axillae negative. Breasts: virginal. No pigmentation of nipples. There is increased fibrous nodularity throughout both breasts, but no masses palpated. No axillary nodes felt. Heart: normal sinus rhythm. Rate 75. PMI at 5th interspace within midclavicular line. No murmurs. P2 greater than A2. Very prominent P2 heard. Chest: clear to P and A. No CVA tenderness. Abdomen: liver not percussible. No abnormal masses. Peristalsis normal.

Pelvic, Rectal: refused. Neurological: deep tendon reflexes equal and active bilaterally, 2+. No abnormalities. Extremities: no evidence of nodes of the hands. On the soles of both feet, there are corn tags for callouses and another corn plaster on the medial aspect of the rt. toe. Impression: No evidence of difficulty from her ingestion of radium and mesothorium.

Laboratory Findings: Urinalysis: sp. gr. 1.020, albumin and sugar negative; 2 wbc and rare epithelial cells/hpf. Hematology: wbc 7700, hgb 12.3, platelets normal, differential P51, M3, L46, hematocrit 41.

Blood Chemistry:	nonprotein nitrogen	31 mg/100 cc
	alkaline phosphatase	1.8 units
	calcium	10.4
	phosphorus	2.0
	electrophoresis	normal.

X-ray Findings: Bone survey, including heart and lungs, is essentially negative, except for the skull which shows changes consistent with radiation osteitis.

(I. Ni.) Born October 1900. After the birth of her first child in April 1927 she developed phlebitis and her physician advised her to take Radithor, starting in June or July of 1927. This was obtained from the Bailey Radium Laboratories in East Orange, N.J. For the first month, she took three bottles a day and for two months thereafter took approximately two bottles a day. The phlebitis gradually improved and her general health seemed to be excellent. Following the death of Mr. Eben Byers who had also taken Radithor, she became somewhat alarmed and went to see Dr. F. B. Flinn.

Dr. Flinn followed her case for the next 3-5 years, took many x-ray pictures, and examined her with a geiger counter. Her second child was born in 1936 and during the next few years she had considerable trouble with her teeth. Whenever any extractions were done they were extremely slow to heal up. In 1944 she broke her lt. kneecap and from that time to the present has had multiple bone fractures, usually spontaneous, the last being a fracture of the rt. femur 6 months ago. According to her family physician, x-rays taken in 1958 showed radiation osteitis, marked.

(R. Os.) Date of birth: January 4, 1909. Present Health: Patient says that she is and has been well in recent years except for some pains in the region of both hips for the past year, left greater than right. Pain goes away with rest.
Systems Review: Shows a tendency to hay fever in spring and fall. She wears glasses for reading. Nose and throat are normal except for occasional upper respiratory infections and hay fever noted above. Cardiorespiratory: for the past three years she has been subject to intermittent pains in the substernal region which she believes are more pronounced and more frequent after exertion. GI: negative. There is no history of any indigestion, nausea, or vomiting. Bowels are regular without laxatives. There is no history of any blood in the stools. GU: normal. Catamenia: menarche at 15, always regular until three months ago when they stopped entirely. Hot flashes, if any, have been infrequent. Neuromuscular: has a tendency to headaches but she notices that if she eliminates eggs from her diet these are much less frequent. She has some pain in the rt. index finger and some paresthesia of the fingers of both hands, also pains in the region of the hips noted above. No skin disorders were noted.

Habits: Appetite is good, too good if anything, although she thinks that she has reduced a total of 10 lbs. in the last year of diet. She sleeps soundly at night. She does not smoke. Alcohol minimal to none. Exercise is considerable at work where she does a lot of walking.

Past History: Had the usual childhood diseases, including scarlet fever, but no specific history of diphtheria or rheumatic fever. She has had no operations at any time. She was hospitalized for childbirth only.

Family History: Father is 82 and living but has had a shock of some sort. Mother is living and well, 80 years old. Six siblings living, ranging in age from 33 to 52 and all are well. There were six other siblings who died in the neonatal period, cause undetermined. There is no familial history of cancer, diabetes, or tuberculosis; no mental illness, allergy, or epilepsy in the family.

Martial History: Has been married 30 years. Her husband is 59, living and well. Four children, living and well, are aged 29, 20, 16, and 12. The second child died at birth, cause presumably was cord wrapped around the neck. Her 29-year-old son is married and has three children. All of the patient's children and grandchildren seem to have developed normally, although the 16-year-old child has what is presumably epilepsy and is being treated for same.

Occupational History: Her first job was dial painting which she began at the age of 16 in 1925 and which she continued for 20 mos. She did some tipping of the brush in her mouth. She noticed definite glowing of the hair and hands at night after working in the dial painting room. No further contact with radium since her marriage.

Dental History: She first started to lose her teeth while she was painting dials at the age of 16, and two teeth were removed during this first year. Her teeth were always very brittle and broke easily. Finally on the advice of her dentist all teeth were removed 15 years ago.

Physical Examination: Shows a well-developed and well-nourished moderately obese woman of 49, weighing 170 lbs. Height 61.5". Eyes: show pupils react normally and equally to light and accommodation. Extraocular movements are normal. Fundi are normal. Ears: drums are normal. Canals are normal. Nose and Throat: normal. Mouth: clean, Teeth are all absent. Patient wears upper and lower plates. Neck: no evidence of adenopathy. Thyroid is not palpable. Heart and Lungs: normal to A and P. Rhythm is regular. No murmurs were heard. Breasts: normal female. No masses were felt. Abdomen: soft and relaxed. Liver and spleen not made out Pelvis: questionable slight enlargement of the uterus , possibly due to fibroids. Cervix is smooth and clean, no evidence of erosion or discharge. Rectal: including hematest, negative. Extremities: Normal. There is no limitation of motion of any joints. Reflexes: equal and active.

Laboratory Findings: Urinalysis: sp. gr. 1.025, albumin and sugar negative, 20-25 epithelial cells/hpf. Hematology: wbc 8400, hgb 13.3 g, 85 percent; differential P37, L60, M3; normocytic rbc; hematocrit 45 percent, sed. rate 16 mm/hr.

Blood Chemistry: urea nitrogen 14 mg percent, sugar 122 mg percent, alkaline phosphatase 3.5 units, Hinton negative.

Electrophoresis: total protein 7.4 g percent

albumin	4.55	alpha 2	0.48
globulin	2.85	beta	0.84
alpha 1	0.37	gamma	1.16

X-ray Findings: Skeletal survey shows no evidence of radium poisoning. There are no significant abnormalities in the bones, and the heart and lungs are normal in appearance.

(G. Pa.) Date of birth: November 19, 1910. Present Health: Patient states that she is in good health and has been, except for some back pains, for the last two or more years. Systems Review: Shows the eyes to be normal; she wears glasses for reading only. She has no difficulty with ears and hearing. Nose and Throat: normal. Few colds experienced. Neck: no enlargement of the thyroid gland detected. No swollen glands. Cardiorespiratory: shows no abnormalities except for occasional palpitation. This palpitation is not related to exertion as far as she knows. Otherwise no difficulties. GI: normal. Bowels fairly regular without laxatives. No history of melena or gross blood in the stools. GU: negative. Catamenia: menarche at 11.5 years. Regular until two years ago but since that time she has skipped several months. Neuromuscular: essentially negative until two years ago when she developed a kink in her back for a period of two weeks. This was followed by intermittent pains down the left leg for two to four months and was not relieved by lying down. On the advice of her physician, she was referred to a Boston physician for x-rays and further diagnosis. It was decided that she was suffering from a question of disc disorder.

She has had several episodes of a similar nature since that time. She now wears a firm corset which she feels helps with this tendency. She is also subject to sudden occipital headaches for the last 10 years. These last from seven to ten days when they occur. No skin disorders, except for one episode of lichen planus lasting five months which came on three years ago. This was eventually cleared up without difficulty.

Habits: Her appetite is good. There has been no recent wight change. She sleeps fairly well. She smokes 10 to 15 cigarettes daily. Alcohol taken only rarely. The only exercise which she gets is doing her housework.

Past History: Had the usual childhood diseases, but no specific history of scarlet fever, diphtheria, or rheumatic fever. No operations, accidents, or injuries. No confining illnesses. She was hospitalized for childbirth only.

Family History: Father died at 73 of heart disease. Mother died at 59, also of heart disease. She has three brothers living and well, ages 53, 50, and 46. There is no familial history of cancer, diabetes, tuberculosis, mental illness, epilepsy, or allergy.

Marital History: She has been married 26 years. Her husband is 54, living and well. There are two children, aged 25 and 13. The older child is married and now has one child of her own. The lack of other pregnancies may probably be attributed to precautions taken by the patient to prevent pregnancy.

Occupational History: She went to work for the Waterbury Clock Co. in 1927 for a period of four months. She does not remember pointing the brush in her mouth. She did notice occasional luminescence on

her clothes at night. Because of this she was forbidden to return to the dial painting work by her parents.

Dental History: Has had very little trouble with her teeth. She has lost only a few in her lifetime.

Physical Examination: Shows a healthy-appearing, well-developed and nourished woman of 47 in no distress. Weight 160 lbs. Height 5'3". Blood pressure 152/100. Pulse 70 at rest. Eyes: show normal extraocular movements. Pupils react normally to light and accommodation. Fundi are normal. Nose: normal. Ears: neg. Throat and Teeth: in good condition. Neck: shows no enlargement of the cervical glands. Thyroid not palpable. Heart and Lungs: normal to A and P. Breasts: normal female, without evidence of masses. Abdomen: soft and relaxed. No masses felt. Pelvic: small fundus in good position, ovaries not palpable, cervix shows 1+ erosion probably of a benign type. Rectal: including hematest, negative. Extremities: normal. Reflexes, superficial and deep: equal and active.

Laboratory Findings: Urinalysis: sp. gr. 1.029, albumin and sugar negative; 4-6 epithelial cells, 2-3 wbc, and 1-2 rbc/hpf. Hematology: wbc 5100, hgb 14.9 g, 96 percent; differential P59, L39, M2; normocytic rbc, hematocrit 45 percent, sed rate 20 mm/hr. Blood Chemistry: urea nitrogen 18 mg percent, sugar 87 mg percent, alkaline phosphatase 3.5 units, Hinton negative. Electrophoresis: total protein 7.7 g percent, albumin 5.06, total globulins 2.64, alpha 1 0.25, alpha 2 0.42, beta 0.68, gamma 1.29.

X-ray Findings: Skeletal survey shows no evidence of radium poisoning. No significant abnormalities in the bones. Heart and lungs are normal.

(M. Pa.) Tissue on this case was received from Dr. Merril Eisenbud. Further information can be obtained from him at the U. S. Atomic Energy Commission, New York Operations Office, 70 Columbus Avenue, New York 23, N. Y.

(D. Ra.) Date of birth: October 12, 1899. Present Health: Patient states that it is good. She says that she is under treatment for high blood pressure and has a tendency to be somewhat nervous; otherwise she feels well.

Systems Review: Reveals no definite difficulty with eyes, ears, nose, or throat. Cardiorespiratory: negative. She admits to no chest pain or shortness of breath and denies any swelling of the ankles. GI: normal. Bowels move regularly without laxatives. No history of blood in the stools. GU: negative, except for occasional nocturia. Catamenia: periods were always regular until menopause many years ago. There has been no bleeding since. Neuromuscular: negative. There is no complaint of skin disorders.

Past History: Shows the usual childhood diseases but no specific history of scarlet fever, diphtheria, or rheumatic fever. There is no mental illness, epilepsy, or allergy in the family. She denies any hospitalizations other than that for childbirth. Her only operation was incision and drainage of infected gland in the neck many years ago.

Family History: Father died at 70, cause not stated. Mother is still living but badly crippled with arthritis. There are six siblings, all living and well, ranging in age from 57 to 47.

Marital History: She has been married over 30 years. Husband is living and well. There was one child that died of infantile paralysis. No other pregnancies.

Occupational History: Patient's first and only job at dial painting began at the age of 20 in November 1920 and continued through March of 1921.

Dental History: Had no trouble with her teeth for three or four years after she left the dial painting job. Most of her difficulty came at the time of her pregnancy. A few years ago all of the teeth were removed and she now wears both upper and lower dentures.

Physical Examination: Shows an alert, somewhat overactive woman of 58 in no apparent distress. Weight 113 lbs, height 62.5". Blood pressure is 170/110. Pulse is 90. Eyes: show extraocular movements to be normal. Pupils react to light and accommodation normally. Ears: normal. Nose and Throat: negative except for small wart inside left nostril. Heart and Lungs: normal to A and P. Heart rate is regular. No murmurs were heard. Examination of abdomen and pelvis was not done due to the extreme nervousness and apprehension of the patient. Reflexes: somewhat hyperactive. Extremities: normal.

Laboratory Findings: Urinalysis: albumin 1+, sugar negative, microscopic: loaded with wbc/hpf. Hematology: wbc 7600, hgb 16.1 g, 103 percent, differential P72, L27, E1; normocytic rbc, hematocrit 47 percent, sed. rate 23 mm/hr.

Blood Chemistry: nonprotein nitrogen 44 mg percent, sugar 99 mg percent, alkaline phosphatase 5.2 units, Hinton negative.

Electrophoresis: total protein 7.7 g percent, albumin 4.87, total globulins 2.84, alpha 1 0.30, alpha 2 0.50, beta 0.90, gamma 1.14.

X-ray Findings: Skeletal survey shows no evidence of radium poisoning. There are no significant abnormalities in the bones, and the heart and lungs are normal in appearance.

(A. St.) Clinical information on this patient was reported by Dr. H. S. Martland in Occupational Tumors, part 6, Bones, International Labor Office, Occupation and Health, Geneva, October 1939. The bone specimen was received from Dr. F. E. Hoecker, Department of Physics, University of Kansas, Lawrence, Kan.

(L. St.) Date of birth: April 4, 1874. This physician had a good deal of exposure to radium and x-ray externally between 1905 and 1915. He has had considerable trouble with skin lesions on both hands resulting in the loss of one finger. Skin grafting was done approximately 20 years ago. He has some atrophy of the skin at the present time on his hands.

(P. Te.) Date of birth: 3 August 1910. Present Health: Patient states that she feels perfectly well except for a tendency to nervousness at times of stress. She has a tendency to high blood pressure which has been present for several years, particularly at times of examinations.

Systems Review: Shows tendency to frequent colds and sore throats, but otherwise no difficulties with the eyes, ears, nose, or throat. Tonsillectomy at age 13. Cardiorespiratory: entirely negative.

GI: normal. Bowels move regularly without laxatives. No history of melena or rectal bleeding. GU: normal. Catamenia: menarche at 13 and all was regular until the age of 41. Since then periods have become more and more irregular. Now no flow for the last six months. Neuromuscular: has had bursitis in the lt. shoulder. Last attack was three years ago. No difficulties since. Broke her rt. arm in childhood. Skin: normal.

Habits: Appetite is too good, if anything. There has been a gradual weight gain in recent years. Sleep is somewhat variable. Smokes approximately one package of cigarettes daily. Alcohol averages two to three drinks per week. Exercise is irregular.

Past History: Had usual childhood diseases but no specific history of scarlet fever, diphtheria, or rheumatic fever. She has been hospitalized for one of these throat infections at the time of the birth of her only child. No other accidents, injuries, or operations.

Family History: Father died at 57 of a cerebral accident. Mother died at 69 of cancer of the breast. Four siblings ranging in age from 41 to 53. All are living and well. Siblings are all married and all have children. No other familial history of cancer. No history of tuberculosis or diabetes.

Marital History: Married at age of 25 and remained married for 15 years when her husband died at 42 of a heart attack. One child, a boy, 15 years old, living and well. For the first year of married life took precautions to keep from getting pregnant. Her husband then went into the service after her only child was born. On his return and before he died precautions were taken to prevent pregnancy. She had no miscarriages at any time.

Occupational History: She painted dials for approximately 15 months at the age of 15, averaging 140 dials per day. She definitely remembers pointing the brush with her tongue during this period of time.

Dental History: One tooth was removed during the time she painted dials because of pyorrhea. She has continued to have a tendency to pyorrhea ever since although she has lost only six teeth in this time. The last one was removed about 1 month ago because of an infected root.

Physical Examination: Shows a rather obese woman of 48 in no apparent distress. Weight is 180 lbs. Blood pressure is 150/100. Pulse is 88 and regular. Eyes: show normal movements. Pupils react normally to light and accommodation. Fundi appear normal. Ears: normal. Drums are intact. Nose: normal. Throat: shows no evidence of infection at this time, Teeth show tendency to pyorrhea particularly in the rear molars. Neck: normal. Thyroid is not palpable. Heart and lungs: normal to A and P. Breasts: rather large but otherwise normal. No masses were palpable. Abdomen: soft and relaxed. Liver and spleen were not felt. Pelvic examination shows small uterus. Ovaries not palpable. Cervix appears to be in good condition. There is no evidence of any discharge. Rectal: including hematest, negative. Extremities: normal with good dorsalis pedis pulsations. Reflexes: equal and active.

Laboratory Findings: Urinalysis: sp. gr. 1.019, albumin and sugar negative, 2-3 wbc and 0-1 epithelial cells/hpf. Hematology: wbc 8400, hgb 16.1 g, 103 percent, differential P50, L50: normocytic rbc, hematocrit 49 percent, sed. rate 20 mm/hr. Blood Chemistry: BUN 16.5 mg percent, sugar 123 mg percent, alk. phos. 13.5 units, Hinton neg. Electrophoresis: total protein 6.4 g/100 cc, albumin 4.2, total globulins 2.25, alpha 1 0.30, alpha 2 0.46, beta 0.69, gamma 0.80.

X-ray Findings: Skeletal survey shows no evidence of radium poisoning. There are no significant abnormalities in the bones, and the heart and lungs are normal in appearance.

(J. Un.) For previous history, see Medicine 31, 289 (1952). Patient died of cancer of the lung in 1957.

(R. Wi.) Clinical information on this patient was reported by Aub, Evans, Hempelmann, and Martland in Medicine 31, 221 (1952), and by Looney, Hasterlik, Brues, and Skirmont in Am. J. Roentgenol. 73, 1006 (1955). Physical measurements were reported by Norris, Speckman, and Gustafson in Am. J. Roentgenol. 73, 785 (1955). The bone sample was provided by Dr. William P. Norris, Argonne National Laboratory, P. O. Box 299, Lemont, Ill.

(K. Wd.) For previous history, see Medicine 31, 273 (1952). Physical examination in1957 by Dr. Richmond Ware showed the patient to be in good condition.

(K. Wds.) Date of birth: January 9, 1901. Present Health: Patient states that her present health is good except for a recent upper respiratory infection.
Systems Review: Shows that her eyes have given her no trouble except for wearing glasses for reading. She has had no trouble with her ears. No nosebleeds. Throat: negative. Few sore throats or colds. No history of any swollen glands. Cardiorespiratory: nothing of importance to report except some dyspnea on exertion which she attributes to being overweight. GI: negative. Bowels regular without laxatives. No history of any blood or melena at

any time. Catamenia: menarche at 16. Periods always regular until panhysterectomy done in 1948 for fibroids. Neuromuscular: some stiffness and soreness of the rt. forearm for the past six months which she has noted has come on since a change of job which requires much more writing than she has been used to doing. Skin: no history of any disorders.

Habits: Appetite too great, if anything, with gradual weight gain during the past three years. Sleeps poorly at night. Rarely sleeps more than five hours per night. Patient has never smoked. Alcohol consumption practically nil. She gets little, if any, regular exercise.

Past History: Shows usual childhood diseases. She states she had what was called "rheumatism" but definitely no rheumatic fever. There was no specific history of diphtheria or scarlet fever. Hospitalizations consist of one for the hysterectomy noted above. Her only other illness was an attack of virus pneumonia which laid her up for a period of three weeks.

Family History: Father died at 47 of heart disease. Mother living and well at 88. Two sisters living and well, one 58 and one 60. One brother, aged 75, living and well. One sister died at the age of 65 of carcinoma of the kidney; otherwise no familial history of cancer. There was no sign of any diabetes, tuberculosis, mental illness, or epilepsy in the family.

Marital History: Patient has never been married.

Occupational History: Patient started to work painting dials with luminous paint in 1920 when she was 19 years old. She continued to paint intermittently for the next 10 or more years. States she was always careful not to get any of the paint in her mouth, even though she tipped the brush with her tongue.

Dental History: Shows a moderate number of dental caries throughout the years and the loss of several teeth.

Physical Examination: Shows an obese but otherwise healthy-appearing woman of 57 weighing 216 lbs. Height 62.5". Blood pressure 130/88. Pulse is 118 at rest. Examination of the eyes showed pupils react normally and equally to light and accommodation. External ocular movements are normal. Fundi are normal. Ears: good light reflex of drum. External canals are normal. Nose: normal. Throat: neg. Teeth: in poor state of repair, marked pyorrhea in some instances. Neck: shows no adenopathy. Thyroid not palpable. Heart and Lungs: normal to A and P. This, however, was not too accurate because of the obesity. Breasts: normal. No tenderness or masses felt. Abdomen: obese. There is a well-healed, lower midline scar. Liver and spleen not felt. Inguinal rings were normal. Pelvic and rectal not done. Extremities: normal. Reflexes: equal and active.

Laboratory Findings: Urinalysis: sp. gr. 1.021, albumin and sugar neg., 1-2 epithelial cells/hpf. Hematology: wbc 9200, hgb 14.9 g, 96 percent, differential P65, L34, M1, normocytic rbc; hematocrit 43 percent, sed. rate 39 mm/hr.

Blood Chemistry: urea nitrogen 14.1 mg percent, sugar 123 mg percent, alkaline phosphatase 5.4 units, Hinton negative. Electrophoresis: total protein 7.2 g percent, albumin 4.6, globulin 2.65, alpha 1 0.27, alpha 2 0.54, beta 0.90, gamma 0.94.

X-ray Findings: Skeletal survey shows no evidence of radium poisoning. There are no significant abnormalities in the bones, and the heart and lungs are normal in appearance.

Appendix 2

Multichannel Analyzer Resolving Time

The resolving time of this analyzer is a function of two fixed time intervals. One is the gating time T at the input (50 μsec) during which time an input pulse height is written as an angular deflection on the one-shot circular trace. The other is the access time T_1 to the memory (3200 μsec). Since T_1 is appreciably longer than T, it is possible that more than one count per a particular channel will accumulate in temporary storage during T_1. Thus, at permanent storage writing time for a particular channel, more counts than can be accepted for permanent storage in that channel may have accumulated. It is possible to accept one or two such counts, but not three or more. This is the case since an add-1 pulse becomes an add-2 when it is delayed by 2 μsec at the binary adder add-1 input. Thus it is only necessary to delay adding time by 2 μsec to store the number 2. The number 3 cannot be handled in this manner since two bits are required to write in binary form.

It is assumed in the following discussion that the analyzer will accept for permanent storage one or two pulses per channel in T_1, and will record the number two when three or more pulses occur in one channel.

The input spectrum to be analyzed represents a stationary random process. The number of pulses occurring in a given time interval follows a Poisson distribution. If the average counting rate (average pulse repetition rate) is k pulses per second, the probability of n pulses occurring in the interval T is P(n,T), where T is the analyzer input gating or dead time.

$$P(n,T) = \frac{(kT)^n}{n!} e^{-kT} \qquad (1)$$

The probability that a pulse is not lost during the dead time of the instrument is P(0,T) which is the probability that no pulse appeared.

$$P(0,T) = e^{-kT} \qquad (2)$$

P(0,T) is also approximately equal to the percentage of pulses counted. If the dead time is small compared to the average period between the incoming pulses ($kT << 1$), the number of pulses counted N_c is related to the total number N_t that appeared by

$$N_c = e^{-kT} N_t \approx (1 - kT) N_t \qquad (3)$$

The dead-time loss correction due to T is made by multiplying the entire spectrum by $1/(1 - kT)$.

Now consider the count loss (due to T_1) in a single channel of the analyzer where the average counting rate in the particular single channel is k' pulses per sec. If one pulse appears in T_1 (3200-μsec storage cycle time), it will be recorded. If two pulses appear, they both will be recorded. If three or more pulses appear, only two will be recorded.

This information plus the properties of the Poisson distribution enables us to estimate the total number of pulses counted on the average in the period T_1. N_c' is the number of pulses counted; T_1 is the 3200-μsec memory access time.

$$N_c' = 0 \cdot P(0,T_1) + 1 \cdot P(1,T_1) + 2\left[P(2,T_1) + P(3,T_1) + \cdots\right]$$

$$= P(1,T_1) + 2\sum_{n=2}^{\infty} P(n,T_1) \qquad (4)$$

During T_1 an average of $k'T_1$ pulses will occur. Therefore, the percentage of information lost during this period is given by

$$\text{Percent counts lost} = 1 - \frac{N_c'}{k'T_1} = 1 - \frac{P(1,T_1) + 2\sum_{n=2}^{\infty} P(n,T_1)}{k'T_1} \qquad (5)$$

It is true that the $\sum_{n=0}^{\infty} P(n,T_1) = 1$, since it is a certainty that some number of pulses from zero to infinity will occur during any period T_1. The percentage of counts lost may then be evaluated.

$$\sum_{n=2}^{\infty} P(n,T_1) = 1 - P(0,T_1) - P(1,T_1) \qquad (6)$$

$$\text{Percent counts lost} = 1 - \frac{P(1,T_1) + 2\left[1 - P(0,T_1) - P(1,T_1)\right]}{k'T_1} \qquad (7)$$

$$\text{Percent counts lost} = 1 + e^{-k'T_1} + \frac{2}{k'T_1}(e^{-k'T_1} - 1) \qquad (8)$$

Equation (8) gives the percentage of counts lost in a given channel in terms of the counting rate <u>in that channel</u>. For T_1 = 3200 μsec, the percentage of counts lost between the temporary storage read-in and read-out is tabulated below.

k' (counts/sec for a single channel)	Percent counts lost
1	0.000177
10	0.01022
100	1.8
300	9.8
1000	45.5

It is evident that the percentage of pulses lost in a given channel varies as the counting rate in that channel. This means that each channel of the resulting spectrum must be corrected independently according to its own counting rate.

In summarizing the statistical properties of the analyzer it is seen that two corrections are required on each measured spectrum. First, the entire spectrum must be multiplied by $1/(1 - kt)$, where k = total count in all channels/running time, and T = 50 μsec. The count in each channel must then be multiplied by 1/(1 - percent counts lost), where the percent counts lost is given by Eq. (8). The k' used in Eq. (8) is the average counting rate for the particular channel: k' = total count in channel/running time. This correction is good provided 50 μsec is small compared to the average period between incoming pulses. For example, consider a spectrum in a 100-channel analyzer. The maximum channel counting rate of 100 pulses per sec occurs in any single channel from 1 to 100. For most spectra if the maximum counting rate for a single channel is 100 pulses per sec, the average counting rate for all channels is at least 10(100) pulses per sec. For a 1000-pulse-per-sec over-all counting rate, there is lost $kT = 1000(50 \times 10^{-6}) = 0.05$ (5 percent) of the input pulses due to analyzer input dead time. At this counting rate the

busiest channel loses only an additional 1.8 percent due to the statistical properties of the temporary storage system.*

(J. F. Frazer and R. J. Massa)

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