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Annual Progress Report

Contract AT(30-1)-952

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

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11. Individual Medical Reports

During the past year the medical work of the Radioactivity Center has continued on well-established lines. Former dial painters and others exposed to radioactive materials have been interviewed with respect to their exposure. Their medical history has been obtained, and breath samples have been collected. Where the level of the breath samples was at or above 0.02 μc Ra^{226}, the person was brought to M.I.T. for more complete testing and for a physical examination. While at M.I.T., x-ray, blood, and urine studies were also carried out. The exhumation program has continued and 9 such examinations have been completed, ranging in place from northern New Hampshire to Ohio and Maryland.

This year marks the first instance of an event which it is hoped will be repeated in the future. Case 01-139 who had a Ra body burden of 1.27 μc following ingestion of Radithor in the 1920's died in August 1964. In accord with carefully prearranged plans agreed upon by the deceased, his body was sent to M.I.T. for intensive study at the Radioactivity Center. As can be imagined, this situation raised several procedural problems that have been met successfully and which will pave the way for other cooperative patients who have expressed in writing their desire to do likewise.

The Clinical Research Center at M.I.T. was completed during the past year with funds supplied by the National Institutes of Health. Since the Radioactivity Center was one of several groups interested in this Center, it was with much gratification that this facility became available this spring. A Radithor case (01-175) was admitted to the Clinical Research Center for body burden and excretion studies. Having trained personnel used to collecting excreta expedites this procedure and makes for a much more accurate result. It is even more advantageous to have this facility on the same campus as the Radioactivity Center.

A trip to Florida by the chief medical officer of the Radioactivity Center in connection with some other duties in April 1965 afforded an opportunity to check up on over a dozen Ra cases that had moved to that state in the past decade. The importance of personal contact with these persons becomes apparent after such a trip when compared with telephone and letter communications.

Attempts have been made for several years to get in direct touch with a known case of injury following a Ra injection in a western city (see Case 01-302, 1960 Progress Report). Her body burden was estimated as 0.5 μc Ra on the basis of one breath sample in 1959 which was provided by her present physician. Until recently we had been balked by the unwillingness of the physician involved to let us interview the patient. When quite independently the lady in question went to the Mayo Clinic for treatment, that hospital notified the Ra study group at the Argonne National Laboratory. Through them we were able to examine x-rays taken in Chicago and consequently were at least able to get some indication of her x-ray score.

During the year Case 01-028, described first in Medicine (1952) died in a drowning accident.

Case 1 [illegible] (a former Waterbury dial painter) was hospitalized with what was presumed to be a spontaneous fracture of the femur.

The medical results on cases studied this year are contained in Tables 15 and 16 and in the Case History Summaries. For complete details, please refer to the Appendix.

(R. D. Evans, A. G. Braun, H. F. Braun, S. D. Clark, M. M. Costello, E. D. Dillon, J. A. Foley, J. E. Gary, A. T. Keane, R. J. Kolenkow, C. J. Maletskos, D. McIntyre, R. H. Ryder, M. M. Shanahan, N. C. Telles, and S. C. Utz)

12. Central Catalog

During the past year cards have been prepared and distributed to all depositories on 54 radium cases from the M. I. T. series. There have been two additional pages added to the code book relating to the assignment for punching purposes of prefix numbers (01, 02, 03, etc.), and to the assignment of one hole designating the control series currently under study by the New Jersey group.

Formerly all our x-ray copies were made by the LogEtronic method at the Maxfield Clinic in Dallas, Texas. The recently developed Eastman Blu-Ray radiograph [illegible]plicator provides copies of equivalently good quality. It has been purchased by the [illegible]adioactivity Center and our films are now being copied locally. The easy availability of this copier facilitates the duplication of x-ray films which are stored for safekeeping outside of the M. I. T. area.

(M. M. Shanahan and A. L. Arvanian)

Table 15. 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 16. Complete histories are given in the appendix, 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 15. Summary of Physical Findings and Body Burdens of Dial Painters.

Case no., date of birth	exposure: duration and date	est. Ra content (μc)	years after initial exposure	age at beginning of exposure	effects of exposure	brush tipping	dental pathology	marital status	no. of children	past medical history	physical examination	x-ray findings bones (score)	lab findings	present health
01-054 1909	~3 yrs. 10 mos. 2 Apr 1924 - 11 Feb 1928	2.10	13-1/2	14	fatal	0	2+	M	-	fracture rt. femur 1933	not done	exhumation: moderate changes, score 11	not done	died 20 July 1937, Ra poisoning
01-052 1910	~2 yrs. 9 mos. 1924-1927	2.00	5-1/2	13	fatal	4+	4+	S	-	osteomyelitis of jaw	had meningitis secondary to osteomyelitis of jaw	exhumation: advanced changes, score 11-1/2	unknown	died 6 Jan 1930, brain abscess, Ra poisoning
01-019 1903	~5 yrs. 1922-1926	0.243	14	~19	fatal	4+	4+	M	0	-	not done	exhumation: minimal changes, score 5	not done	died 17 Jan 1936, giant cell tumor of jaw
01-264 1910	~20 yrs. 1944-1964	0.09	21	38	none	0	-	M	-	paranoia	not done	not done	not done	in mental hospital
01-147 ~1902	6 mos., 1917-1918	~0.07	48	15	none	4+	-	M	-	-	not done	not done	not done	good
01-379 1909	19 Jan - 5 Mar 1926	0.032	38	16	none	3+	3+	M (2)	6, 1 misc.	noncontributory	negative	negative, score 0	negative	good
01-252 1898	2 yrs., 1917-1919	0.02	~48	18	none	-	3+	M	0	traumatic fractures of femur and toe	not done	not done	not done	good
01-448 1907	16 Oct - 27 Nov 1925	0.02	19	17	none	2+	-	D	-	-	not done	not done	not done	apparently good
01-236 1910	3 mos., 28 July - 28 Sep 1922	≤0.02	12	16	none	0	1+	M	4, 2 misc.	noncontributory	not done	not done	not done	good
01-130 1909	17 Feb 1926 - 8 Oct 1928; 20 Nov 1928 - 11 Oct 1929; 10 Aug - 17 Nov 1932	0.011	38-1/2	16	none	4+	1+	M	5, 2 misc.	noncontributory	negative	polypoid filling defect rt. antrum, score 0	a few atypical lymphocytes	good
01-094 1891	~2-1/2 yrs. 18 July 1921 - 23 Nov 1922; 1 May 1923 - 2 July 1924	≤0.01	33-1/2	30	none	4+	-	M	0	noncontributory	not done	not done	not done	good
01-122 1912	~1 yr., 26 Sep 1927 - 1 Sep 1928	≤0.01	37-1/2	15	none	0	1+	M	0	noncontriburtory	not done	not done	not done	good

Table 15 (cont)

Case no. date of birth	exposure: duration and date	est. Ra content (μc)	years after initial exposure	age at beginning of exposure	effects of exposure	breast tissue	dental pathology	menstrual status	no. of children	past medical history	physical examination	x-ray findings: bones (scored)	RA findings	present health
01-254 1910	2 wks., 2 - 15 Feb 1927	≤0.01	38	16	none	0	1+	M	4	noncontributory	not done	not done	not done	good
01-301 1919	~2 yrs., July 1940 - July 1942	<0.01	23	23	none	0	1+	M	2	mild diabetes, hypogonadism	not done	not done	not done	good
01-327 1908	~1 wk., 28 Oct - 2 Nov 1927	≤0.01	37-1/2	19	none	0	2+	M	1	obesity, mod cardiac decompensation	not done	not done	not done	poor
01-332 1912	8 Aug 1927 - 2 Aug 1928	≤0.01	37	14	none	0	-	-	-	–	not done	not done	not done	good
01-364 1911	8-1/2 yrs., 31 Jan 1927 - 10 June 1935	≤0.01	37	16	none	0	1+	M	1	noncontributory	not done	not done	not done	good
01-435 ~1907	20 Oct - 24 Nov 1925	≤0.01	39	18	none	1+	3+	M (2)	4	possible malignant adenoma of thyroid	not done	not done	not done	fairly good
01-436 1895	31 Jan 1927 - 20 July 1929; 9 Oct - 8 Dec 1933, 15 Feb - 10 Dec 1934	≤0.01	37	31	none	0	-	M	0	mild diabetes	not done	not done	not done	fairly good
01-446 1907	2 - 3 Dec 1925	≤0.01	39	18	none	1+	-	-	-	–	not done	not done	not done	apparently good
01-468 1910	3 - 4 Mar 1927	≤0.01	38	16	none	0	3+	D	1	arthritis, Parkinson's disease	not done	not done	not done	poor
01-470 1912	17 Oct 1927 - 6 Aug 1928; 12 Sep 1928 - 22 Mar 1929.	≤0.01	37	15	none	0	-	M	3	noncontributory	not done	not done	not done	good

Table 16. 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 the appendix, 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 16. Summary of Physical Findings and Body Burdens of Individuals Exposed to Radioactive Materials by Means Other Than Dial Painting

Case no., date of birth	exposure: type and date	est. Ra content (μc)	years after initial exposure	age at beginning of exposure	effects of exposure	dental pathology	marital status	no. of children	past medical history	physical examination	x-ray findings (score)	lab findings	present health
01-390 1887	drank Radithor ~200 bots. 1925-1929	7.5	6	38	fatal	4+	M	2	high wbc, anemia	-	exhumation: minimal changes, score 3-1/2	-	died 4 Oct 1931, ca poisoning, [illegible] Ra water osteomyelitis facial bones
01-434 1880	drank Radithor ~1000-2000 bots. 1927-1930	5.60	4	47	fatal	4+	S	-	osteomyelitis of mandible and maxillae	necrosis of jaw and maxilla	exhumation: minimal changes, score 3		died 31 Mar 1932. Necrosis of jaw, brain abscess, Ra poisoning
01-388 1873	drank Radithor, amt. unknown; >2 yrs, 1928-1930	2.54	16	55	severe	3+	M	0	spontaneous fractures of femurs in 1932, 1933, 1934, 1936	-	exhumation: advanced changes, score 19-1/2F	-	died 25 Apr 1944. Coronf thromb.; coron. sclerosis; frac. femurs; pathological
01-179 1890	Ra injections 1924; drank Ra water 1924-1925	2.0 (1959)	40	34	severe	2+	M	2	osteogenic sarcoma, lt. leg amputated 1943	mod. hypertension; amp. left leg; arthritis rt. shoulder 1959	advanced changes, score 14 (1959)	neg.	fair
01-404 1875	Ra chemist; resident in Ra-contaminated house ~1919-1945	2.8	25	44	?	2+	M	5, 2 stillbirths	emphysema and pulmonary fibrosis	not done	exhumation: mild changes, score 12	low wbc	died 13 Nov 1945, pulmonary fibrosis
01-438 1867	drank ~1200 bots. Radithor, 4 May 1925-1929	1.85	15	58	minimal	2+	S	-	-	-	exhumation: minimal changes, score 3-1/2	-	[illegible] Jan 1943, acute [illegible] arthritis, exposure
01-175 1900	drank ~210 bots. Radithor, 1927	1.53	38	27	severe	4+	M	2	spontaneous fractures of multiple bones; amputation lt. leg at thigh	arteriosclerosis, reunited frac.	advanced changes score 29-1/2F	elev. sed. rate	fair
01-431 1901	Ra injections ~300 μc $RaCl_2$ 1922	0.96	42	21	none	3+	M	4	asthma	negative	minimal changes score 3-1/2	negative	good
01-302 1900	Ra injections ~1928	0.56 (1956)	38	26	severe	3+	S	-	multiple spon. frac. of bones in legs, amp. rt. leg	not done	advanced changes, score 25	not done	fair
01-424 1882	Ra injections ~300 μc $RaCl_2$ 1924	0.28	40	42	minimal	3+	M	2, 1 misc.	bronchial asthma; traumatic fract. of hip, 1963	not done	not done	not done	fairly good
09-102 1882	drank Ra water (~100 μc); Ra chemist 1912 on	0.15	39	30	none	3+	M	2	-	not done	exhumation: negative, score 0	not done	died 5 Jan 1951 diverticulitis of colon with obstruction, coronary heart disease
01-458 1892	exposed to radioactive fallout 1 Sep 1957	0.06	7	65	none	3+	M	0	several traumatic fractures (1942, 1958, 1963)	-	not done	not done	good

Table 16. (cont.)

Case no. date of birth	exposure: type and date	est. Ra content (μc)	years after initial exposure	age at beginning of exposure	effects of exposure	dental pathology	marital status	no. of children	past medical history	physical examination	x-ray findings bones (score)	lab findings	present health
01-430 1880	drank Radithor, unknown amt., ~ 1930	0.04	34	50	none	-	M	5	noncontributory	not done	not done	not done	good
09-104 1880	Ra chemist 1906-1913	0.04	59	26	none	-	M	1	noncontributory	not done	not done	not done	good
01-472 1896	lab worker 1920-1923	0.02	45	24	none	-	M	-	-	not done	not done	not done	fair, stroke in 1960
01-432 1895	Ra chemist 1915-1925	0.017	49	20	none	-	M	-	acute arthritis, ? mild diabetes	traumatic blindness of rt. eye, mild hypertension	minimal changes, score 1	elev. blood sugar, 1+ glycosuria	good
01-426 1930	resident in Ra contaminated house 1960-1962	0.005	4	30	none	0	M	2	noncontributory	negative	negative score 0	reversal poly-lymph ratio, sl. elev. sed. rate	good
01-427 1960	resident in Ra contaminated house 1960-1962	0.005	4	6 mos.	none	0	-	-	duodenal ulcer at age 1	negative	negative score 0	negative	good
01-428 1957	resident in Ra contaminated house 1960-1962	0.002	3	4	none	0	-	-	negative	negative	negative score 0	elev. wbc	good
01-192 1913	resident in Ra contaminated house 1950-1960	0.001	14	37	none	24	M	7	noncontributory	negative	negative score 0	sl. elev. blood sugar, 11% eosinophils, 1+ albuminuria	good
01-417 1910	Ra chemist 1931-1933	0.001	34	21	none	24	M	1	noncontributory	mild hypertension, slight enlargement of thyroid	negative score 0	negative	fairly good
01-429 1897	lab assistant working with Ra 1922-1923	≤0.01	42	25	none	34	M	2	noncontributory	not done	not done	not done	good
01-457 1904	Ra chemist, 1 yr 1921; summers 1922 and 1923	≤0.01	44	17	none	-	M	3	-	not done	not done	not done	good
01-459 1887	Ra chemist, 1 yr 1921	≤0.01	43	34	none	34	M	0	noncontributory	not done	not done	not done	poor
01-460 1880	Ra chemist, 2 yrs ~ 1912-1914	≤0.01	51	33	none	-	M	5, 1 misc.	noncontributory	not done	not done	not done	fairly good

Case no.; date of birth	exposure: type and date	est. Ra content (μc)	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	past medical history	physical examination	x-ray findings bones (score)	lab findings	present health
01-461 1914	Lab. worker, intermitt. 1925-1933	≤0.01	41	19	none	-	M	1	noncontributory	not done	not done	not done	fair
09-101 1895	Ra chemist 1918-1926	≤0.01	47	23	none	24	M	2	noncontributory	not done	not done	not done	good
01-415 1898	Ra chemist 1921-1931	-0.001 ± 0.001	43	23	none	14	M	1	noncontributory	negative	negative, score 0	normal	good
01-425 1913	resident in Ra contaminated house 1960-1962	-0.001 ± 0.001	4	27	none	14	M	2	noncontributory	negative	negative, score 0	slight glycosuria	good

Case History Summaries

(01-019) See case 19 (Mrs. K.M.), Medicine 31, 221 (1952). Body burden Ra 0.243 μc in 1965. Fatal effects from radiation 15 yrs. after beginning of exposure.
X-ray studies of exhumation specimens show minimal radiation changes, score 5+.

(01-052) See case 01-052, M.I.T.-952-1, 1964. Body burden Ra 2.00 μc in 1965. Fatal effects from radiation about 5-1/2 yrs. after beginning of exposure.
X-ray studies of exhumation specimens show advanced radiation changes, score 13-1/2.

(01-054) See case 01-054, M.I.T. annual progress report, 1960. Born 31 July 1909. Died 20 July 1937. Ra dial painter 2 April 1924 - 12 February 1928 starting at age 14. Body burden Ra 2.10 μc in 1965. Fatal effects from radiation about 13-1/3 yrs. after beginning of exposure.
X-ray studies of exhumation specimens show moderate radiation changes, score 21.

(01-094) See case 01-094, AECU-4285, 1959. Living and in good health. Luminous dial painter 18 July 1921 - 23 November 1922; 1 May 1923 - 2 July 1924. Body burden Ra ≤ 0.01 μc in 1965. No effects from radiation 43-1/2 yrs. after beginning of exposure.
No physical exam., x-ray, or lab. work done.

(01-122) See case 01-122, AECU-4285, 1959. Born 10 March 1912. Living and in good health. Ra dial painter 26 September 1927 - 1 September 1928, starting at age 15. Did not tip brush. Body burden Ra ≤ 0.01 μc in 1965. No effects from radiation 37-1/2 yrs. after beginning of exposure.
Has all but 2 of her own teeth. Married 1946 - 1957. Husband dead. No pregnancies. Past medical history noncontributory. No physical exam., lab., or x-ray studies done.

(01-130) Born 8 October 1909. Living and in good health. Ra dial painter 17 February 1926 - 8 October 1928; 20 November 1928 - 14 October 1929; 30 August - 17 November 1932, starting at age 16. Tipped brush. Body burden Ra 0.011 μc in 1964. No effects from radiation 38-1/2 yrs. after beginning of exposure.
Has 13 teeth remaining. Married, husband and 3 children living and well, 2 miscarriages. Past medical history noncontributory. Physical exam. essentially negative. Lab. findings normal except for a few atypical lymphocytes. X-ray studies showed ? polyp or mucocele in rt. antrum, score 0.

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*Note: The Ra body burdens listed in these summaries are the Ra^{226} component only. For the contribution of MsTh, and the corresponding PRE values, see Tables nos. 6, 7, 10, 15, and 16.

(01-147) See case 01-147, AECU-4285, 1959. Living and in apparently good health. Body burden Ra 0.07 μc in 1965. No apparent effects from radiation 48 yrs. after beginning of exposure. No physical exam., lab., or x-ray studies done.

(01-175) See case 01-175, M.I.T.-952-1, 1964. Living and in fair health. Body burden Ra 1.53 μc in 1965. Severe effects from radiation 38 yrs. after beginning of exposure. Since last admission 2 yrs. ago has had regressive loss of vision and 3 attacks of cardiac decompensation. Physical exam. showed almost complete loss of vision. Lab. findings normal except for some elevation of sedimentation rate.
X-ray studies showed advanced radiation changes, score 29.5F.

(01-179) See case 01-179, M.I.T.-952-1, 1964. Living and in fair health. Body burden Ra 2.05 μc in 1959. Marked effects from radiation 40 yrs. after beginning of exposure. Patient has recently had double vision with paresis of eye muscles, subretinal hemorrhages, and petechias. Increasingly severe headaches. Hearing appears normal. Physical exam., lab., and x-ray studies not done.

(01-236) Born 18 November 1910. Living and well. Dial painter 28 July - 28 September 1927, starting at age 16. Did not tip. Body burden Ra $\leq$ 0.02 μc in 1965. No effects from radiation 37 yrs. after beginning of exposure.
Has lost only 4 teeth to present. Married 33 yrs. Husband is semi-invalid. One child living and well, 2 miscarriages. Past medical history noncontributory. No physical exam, lab. or x-ray studies done.

(01-252) See case 01-252, M.I.T. annual progress report May 1960. Born 13 July 1898. Living and well. Body burden Ra 0.02 μc in 1965. No effects from radiation about 48 yrs. after beginning of exposure.
Edentulous. Married 1919 - 1960, no pregnancies. Past medical history of fractures of femur and toe, both presumably traumatic. No physical exam., lab., or x-ray studies done.

(01-254) Born 31 March 1910. Living and well. Dial painter 2 - 15 February 1927, starting at age 16. Did not tip. Body burden Ra $\leq$ 0.01 μc in 1965. No effects from radiation 38 yrs. after beginning of exposure.
Has lost only 4 teeth to date. Married, 3 children living and well. Past medical history noncontributory. No physical exam., lab., or x-ray studies done.

(01-264) See case 01-264, M.I.T. annual progress report May 1960. Body burden Ra 0.09 μc in 1964. Patient is confined to mental hospital with diagnosis of paranoia.

(01-302) See case 01-302, M.I.T. annual progress report May 1960. No radioactivity measurements made by M.I.T.
X-ray findings (incomplete survey) showed advanced radiation changes, score 25.

(01-303) See case 01-303, M.I.T. annual progress report May 1960. Born 26 November 1919. Living and well. Body burden Ra $\leq$ 0.01 μc in 1965. No effects from radiation 25 yrs. after beginning of exposure.
Has 20 teeth remaining. Married 1941 to present. Two children living and well. Past medical history noncontributory. No physical exam., lab., or x-ray studies done.

(01-327) Born 21 September 1908. Living and in poor health. Dial painter 28 October - 2 November 1927, starting at age 19. Did not tip. Body burden Ra $\leq$ 0.01 μc in 1965. No effects from radiation 38 yrs. after beginning of exposure.
Has only 10 teeth remaining. Married 1946 to present. One child living and well. Past medical history noncontributory. No physical exam., lab., or x-ray studies done.

(01-332) Born 11 August 1912. Living and apparently well. Dial painter 8 August 1927 - 2 August 1928, starting at age 14. Body burden Ra $\leq$ 0.01 μc in 1965. No effects apparent from radiation 37 yrs. after beginning of exposure.
No medical history available at present. No physical exam., lab., or x-ray studies done.

(01-364) See case 01-364, TID-16349, 1962. Body burden Ra $\leq$ 0.01 μc in 1964. No effects from radiation 37 yrs. after beginning of exposure.
No further medical history obtained. No physical exam., lab., or x-ray studies done.

(01-379) See case 01-379, NYO-9505, 1963. Born 22 December 1909. Dial painter 19 January - 5 March 1926, starting at age 16. Tipped regularly. Body burden Ra 0.032 μc in 1964. No effects from radiation 38 yrs. after beginning of exposure.
Edentulous. Married first time 1929 - 1939; 4 children living and well, 1 miscarriage. Second marriage 1944 to present, 2 children living and well. Past medical history non-contributory. Physical exam., lab., and x-ray studies negative.

(01-388) Born 31 October 1873. Died 25 April 1944. Cause of death per death certificate was coronary thrombosis; coronary sclerosis; fractured thighs, pathological. Drank unknown amount of Radithor, probably several hundred bottles, 1928 - 1930. Body burden Ra 2.60 μc in 1965. Severe effects from radiation 16 yrs. after beginning of exposure.
Edentulous. Married, no children. Past medical history of epilation and four spontaneous fractures in 1932, 1933, 1934, and 1936. No further medical data available at present.
X-ray studies of exhumation specimens showed advanced radiation changes, score 19-1/2F.

(01-390) Born 19 September 1887. Died 4 October 1931. Cause of death per death certificate was Ra poisoning, ingestion of Ra water, osteomyelitis of facial bones. Drank about 200 bottles of Radithor 1925 - 1929. Body burden Ra 7.41 μc in 1965. Fatal effects from radiation 6 yrs. after beginning of exposure.
Edentulous. Married, 2 children. Past medical history of high wbc, anemia, multiple transfusions. No further medical data available at present. X-ray studies of exhumation specimens showed minimal radiation changes, score 3-1/2+.

(01-392) Born 4 June 1913. Living and well. Lived in Ra-contaminated home for 10 yrs. (1950-1960) starting at age 37. Body burden Ra 0.001 μc in 1964. No effects from radiation 14 yrs. after beginning of exposure.
Has 9 teeth remaining. Married 25 November 1936 to present. Wife, age 50, living and well; 7 children living and well. Past medical history noncontributory. Physical exam. negative. Lab. findings normal except for sl. elevated blood sugar, 11% eosinophils, 1+ albuminuria. X-ray findings negative for radiation changes, score 0.

(01-404) See case 01-404, M.I.T.-952-1, 1964. Body burden Ra 2.80 μc in 1965.

(01-415) See case 01-415, M.I.T.-952-1, 1964. Born 21 July 1898. Ra chemist 1921 - 1931, starting at age 23. Body burden Ra -0.001 μc in 1964. No effects from radiation 43 yrs. after beginning of exposure.
Has lost only 3 teeth to date. Married July 1924 to present. Wife, 64, living and well. Three children living and well. Past medical history noncontributory. Physical exam., lab. and x-ray findings negative, score 0.

(01-424) Born 12 December 1882. Living and fairly well. Received about 300 μc Ra Cl_2 (i.v.) in 1924, for asthma, at age 42. Body burden Ra 0.28 μc in 1964. Minimal effects from radiation 40 yrs. after beginning of exposure.
Edentulous. Married 19 February 1900 to present. Two children living and well, 1 miscarriage. Past medical history of bronchial asthma in 1924, fracture of rt. femur in 1963. No physical exam., lab., or x-ray studies done.

(01-425) Born 13 August 1933. Living and well. Lived in Ra-contaminated house 1960 - 1962, starting at age 27. Body burden Ra -0.001 μc in 1964. No effects from radiation 4 yrs. after beginning of exposure.
Has lost only 2 teeth to date. Married 24 April 1954 to present. Wife, living and well, 2 children living and well. Past medical history noncontributory. Physical exam., and lab. findings negative except for slight glycosuria. X-ray studies negative, score 0.

(01-426) Born 8 November 1930. Living and well. Lived in Ra-contaminated house 1960 - 1962, starting at age 30. Body burden Ra 0.005 μc in 1964. No effects from radiation 4 yrs. after beginning of exposure.
Has lost no permanent teeth. Married 24 April 1954 to present. Husband living and well; 2 children living and well. Past medical history noncontributory. Physical exam. negative except for minimal enlargement of thyroid, lipoma on lt. buttock. Lab. studies negative except for reversal of poly-lymph ratio and sl. elevation of sedimentation rate. X-ray studies negative, score 0.

(01-427) Born 10 July 1960. Living and well. Lived in Ra-contaminated house 1960 - 1962, starting at age 6 months. Body burden Ra 0.005 μc in 1964. No effects from radiation 4 yrs. after beginning of exposure.
No dental pathology. Past medical history negative except for duodenal ulcer. Physical exam., lab., and x-ray studies negative, score 0.

(01-428) Born 28 November 1957. Living and well. Lived in Ra-contaminated house 1960 - 1962, starting at age 3. Body burden Ra 0.002 μc in 1964. No effects from radiation 4 yrs. after beginning of exposure.
No dental pathology. Past medical history negative. Physical exam. negative. Lab. studies showed elevated wbc. X-ray studies negative, score 0.

(01-429) Born 26 August 1897. Living and well. Laboratory assistant 1922 - 1926, starting at age 25. Body burden Ra ≤ 0.01 μc in 1965. No effects from radiation 42 yrs. after beginning of exposure.
Edentulous. Married 1929 to present. Two children. Past medical history noncontributory. No physical exam., lab., or x-ray studies done.

(01-430) Born 1880. Living and well. Drank unknown amount of Radithor about 1930. Body burden Ra 0.04 μc in 1964. No effects from radiation 34 yrs. after beginning of exposure.
Dental history unknown. Married 35 yrs.; wife died of cancer of large bowel; 5 children. Past medical history noncontributory. No physical exam., lab., or x-ray studies done.

(01-431) Born 23 December 1901. Living and well. Received about 300 μc $RaCl_2$ (i.v.) in 1922, starting at age 21, for asthma. Body burden 0.96 μc in 1964. No effects from radiation 42 yrs. after beginning of exposure.
Edentulous. Married 1920 to 1963, four children living and well. Past medical history noncontributory. Physical exam. negative. Lab. studies neg. X-ray studies showed minimal radiation changes, score 3-1/2+.

(01-432) Born 7 February 1895. Living and well. Ra chemist 1915 to 1925, starting at age 20. Body burden Ra 0.017 μc in 1964. No effects from radiation 49 yrs. after beginning of exposure.
No dental history available. Married 1939 to present. Past medical history noncontributory. Physical exam. showed diabetes mellitis with peripheral neuropathy, hypertensive arteriosclerotic cardiovascular disease with mild chronic congestive failure, post-traumatic blindness of rt. eye, degenerative osteoarthritis of dorsal spine and both hands. Lab. studies negative except for elev. blood sugar and 1+ glycosuria. X-ray studies showed only questionable radiation changes, score 1+.

(01-434) Born 12 April 1880. Died 31 March 1932. Cause of death per death certificate was necrosis of jaw, abscess of brain, Ra poisoning. Drank ~1000 - 1200 bottles of Radithor 1927 - 1930. Body burden Ra 5.60 μc in 1965. Fatal effects from radiation about 4 yrs. after beginning of exposure.
Only 1 tooth remaining. Never married. Past medical history of severe osteomyelitis and bone necrosis of both jaws, brain abscess of rt. temporal lobe. Physical exam. at time of death showed jaw necrosis and extension of bone infection to rt. temporal lobe of brain. Severe anemia, [illegible] and differential normal. X-ray studies of exhumation specimens showed minimal [illegible] changes, score 3+.

(01-435) Born May 1907. Living and fairly well. Ra dial painter 20 October - 24 November 1925, starting at age 18. Did not tip. Body burden Ra ≤0.01 μc in 1964. No effects from radiation 39 yrs. after beginning of exposure.
Edentulous. Married first time 1927 to 1956. Four children living and well. Second marriage June 1964 to present. Past medical history negative except for possible malignant adenoma of thyroid. No physical exam., lab., or x-ray studies done.

(01-436) Born 26 November 1895. Living and fairly well. Dial printer 31 January 1927 - 20 July 1929; 9 October - 8 December 1933; 15 February - 10 December 1934. Body burden Ra ≤0.01 μc in 1964. No effects from radiation 37 yrs. after beginning of exposure.
No dental information available. Married 1 December 1916 to present, no pregnancies. Past medical history noncontributory. Has mild diabetes. No physical exam., lab., or x-ray studies done.

(01-437) Born 29 December 1910. Living and fairly well. Ra chemist 1931 - 1933. Body burden Ra 0.001 μc in 1965. No effects from radiation 34 yrs. after beginning of exposure.
Has lost only 9 teeth to date. Married 30 June 1941 to present; one child living and well. Past medical history noncontributory. Physical exam. showed moderate hypertension with a slightly enlarged thyroid gland. Lab. and x-ray studies negative, score 0.

(01-438) Born 1 February 1867. Died 21 January 1930. Cause of death per death certificate was acute endocarditis, exposure, and arthritis. Drank ~1200 bottles of Radithor 1925 - 1929. Body burden Ra 1.85 μc in 1965. Minimal effects from radiation 15 yrs. after beginning of exposure. No past medical data available at present. X-ray studies of exhumation specimens show minimal radiation effects, score 3-1/2.

(01-446) Born 27 July 1907. Living and apparently in good health. Dial painter 2 - 3 December 1925, starting at age 18. Body burden Ra $\leq$0.01 μc in 1964. No apparent effects from radiation 39 yrs. after beginning of exposure. No medical data available. No physical exam., lab., or x-ray studies done.

(01-448) Born 19 June 1907. Living and apparently in good health. Dial painter 16 October - 27 November 1925, starting at age 18. Body burden Ra 0.02 μc in 1964. No apparent effects from radiation 39 yrs. after beginning of exposure. Patient refused to give any medical data.

(01-457) Born 1904. Living and well. Ra chemist 1921 - 1923, starting at age 17. Body burden Ra $\leq$0.01 μc in 1965. No effects from radiation 44 yrs. after beginning of exposure.
No dental history obtained. Married 34 yrs. to present time. Three children living and well. Past medical history - no information recorded. No physical exam., lab., or x-ray studies done.

(01-458) Born 18 May 1892. Exposed to radioactive fallout 1 September 1957 at age 65. Body burden Ra 0.06 μc in 1964. No effects from radiation 7 yrs. after beginning of exposure.
Edentulous. Married 1926 - 1942, no pregnancies. Past medical history negative except for several traumatic fractures (1942, 1958, 1963). No physical exam., lab., or x-ray studies done.

(01-459) Born 1887. Living, in poor health due to diabetes and stroke. Ra chemist for 1 yr. 1921 at age 34. Body burden Ra $\leq$0.01 μc in 1964. No effects from radiation 43 yrs. after beginning of exposure.
Edentulous. Married, no pregnancies. Past medical history noncontributory. No physical exam., lab., or x-ray studies done.

(01-460) Born 1880. Living and in fairly good health. Ra chemist between about 1912 and 1914 for 2 yrs. starting at about age 33. Body burden Ra $\leq$0.01 μc in 1964. No effects from radiation 51 yrs. after beginning of exposure.
Dental history not remarkable. Married 1908, 5 children, 1 miscarriage. Past medical history noncontributory. No physical exam., lab., or x-ray studies done.

(01-461) Born 1914. Laboratory assistant intermittently about 1933, starting at about age 19. Body burden Ra $\leq$0.01 μc in 1964. No effects from radiation 31 yrs. after beginning of exposure.
Dental history not remarkable. Married, 1 child. Past medical history noncontributory. No physical exam., lab., or x-ray studies done.

(01-468) Born 30 July 1910. Living, in poor health due to Parkinson's disease. Dial painter 3 - 4 March 1927, never tipped brush. Body burden Ra $\leq$0.01 μc in 1965. No effects from radiation 38 yrs. after beginning of exposure.
Edentulous. Married 1934 to 1946, 1 child. Past medical history noncontributory. No physical exam., lab., or x-ray studies done.

(01-470) Born 26 May 1912. Living and well. Dial painter 17 October - 5 December 1927, 12 September 1928 - 22 March 1929. Never tipped brush. Body burden Ra $\leq$0.01 μc in 1965. No effects from radiation 37 yrs. after beginning of exposure.
No dental history obtained. Three marriages. One child by each marriage, living and well. Past medical history noncontributory. No physical exam., lab., or x-ray studies done.

(01-472) Born 24 April 1896. Living in poor health following stroke 5 yrs. ago. Ra chemist 1920 - 1923, starting at about age 24. Body burden Ra 0.02 μc in 1965. No effects from radiation 45 yrs. after beginning of exposure.

(09-102) See H.A. Seil, C.H. Viol, and M.A. Gordon, N.Y. Med. J., 1 May 1915. Born 5 February 1882. Died 5 January 1951. Cause of death per death certificate was diverticulosis of colon with obstruction, coronary heart disease, arteriosclerosis, obstruction of sigmoid. Ra chemist, 1912, for indeterminate time. Body burden Ra 0.15 μc in 1964. No effects from radiation 39 yrs. after beginning of exposure.
No further medical data available at present.

(09-103) Born 29 May 1895. Living and well. Ra chemist 1918 - 1926, starting at age 23. Body burden Ra $\leq$0.01 μc in 1965. No effects from radiation 47 yrs. after beginning of exposure.
Has 8 teeth remaining. Married 1 May 1920 to present, 2 children. Past medical history noncontributory. No physical exam., lab., or x-ray studies done.

(09-104) Born 24 October 1880. Living and well. Ra chemist 1906 - 1913. Has been drinking Rn water for many years. Body burden Ra 0.04 μc in 1965. No effects from radiation 59 yrs. after beginning of exposure.
Dental history unknown. Past medical history noncontributory. No physical exam., lab., or x-ray studies done.

B. Differential Uptake of Elements 88 and 90 Following Oral Ingestion by Human Beings

Previous progress reports[1] have described the reasons for conducting this experiment and the development of methods and procedures for it. The question concerns the extent to which Th^{228} influences the toxicity results in those subjects who ingested Ra dial paint containing Ra^{228} in addition to Ra^{226}. The intravenous metabolism of Ra and Th (using Ra^{224} and Th^{234} as respective short-lived tracers) in elderly human beings has also been described, from which results calibration factors have been obtained for use in the experiments involving the ingestion of these nuclides.

This report describes this final phase of the experiment in which human subjects ingested mock Ra dial paint containing $\sim$1 μc Ra^{224} and $\sim$150 μc Th^{234}. The mock paint was administered in a gelatin capsule and was swallowed with water $\sim$1-2 hr after breakfast. Both isotopes were given to each subject as the same time so that the subjects acted as their own controls for establishing the absorption of Th relative to that of Ra. The results of the experiment, carried out on elderly male and female human subjects, are given below. The assessment of the results, the conclusions, and the implications to Ra toxicity are also presented.

1. Results and Discussion on the Relative Absorption of Ra^{224} and Th^{234} Administered Orally

Having obtained information on the metabolism of Ra^{224} and Th^{234} and on the calibration factors derived from these results, pilot experiments were conducted to assess the problems to be encountered and to get an estimate of the absolute absorption by means of the separate oral administration of Ra^{224} and Th^{234} to two subjects. In particular, it was necessary to show that the shielding for the SXB positions, when large amounts of activity were in the stomachs of people (as opposed to phantoms), was adequate, to show the extent to which scattering of the γ rays may influence the SXB positions, especially the L8 positions; to see how much time was required to eliminate the bulk of the activity from the GI tract and whether a good accounting of the total activity was obtainable; to see if the absorption calculated from the several parameters gave the same answer; and to determine whether the precautions did prevent radioactive contamination.

The two pilot experiments showed that everything worked favorably and this information is shown later with the results from the main study. The adequacy of the shielding

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1. C. J. Maletskos, et al., pp. 113-149, MIT-952-1, (1964).

for Th^{234} can be shown only when it is administered separately. The results are given in Table 17 and show that the H8 SXB method meets the attenuation requirements of 10^{-3}-10^{-4} originally specified. Scattering in the 1.00-MeV region for Th^{234} is presumed to be observable from the few higher energy γ rays of Th^{234} because the contribution decreases after the first day. On the other hand, scattering is noticeable in the L8 SXB measurements and interferes for the first few days while significant activity is still present in the G.I. tract.

The pilot experiment on Ra^{224} also showed that the absorption of Ra^{224} is ~ 10 times greater than the $\sim 1\%$ anticipated from previous information. This result pointed to the success of the experiment in the determination of the low relative absorption of Th to R[illegible], but showed that no meaningful L8 SXB measurements could be made for Th^{234} within a few days after the administration. Thus, while much information was developed in the intravenous part of the experiment, Ra^{224} body γ measurements for the oral part of the study were done with the H8 SXB position soon after administration. The Th^{234} body γ measurements were done with the L8 SXB position long after the Ra^{224} had decayed, and this was possible, fortunately, because of the high Th^{234} retention.

Absorption from the gut (that is, the transport of material from the gut to the blood, irrespective of what happens to this material after it gets in the blood, otherwise called cumulative absorption) can be measured in many ways such as: (a) the balance technique with stable material, (b) the balance technique with radioactive material when endogenous excretion is known or known to be low, and (c) the radioisotope method using the blood activity obtained from both oral and intravenous administration. The latter technique (described, for example, by Silverman and Burgen[2]) is particularly useful for carrying out the experiment over a relatively short period of time.

The information contained in the blood curves, for example, obtained from an intravenous and a per os administration, is the same even though the two curves are different at short times after the administration. At times long compared with the rate constants involved in the absorption process, however, the two curves become essentially equal in magnitude and identical as to shape, on a per μc retained basis. This condition is similar to the situation encountered for the relative activities between a short-lived daughter radioactive isotope and a long-lived parent. At times (days) long after the absorption is complete ($\sim$ 5-10 hr) the respective curves from the two methods of administration for all the variables of the system (blood, urine, feces, retention, etc.) will be indistinguishable from each other. At these long times, then, the data obtained from the intravenous administration can be used as calibration data for determining the amount of material that was transported across the gut wall or absorbed after the oral

2. M. Silverman and A. S. V. Burgen, J. Appl. Physiol., 16, 911 (1961).

Table 17. Attenuation by Pb Shield in SXB Positions

Subject	Radio-nuclide	Time After Adminis-tration	Activity in G.I. Tract (μc)	Effective Activity* Observed in H8SXB (μc)	$\frac{\text{H8SXB } \mu c}{\text{G.I. } \mu c} \times 10^3$	Effective Activity* Observed in L8SXB (μc)	$\frac{\text{L8SXB } \mu c}{\text{G.I. } \mu c}$
TRPOM1	Ra^{224}	~ 1 hr	1.43	$(2.2 \pm 2.1) \times 10^{-3}$	(1.5 ± 1.5)	-	-
TPOM1	Th^{234}	~ 1 hr	120	0.22 ± 0.08	(1.8 ± 0.7)	4.4	0.037
		~2 d	54	0.16 ± 0.07	(3.0 ± 1.3)	1.2	0.023
		~3 d	18	0.05 ± 0.07	(2.8 ± 3.9)	0.3	0.017
		~ 6 d	~ 1.3	0.08 ± 0.10	-	0.012 ± 0.007	0.009 ± 0.005

* This is the contribution, expressed as total skeletal burden, due to scattering of the non-absorbed activity in the G.I. tract.

administration. As a further check on this, several consecutive measurements of each variable, after the appropriate delay, should give the same value of absorption within the experiment error. And finally, the same value of absorption should be obtained from each of the different variables measured, again within the experimental error.

The absorption of Ra^{224} was determined by measurements made on the 4th day and as long as possible thereafter until radioactive decay prevented further reliable measurements. The adequacy for this procedure is shown in Figs. 23 and 24 obtained from a subject administered mock Ra paint containing only Ra^{224}. Figure 23 shows that stabilization in the body measurements does not take place until ~ 4 d after the Ra^{224} is administered. By this time the transitory effects of absorption from the G.I. tract have become negligible. This is shown in Fig. 24 where the first blood value taken at 1.12 hr after the administration has the highest value; that is, the peak in the blood curve occurs at $t \leq 1.12$ hr. This blood curve has the same shape as the blood curves from the experiments with the intravenous injections. The blood results obtained from the subject administered mock Ra paint containing only Th^{234} were too low to deduce a reliable shape for the curve.

The results from the oral administration of mock Ra paint containing both Ra^{224} and Th^{234} are shown in Tables 18-20. Tables 18 and 19 show the results separately for Ra^{224} and Th^{234}, respectively, as obtained from the several metabolic parameters. On the average, the results in both Tables 18 and 19 agree with each other within a factor of ~ 2. The results show that the values of fractional absorption calculated from the several parameters are consistent. The conclusion can also be made that no significant contamination has taken place for any particular sample or sample type.

One exception to this is the results on the absorption of Th^{234} obtained from the blood values. The blood samples were taken soon (2 + 4 hr) after the administration in order to observe some significant activity above background before metabolic activity reduced the Th^{234} concentration below the detection limit. The absorption calculated from blood samples taken at this early time (using the method of calculation described above) will underestimate the true value as the results in Table 19 indicate. These results confirm that Th^{234} was absorbed into the blood, but they cannot be and are not used for calculation of the average absorption.

Average values of fractional absorption or transport have been calculated from Tables 18 and 19 for Ra^{224} and Th^{234} for each subject and these results are shown in Table 20.

The fractional Th absorption or transport averages $\leq 3 \times 10^{-4}$ with a most probable value of 2×10^{-4}. A difference in absorption due to sex is not indicated. This value is greater and within an order of magnitude of the values determined in the Utah experiments on rats, guinea pigs, and monkeys.

The fractional Ra absorption averages 0.2 with a most probable value of 0.2. Again, there is no sex difference indicated.

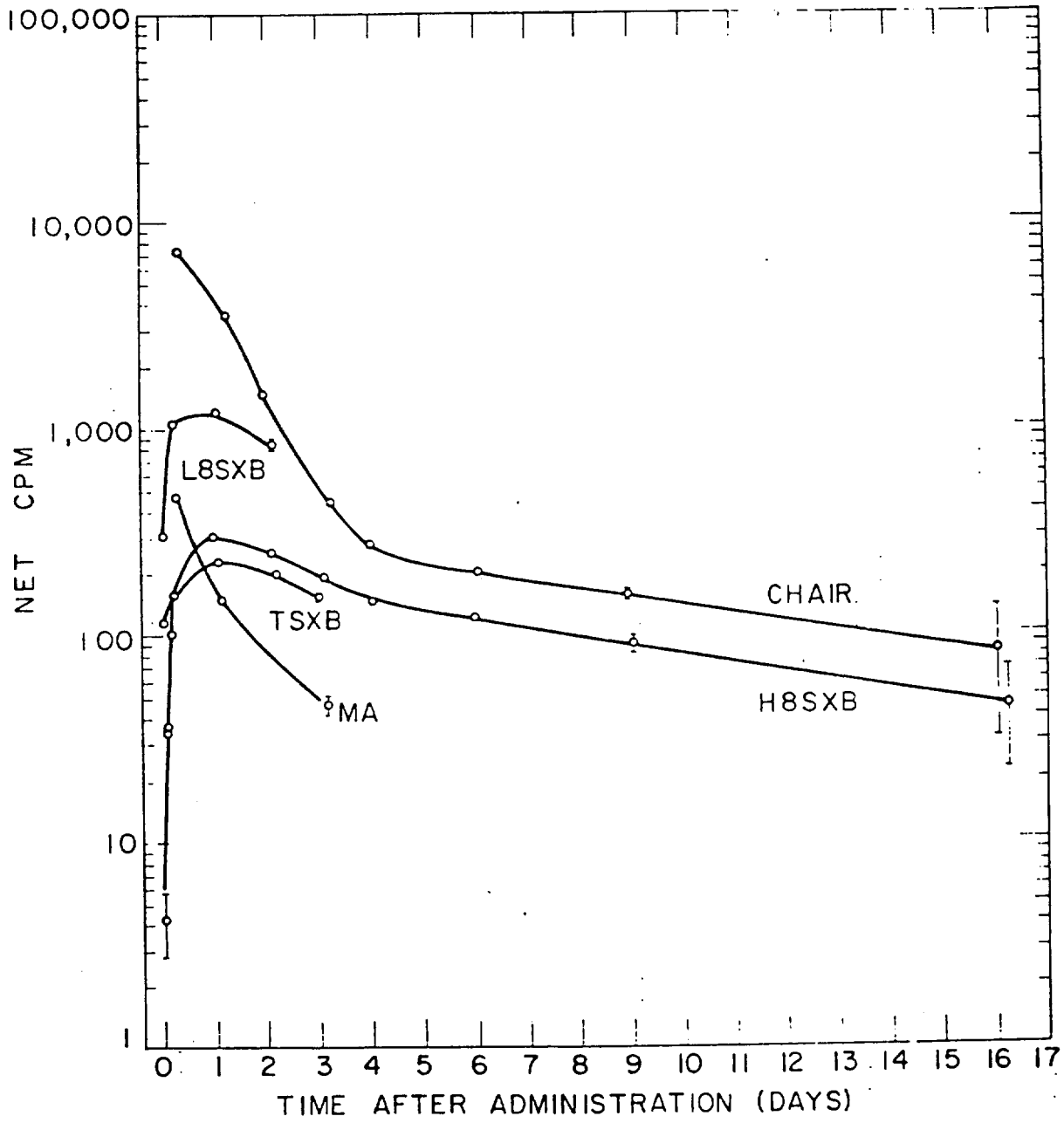

FIG. 23 COMPARATIVE NET COUNTING RATES AFTER ORAL ADMINISTRATION OF Ra^{224} FOR VARIOUS COBAFAC COUNTING METHODS, SUBJECT RPOM I

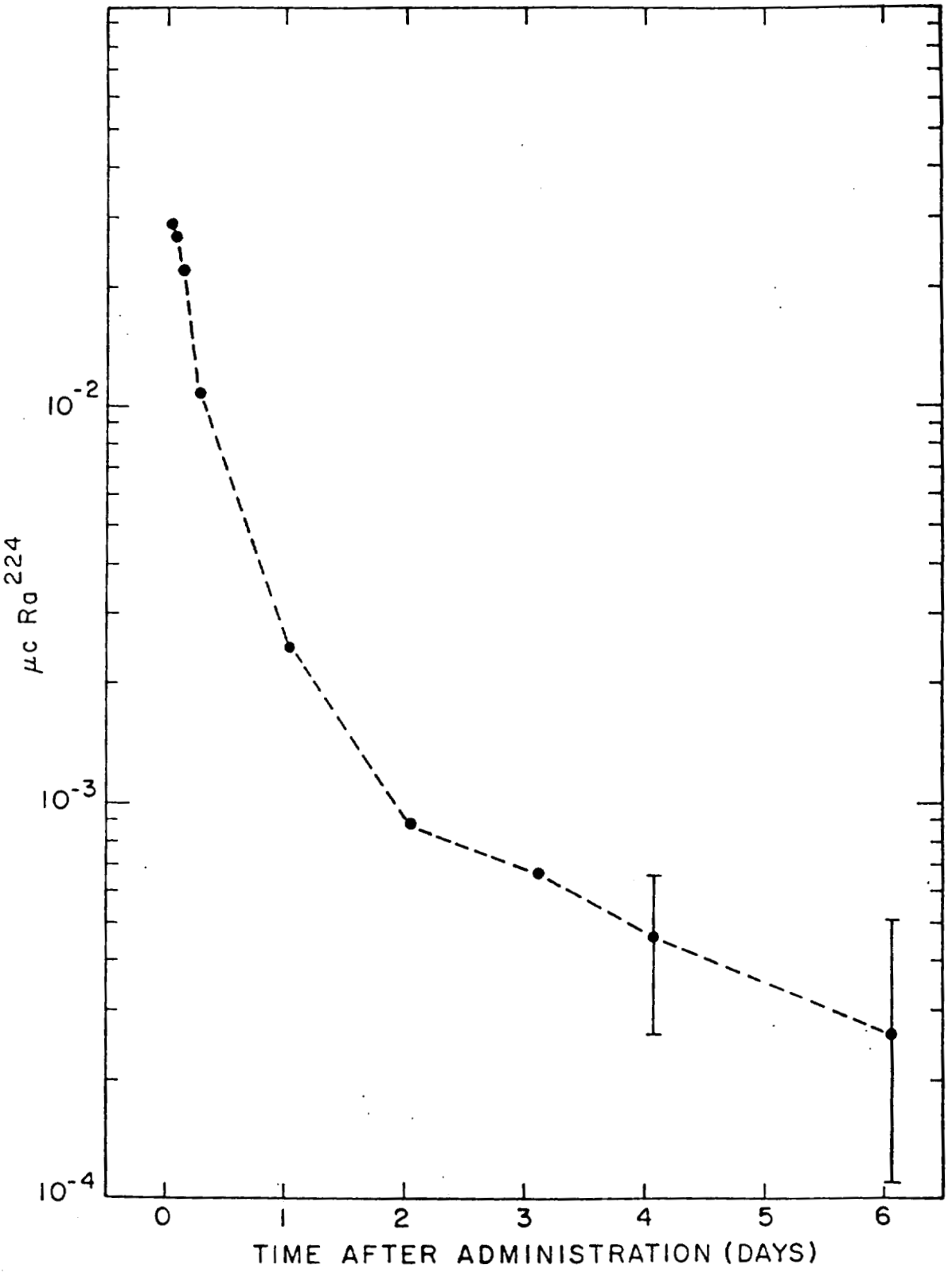

FIG. 24 Ra^{224} IN ESTIMATED TOTAL BLOOD VOLUME FOLLOWING ORAL ADMINISTRATION OF 2.45 μc Ra^{224}, SUBJECT RPOMI

Table 18. Fractional Transport of Ra^{224} Across Human Gut

	Parameters		
Subject	Body γ Meas. H8 SXB	Breath Tn	Urine
TRPOM1	≤ 0.014	0.007	≤ 0.06
TRPOM2	0.21	0.18	0.16
TRPOM3	0.14	0.18	0.09
TRPOF1	0.20	0.18	0.13**
TRPOF2	0.18	0.23	0.13**
TRPOF4	0.27	0.28	0.21**
Averages*	0.20	0.21	0.14

* Excluding TRPOM1

** Error associated with these values is ~ 50%.

Table 19. Fractional Transport of Th^{234} Across Human Gut

	Parameters		
Subject	Body γ Meas. L8 SXB	Urine	Blood
TRPOM1	≤ 0.0003	≤ 0.0006	≤ 0.0001
TRPOM2	0.0006	0.0009	0.0003
TRPOM3	≤ 0.0003	≤ 0.0003	≤ 0.0001
TRPOF1	0.0002	0.0002	0.0003
TRPOF2	≤ 0.0001	0.0003	0.0001
TRPOF4	0.0002	0.0008	0.0001
Averages	≤ 0.0003	≤ 0.0005	≤ 0.0002

Table 20. Absorption of Th and Ra From Mock Ra Dial Paint by Human Beings

Subject	Fractional Th Transport	Fractional Ra Transport	Relative Uptake Th/Ra
TRPOM1	$\leq$0.0003	0.01	$\leq$ 0.03
TRPOM2	0.0006	0.2	0.003
TRPOM3	$\leq$0.0003	0.1	$\leq$ 0.003
TRPOF1	0.0002	0.2	0.001
TRPOF2	0.0001	0.2	0.0005
TRPOF4	0.0002	0.3	0.0007
Averages	$\leq$0.0003	0.2	$\leq$ 0.006
Most Probable Value	0.0002	0.2	0.001

The first male subject, TRPOM1, has a fractional Ra absorption of $\sim$ 0.01, about 20 times less than the other subjects. This difference is real since the values of absorption calculated from the different parameters are consistent (Table 20). To this date there is no known reason to explain this difference. At one time it was suspected that the subject had had gastric surgery, especially with the evidence of an abdominal scar. But a detailed check of his hospital records and a check of the anatomy and function of his G.I. tract by radiography indicated that he is normal. His results are included because there is no reason to omit them, but they appear to be highly unlikely especially since the paint he ingested was from the same batch administered to subjects TRPOM2 and TRPOM3.

The fractional Ra absorption of 0.2, obtained from a supposedly "insoluble" material is much larger than those of the Utah animal experiments by as much as 2-3 orders of magnitude. The value of 0.2 is in agreement with the value of 0.2 found in the dog experiment conducted as a preliminary to the experiments on the human subjects. The value is about the same as that calculated for human subjects ingesting Ra from drinking water and foodstuffs. Using the data of Lucas[3] on the Ra^{226} body burden of normal human subjects and the Ra^{226} concentrations in their food and water intakes, an absorption of $\sim$0.15 is calculated. This calculated absorption value applies to the condition when Ra^{226} in water is the primary source of Ra or when Ra^{226} in food is the primary

3. H. F. Lucas, ANL-6297, p. 55 (July - Dec. 1960).

source of Ra under circumstances where the Ra^{226} in water is extremely low. A somewhat higher absorption value (best estimate ~0.3-0.5) can be calculated from the data of Seil et al.[4] for a male subject (age ~33 yr) ingesting a "Ra solution" (presumable $RaCl_2$).

Finally, the result of interest, the relative absorption of Th to Ra, is given in the last column of Table 20. Except for the first subject all the values are consistent, yielding a most probable value of $\sim 1 \times 10^{-3}$. This value is close to the lowest value found in the Utah experiments and is ~10 times lower than the value of $\sim 10^{-2}$ acceptable from the dosimetric viewpoints, indicated as being desirable for the human toxicity results described in the introduction and in the section on methods.

What is the validity of this relative Th to Ra absorption value of 10^{-3} in human beings and its applicability to the Ra dial paint problem? In the first place, the absorption of Ra from the insoluble $RaSO_4$ (with Ba carrier) deposited on the ZnS phosphor is quite large. The absorption of Ra under the best circumstances of full solubility cannot be more than 5 times greater than the 0.2 found and very few substances are absorbed 100% from the G.I. tract. The high value of 0.2 would indicate that most, if not all, the ZnS was dissolved in the stomach leaving the absorption process to act on essentially free $RaSO_4$. The chemicals of the G.I. tract, the pH, and the water content are such that 20% of this insoluble material is absorbed. (The preparation of the paint insured that the Ra^{224} found in the wash water was consistent with the $RaSO_4$ solubility product.)

As to what extent the Ra absorption may be lower than 0.2 in human subjects, the best evidence is a comparison of the estimated amount of Ra^{226} eaten by dial painters and the estimated amount predicted from measurements 30-40 yrs later. To calculate the amount ingested by a subject the present body burden is multiplied by 250 for physiological loss based on the Norris equation and by 5 = 1/0.2 for absorption or by a total of ~1250. Thus, persons with present day body burdens of 1-10 μc Ra^{226} presumably ingested ~ 1.25-12.5 mc Ra^{226} in the form of dial paint. Analysis of histories of dial painters indicates that those who tipped their brushes more often have the higher body burdens. Calculations based on the brush tipping frequencies, the amount of paint on a brush, etc. would indicate that such painters ingested 1-10 mc per total exposure period. Thus, while an exact 1 to 1 correspondence cannot be established now, it would appear that this analysis is consistent with a Ra absorption of ~ 0.2, including the variable nature of the dial paint as made by different manufacturers and at different times.

It is concluded that a Ra absorption of ~0.2 is probably good within a factor of ~2-3 and that there are no indications that it would be significantly less such as, say, 10 times, in human beings for Ra dial paint conditions.

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4. H. A. Seil, C. H. Viol, and M. A. Gordon, N.Y. Med. J., 101, 896 (1915) or Radium 5, 40 (1915).

With regard to Th one has only to consider how much larger the absorption may be, for if it is less than that found in this experiment the result would be even more favorable to neglecting the toxicity of Th^{228} after ingesting Ra dial paint. There is no good evidence for a greater Th absorption and, at best, it is indirect. $Th(SO_4)_2$ is much more soluble than $RaSO_4$ and is trapped on the ZnS-mock Ra paint complex only with great difficulty during preparation of the paint. In fact, Th^{234} is washed off the mock paint with ease during the final washing steps. In view of these facts and in view of the high absorption of the Ra^{224}, it would appear that Th^{234} could be more "solubilized" by the gastrointestinal actions and be put in a more favorable state for absorption than the Ra is. One could argue that, since so much Ra was absorbed, the conditions were most favorable for absorbing the Th and that, because of this, the absorption could approach that from ingesting $Th(SO_4)_2$ in solution. This argument, however, gives no clue as to how much more the Th might be absorbed but suggests that it might not be too much greater.

In the applicable experiments at Utah, the relative absorption of Th/Ra in the rat for chloride and citrate solutions are ~ 0.02 and ~ 0.0001, respectively. Unfortunately, the relative absorption is ~ 5 when the mock Ra dial paint is administered indicating that Th is absorbed more effectively than Ra in this species. These results, therefore, cannot be used to deduce or estimate how large the absorption of soluble Th might be in human beings.

The Ra dial paints used in the early 1920's were made in a variety of ways and with varying degrees of care. In many or even most paints, the soluble activities were not washed off. Varying compounds were used for the matrix to make the paint adhere to the different surfaces on which it was applied. Varying screen sizes and clumping after drying, along with varying ages of the paint, all introduce variables for absorption. The radiation dose from the rays may also have an effect on older paint that freshly made paint might not encounter. Thus it is impossible to duplicate the original paints in their final working form, and the extent to which "soluble" activities were present. Finally, even the subjects cannot be reproduced, since the dial painters were young girls usually in their late teens and early twenties as compared with the older subjects who participated in this experiment. All these are variables that make it difficult for an experiment conducted today to duplicate the conditions of the past and that make interpretations of present experiments complicated.

It is interesting to note that the absorption values used for Ra andTh in NBS Handbook 52 (March 1953) are 0.2 and 5×10^{-4}, respectively, presumably in soluble form. The Ra value is the same as that found in this experiment for an "insoluble" paint, while the Th is only $\sim$2-3 times larger. The more recent values for calculating the maximum permissible concentrations for NBS Handbook 69 (June 1959) are found in the ICRP Report Committee II on Permissible Doses for Internal Emitters (1959) and are 0.3 and $< 10^{-4}$ respectively. These absorption values are based mainly on the literature of the 1930's and 1940's and are derived and estimated from animal experiments.

In view of the goal of finding a relative absorption of Th/Ra $\leq 10^{-2}$, and in view of finding a value of $\sim 10^{-3}$, it is concluded that, even in the face of the possible complications enumerated above, the absorption of Th^{228} (present in amounts up to equilibrium with its parent Ra^{228}) from real dial paints is unlikely to have been large while dial painters tipped their brushes in the 1920's. In these subjects the contribution to the integrated radiation dose over 30-40 yrs by the initially absorbed Th^{228} is $\leq 5\%$ that due to Ra^{228}.

On the basis of this conclusion, comparison between the effects of Ra^{228} and Ra^{226} in human beings with these burdens can be continued using the concept of pure radium equivalent (PRE). On the other hand, use of the concept of minimum pure radium equivalent (MPRE) can be discarded with reasonably good confidence.

(C. J. Maletskos, H. P. Anderson, A. G. Braun, H. F. Braun
J. F. Byrum, S. D. Clark, M. M. Costello, E. D. Dillon,
J. A. Foley, J. E. Gary, A. T. Keane, J. A. Kelley,
M. Lubin, M. M. Shanahan, N. C. Telles)