studied up to 6 years after the test (*2*).

Now, 20 years later, we have obtained the γ-ray spectra, over the energy range 0.1 to 3 Mev, of random pieces of trinitite from three independent sources, with a NaI(Tl) crystal (20 by 10 cm). Samples from the three sources gave similar γ-ray spectra (Fig. 1). Moving the sample away from the face of the crystal lowered the peaks at 1.5 and 2.50 Mev relative to the peaks at other energies, an indication that the peaks at 1.5 and 2.50 Mev are due to sum effects.

The peak from the long-lived fission product Cs^{137} (30.5-year half-life) at 0.662 Mev is readily recognized in the spectra. As expected, other significant γ-emitting fission products have decayed so that they are now undetectable. We therefore investigated the long-lived neutron activation products to account for the presence of the other peaks in the spectra.

Cobalt-60 (5.27-year half-life) emits 1.17 and 1.33 Mev photons in cascade with a sum peak at 2.50 Mev. These energies appear in the trinitite spectra. By subtracting an appropriate Co^{60} spectrum from the spectrum shown in Fig. 1, we obtained the net spectrum shown in Fig. 2. This removed the 2.50-Mev peak and improved the resolution of the two peaks at 1.10 and 1.40 Mev. These appear broad in the original spectrum (Fig. 1) as they are distorted by the 1.17- and 1.33-Mev photons from Co^{60}.

The seven major unidentified peaks in the net spectrum (Fig. 2), 0.12, 0.25, 0.34, 0.77, 0.97, 1.10, and 1.40 Mev, are identical with the most abundant photons listed for Eu^{152} (12.4-year half-life) (*3*) and indicate the presence of this radionuclide. Europium-152 has a sum peak at 1.53 Mev also, which accounts for the sum peak we obtained at 1.5 Mev.

Using appropriate radioactive standard sources we estimated the present concentrations (disintegrations per minute per gram—dpm/g) of the major γ-emitting constituents in a sample of trinitite as follows: Co^{60}, 0.4×10^3 dpm/g; Cs^{137}, 1×10^3 dpm/g; Eu^{152}, 2×10^3 dpm/g. In addition, analysis of the beta activity indicated substantial amounts of the Sr^{90}, Y^{90} pair.

The composition of this local debris is not unique, since we found a similar spectrum for comparable material from one of the early detonations at the Nevada Test Site. No evidence exists for the formation of either Co^{60} or Eu^{152} in fission. They may be products of the neutron activation of stable Co^{59} and Eu^{151}, respectively. Although Co^{60} resulting from nuclear weapons tests was noted previously (*4*), the presence of Eu^{152} in worldwide fallout has not been reported (*5*). If present, it is not of interest with respect to plant or animal metabolism, but could contribute to the external dose of γ-radiation from fallout.

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5. Concurrent measurements made by personnel at the White Sands Missile Range confirm the presence and general amounts of Eu^{152} in this material. We thank them for making their findings known to us.

1 February 1965

Radioactive Strontium: Estimation of the Amount Accidentally Ingested

Abstract. *If radioactive strontium is accidentally ingested or inhaled, the amount absorbed may be calculated with reasonable accuracy from the amount of calcium and strontium excreted in the urine in a single day. The amount retained by the body initially may be calculated from the amount of radiostrontium excreted in the feces in the first few days.*

Considerable work has been done on the metabolism of radioactive strontium (*1*, *2*) both because of the risks inherent in the presence of Sr^{90} in fallout and because of the hazards that may result from exposure to large amounts of this radioisotope when it is used industrially. Several accidents have already occurred (*3*, *4*) and it is important in such cases to know how much Sr^{90} has been absorbed and how its retention in the body can be decreased.

If, soon after the administration of radiostrontium, ammonium chloride is given orally at the same time as calcium gluconate is given intravenously, the amount of strontium retained in the body is appreciably reduced (*5*). However, in cases of accidents it has been difficult to estimate the amount of Sr^{90} retained. Bradley *et al.* (*4*) obtained estimates of the radioactivity retained by counting the secondary x-rays produced by Sr^{90} with a whole-body counter, by using a formula developed by Bishop *et al.* for use in conjunction with data on radiostrontium excretion (*6*) and by determining the Sr^{90} activity of plasma. To make some of these estimates, the methods of Bradley *et al.* require the accumulation of considerable data (*4*).

The object of this report is to show how a minimum of data can be used to calculate the amount of Sr^{90} absorbed and the amount retained.

The retention and excretion of Sr^{85} were studied in 45 patients, each of whom received an intravenous injection of Sr^{85} (0.1 to 0.4 μc per kg of body weight). Most of the patients were maintained under controlled conditions and their calcium intake was kept constant. Table 1 gives the ranges of urinary calcium, of urinary Sr^{85} for the first day, and of cumulative urinary Sr^{85} for 12 days following administration of the dose. As reported

Table 1. Ranges of Sr^{85} and stable calcium excreted in urine of patients injected intravenously with Sr^{85}, on the first day after administration of the dose and the totals for 12 days. The values are for groups of five patients.

Calcium (mg/day)	Sr^{85} 1st day (% of dose)	Total Sr^{85} excretion for 12 days (% of dose)
6– 33	1.30– 3.96	5.21–17.44
35– 45	3.20– 6.05	14.17–25.15
46– 62	1.10–10.19	5.10–39.32
67– 75	5.05– 8.63	25.17–39.63
85–100	5.97–15.91	21.89–48.69
110–130	3.33–17.06	9.88–48.50
141–158	10.29–23.16	38.38–67.37
166–212	10.85–23.39	26.54–61.28
215–326	14.38–28.00	47.74–68.65

Table 2. The average amount of Sr^{85} and Ca (mg/day) excreted in the urine on each of 12 days after the administration of Sr^{85} by intravenous injection. Each value represents the average amount excreted by five patients.

Average amount of Ca excreted (mg/day)	Average amount of Sr^{85} excreted per day (% of dose)											
	1	2	3	4	5	6	7	8	9	10	11	12
21	2.43	1.84	1.25	1.08	1.15	1.08	1.31	0.69	0.50	0.66	0.48	0.46
40	4.47	2.80	2.11	1.71	1.55	1.13	1.07	1.00	1.02	0.79	0.79	0.56
54	7.02	4.06	2.99	2.46	2.34	1.80	1.67	1.25	1.32	1.05	0.94	0.78
72	7.51	4.92	3.77	3.20	2.81	2.17	2.29	1.79	1.87	1.33	1.10	1.18
92	11.19	6.38	4.46	3.32	3.07	2.35	2.14	1.95	1.59	1.43	1.21	1.08
119	11.48	6.09	4.48	3.47	2.75	1.85	1.96	1.51	1.31	1.08	1.15	0.97
149	14.55	8.65	6.03	4.78	3.27	2.66	2.13	1.55	1.49	1.33	1.17	0.91
185	17.00	8.80	5.90	4.37	3.52	2.49	2.33	1.78	1.54	1.40	1.08	0.88
274	20.80	10.23	6.30	4.83	3.17	2.89	1.99	1.93	1.50	1.18	0.91	0.94

Table 3. Factors for calculating the amount of Sr^{90} absorbed from the amount of Sr^{90} and Ca excreted in urine.

Average amount of Ca excreted (mg/day)	Days											
	1	2	3	4	5	6	7	8	9	10	11	12
21	41	54	80	91	91	91	143	143	143	143	208	217
40	22	36	47	69	69	69	93	108	108	108	127	179
54	14	25	33	41	43	56	60	84	84	84	106	128
72	13	20	24	30	35	48	48	56	65	78	92	102
92	9	16	24	30	35	48	48	56	65	78	92	102
119	9	16	24	30	35	48	48	56	65	78	92	102
149	7	12	17	22	30	38	46	56	65	78	92	102
185	6	11	17	22	30	38	46	56	65	78	92	102
274	5	10	17	22	30	38	46	56	65	78	92	102

previously (*2*), when Sr^{85} is administered intravenously, the amount excreted in the urine during the first day after administration and the cumulative excretion for 12 days depend upon the amount of calcium excreted in the urine. The values in Table 1 are listed for groups of five patients according to the amount of calcium excreted daily. In most instances, the highest values for Sr^{85} in any group are only 2 or 3 times the lowest. In two instances, however, for the ranges 46 to 62 and 110 to 130 mg of calcium per day, because a single patient in each group excreted very little Sr^{85}, the minimum Sr^{85} values are extremely low. These two patients had carcinoma of the prostate gland and sarcoidosis, respectively. If their data are omitted, the ranges for the two groups become 6.34 to 10.19 and 9.16 to 17.06, respectively. Similar ranges, with unusually low values for these two patients, were found for the other days and for the 12-day cumulative Sr^{85} excretion.

The average values obtained for each of the first 12 days for the same groups of five patients are summarized in Table 2. The correlation between the amounts of Sr^{85} and calcium excreted becomes smaller with time and, on day 12, there is little or no correlation between them.

Because this correlation is far from perfect, the data of Table 2 exhibit certain irregularities. For instance, for an average of 21 mg of calcium per day, the excretion of Sr^{85} decreases from day 3 to day 4, increases on day 5, decreases again on day 6, and so on. For estimation of the amount of radiostrontium absorbed by the body it is preferable to minimize the effects of these irregularities. Accordingly, the percentages of Sr^{85} given in Table 2 have been divided into 100 and then averaged for certain days and for certain ranges of calcium excretion. Factors obtained by this procedure, and listed in Table 3, can be used to calculate the amount of a strontium radioisotope, such as Sr^{90}, absorbed by the body. Only a single measurement of the 24-hour urinary excretion of Sr^{90} and of calcium is needed. The urinary excretion of Sr^{90} is multiplied by the appropriate factor in Table 3 to give the amount absorbed into the blood stream from the intestines and lungs.

Estimates made from data of the 1st day are highly dependent on the amount of calcium excreted, the factors for this day's excretion varying from 41 to 5 as the amounts of calcium increase from 21 to 274 mg per day. This relation between urinary calcium and urinary strontium has not previously been used in the estimation of the total body burden of Sr^{90} (*3*, *4*), but it is obviously of great importance immediately after accidental exposure to radiostrontium, even though the patient may be on an uncontrolled diet, and his urinary calcium may vary from day to day.

Table 4. Excretion and retention of Sr^{85} in 12 days after intravenous injection of Sr^{85}. The results are expressed as percentages of administered dose.

Average amount urinary Ca excreted (mg/day)	Total urine	Total stool	Retention
21	10.26	19.57	70.17
40	19.53	15.08	65.39
54	27.68	16.61	55.71
72	33.64	15.07	51.29
92	39.98	15.04	44.98
119	38.42	14.50	47.08
149	48.88	13.53	37.59
185	51.02	11.69	37.29
274	53.84	8.10	38.06

The data for cumulative urinary and fecal excretion of intravenously injected radiostrontium in the 45 patients are summarized in Table 4. At the end of 12 days, patients who excreted very small amounts of calcium in the urine retained almost twice as much of an injected dose as patients who excreted very large amounts of urinary calcium. There appeared to be a nega-

tive correlation between the amount of Sr^{85} in the urine and that in the stool, a large amount excreted in the urine reducing the body burden and leaving less to be excreted in the stool.

To calculate the initial body burden of Sr^{90}, total fecal excretion for 12 days was divided by 0.85 on the assumption that net absorption was 15 percent (*7, 8*). Actual absorption varies somewhat, but the errors in using this factor are relatively minor.

From the data given by Bradley *et al.* (*4*), we can arrive at estimates of body burden that agree with theirs. However, much of this agreement is fortuitous. Because of the variability in the relation between urinary calcium and urinary strontium, the true values may differ by roughly 50 percent from the values found, and in some cases by even more. This variability creates difficulties in all methods used for calculating body retention from assays of urinary Sr^{90}. Calculation from the amount of Sr^{90} in the plasma does not avoid the difficulty, as the rate at which the concentration decreases in the plasma also varies from one patient to another. Although these objections do not apply to the estimation of Sr^{90} body content from secondary x-rays, this method presents other difficulties. The method reported here, therefore, has two major advantages: first, its relative simplicity, and second, its taking into account the relation between the amounts of calcium and radiostrontium excreted in the urine. For many purposes the results obtained are sufficiently accurate and can be practically useful.

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Hereditary Angioneurotic Edema: Two Genetic Variants

Abstract. *Serums of patients with hereditary angioneurotic edema lack inhibitory activity against the esterase derived from the first component of complement. In one group of patients this lack appears to result from failure to synthesize the esterase inhibitor of the first component of complement, whereas in another group of patients an abnormal, nonfunctional protein is synthesized.*

The serums of patients with hereditary angioneurotic edema (HANE) are unique in that they do not inhibit the hydrolysis of *N*-acetyl-L-tyrosine ethyl ester by the esterase derived from the first component of complement (C'1) (*1*). This observation led to the conclusion that serums of such patients lack the C'1 esterase inhibitor (EI). Further support for this observation was obtained from the demonstration that the titer of the fourth component of complement is decreased in vivo in the blood of these patients and that the free esterolytic activity in their serum or plasma has similar ultracentrifugal characteristics to C'1 esterase (*1*).

The C'1 esterase inhibitor has been isolated in a highly purified state; it is an acid labile α_2 globulin (*2*). In order to estimate the amount of this inhibitor in normal serums and in the serums of patients with hereditary angioneurotic edema by immunochemical means, two rabbits were repeatedly injected in the foot pads during the course of 1 year with a total of 4 mg of the purified inhibitor in complete adjuvant. Upon immunoelectrophoresis, the rabbit antiserum formed three bands of precipitation with normal human serum. This antiserum could be made specific for the inhibitor without diminution in its potency, and two contaminating bands could be eliminated by mixing 20 parts of the rabbit antiserum with 1 part of the serum from a patient whose serum contained only trace amounts of the inhibitor. The antiserum was titrated by agar-gel diffusion (*3*) against a highly purified preparation of the inhibitor freed of contaminating protein as measured by immunologic criteria. The concentration of the inhibitor in normal serum was 2.4 ± 0.4 mg per 100 ml.

The serums of 25 patients from ten kindreds with hereditary angioneurotic edema contained 0.16 to 0.64 mg of EI per 100 ml. Upon immunoelectrophoresis, these 25 serums formed only faint bands of precipitation with antiserum against EI. The serums of the "normal" relatives of the 25 patients contained normal concentrations of the inhibitor. In contrast, the serums of nine patients in two additional affected kindreds contained normal amounts of inhibitor as estimated by immunochemical means, even though these serums had no inhibitory activity in the esterolytic assay. The rabbit antibody to the inhibitor prepared from a pool of normal human serums gave a reaction of complete identity with the nonfunctional inhibitor of these nine patients, an indication that the abnormal protein was not deficient in antigenic determinants (Fig. 1). Upon immunoelectrophoretic analysis in barbital buffer at *p*H 8.2 (ionic-strength 0.05), no difference could be discerned between the bands of precipitation formed with EI in normal serums or with the nonfunctional inhibitor in the serums of patients. However, immunoelectrophoresis in the presence of calcium lactate, as outlined by Hirschfeld (*4*), showed a clear differ-

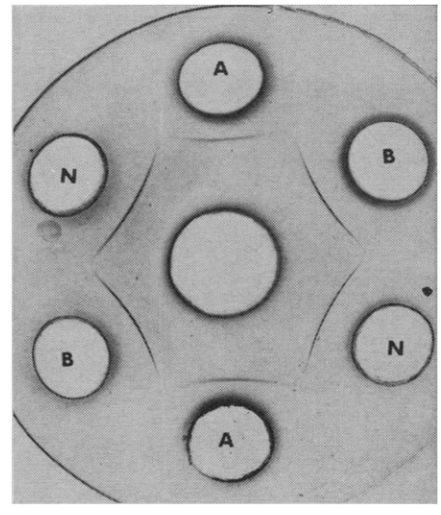

Fig. 1. Agar double diffusion of serum from normal humans (*N*), serum deficient in EI from patients with hereditary angioneurotic edema (*A*), and serum from patients synthesizing nonfunctional EI (*B*) against rabbit antiserum to EI.

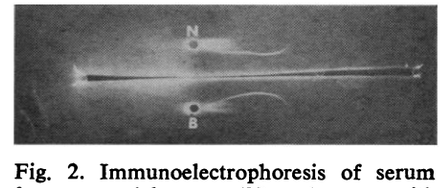

Fig. 2. Immunoelectrophoresis of serum from normal humans (*N*) and serum with nonfunctional EI from a patient with hereditary angioneurotic edema (*B*) against rabbit antiserum to EI. The anode is to the right.