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ERRATA

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PAGE NO.	COLUMN	LINE	ERRATA
19	2	7	Sentence should read: For H^+ saturated soil, for example, the order of removal was $Nb^{95} = Zr^{95} \geq Cs^{137} > Ru^{106} > Y^{90} > Sr^{90}$.

Changed 6-27-55 mmj

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HEALTH PHYSICS DIVISION SEMIANNUAL PROGRESS REPORT

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K. Z. Morgan, Director

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HEALTH PHYSICS DIVISION
SEMIANNUAL PROGRESS REPORT

APPLIED RADIOBIOLOGY

E. G. Struxness

DISTRIBUTION AND EXCRETION OF URANIUM IN MAN

S. R. Bernard
J. C. Gallimore
C. S. Banks
G. W. Royster, Jr.
B. L. Harless
J. R. Muir
G. J. Dodson
N. L. Gillum

A study of the metabolism of uranium in humans after a single intravenous injection of uranyl nitrate hexahydrate is under way. This is a cooperative study with Dr. W. H. Sweet of the Massachusetts General Hospital. It has a dual purpose: (1) to determine the feasibility of employing enriched uranium in the treatment of brain tumors by the recent technique of neutron-capture therapy and (2) to test the relationship between excretion and distribution theoretically described by a mathematical model.

The model of the distribution and excretion shown in Fig. 1 employs systems of linear differential

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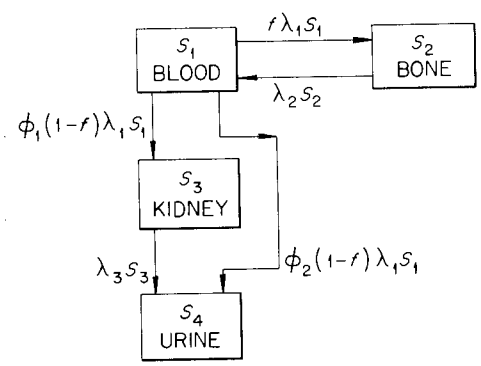
THE MODEL:



THE DIFFERENTIAL EQUATIONS:

BLOOD

$$\frac{dS_1}{dt} = \lambda_2 S_2 - \lambda_1 S_1$$

BONES

$$\frac{dS_2}{dt} = f\lambda_1 S_1 - \lambda_2 S_2$$

KIDNEY

$$\frac{dS_3}{dt} = \phi_1(1-f)\lambda_1 S_1 - \lambda_3 S_3$$

URINE

$$\frac{dS_4}{dt} = \phi_2(1-f)\lambda_1 S_1 + \lambda_3 S_3$$

THE INTEGRATED EQUATIONS:

BLOOD

$$S_1(t) = \frac{I}{\mu_2-\mu_1}\left[(\mu_2-\lambda_1)\epsilon^{-\mu_1 t} + (\lambda_1-\mu_1)\epsilon^{-\mu_2 t}\right]$$

BONES

$$S_2(t) = \frac{f\lambda_1 I}{\mu_2-\mu_1}\left[\epsilon^{-\mu_1 t} - \epsilon^{-\mu_2 t}\right]$$

KIDNEY

$$S_3(t) = \frac{\phi_1(1-f)\lambda_1 I}{\mu_2-\mu_1}\left[\frac{\mu_2-\lambda_1}{\lambda_3-\mu_1}\epsilon^{-\mu_1 t} + \frac{\lambda_1-\mu_1}{\lambda_3-\mu_2}\epsilon^{-\mu_2 t} + \frac{(\lambda_2-\lambda_3)(\mu_2-\mu_1)}{(\lambda_3-\mu_1)(\lambda_3-\mu_2)}\epsilon^{-\lambda_3 t}\right]$$

URINE

$$S_4(t) = I - \frac{(1-f)\lambda_1 I}{\mu_2-\mu_1}\left[\frac{(\mu_2-\lambda_1)(\lambda_3-\phi_2\mu_1)}{\mu_1(\lambda_3-\mu_1)}\epsilon^{-\mu_1 t} + \frac{(\lambda_1-\mu_1)(\lambda_3-\phi_2\mu_2)}{\mu_2(\lambda_3-\mu_2)}\epsilon^{-\mu_2 t} + \frac{\phi_1(\mu_2-\mu_1)(\lambda_2-\lambda_3)}{(\lambda_3-\mu_1)(\lambda_3-\mu_2)}\epsilon^{-\lambda_3 t}\right]$$

Fig. 1. A Model for the Distribution and Excretion of U(VI).

equations. Its design[1] is based on the considerations of small-animal data available in the literature. The excretion equation contains three exponential terms and requires a fit by an exponential series having no more than three terms. The values of the parameters contained in the coefficients are unknown but may be determined by fitting a curve to the excretion data and equating this to the theoretical equation. After some manipulation the following equations permit solutions to be obtained for the unknowns:

$$
(1)\quad \begin{cases}
\phi_2^2(\mu_1 \times \mu_2) - [(\mu_1 + \mu_2)\lambda k \\
\qquad - M(\lambda k - \mu_2)\mu_1 - N(\lambda k - \mu_1)\mu_2]\phi_2 \\
+ \lambda k[\lambda k - M(\lambda k - \mu_2) - N(\lambda k - \mu_1)] = 0 , \\
\phi_1 = 1 - \phi_2 , \\
\lambda_2 = \dfrac{\phi_1\mu_1\mu_2\lambda k}{\phi_1\mu_1\mu_2 - O(\lambda k - \mu_1)(\lambda k - \mu_2)} , \\
\lambda_1 = \mu_1 + \mu_2 - \lambda_2 , \\
1 - f = \dfrac{\mu_1\mu_2}{\lambda_1\lambda_2} ,
\end{cases}
$$

where

$M \sim$ coefficient of $\epsilon^{-\mu_2 t}$,

$N \sim$ coefficient of $\epsilon^{-\mu_1 t}$,

$O \sim$ coefficient of $\epsilon^{-\lambda_3 t}$,

$\mu_1 \ll \lambda_{3=k} < \mu_2$

or

$\lambda_{\text{bone}} \ll \lambda_{\text{kidneys}} < \lambda_{\text{blood}}$.

The numerical solutions of these equations, when substituted into the integrated equations for bones, blood, and kidneys, yield estimates of the contents of these organs.

To date, six brain-tumor patients at Massachusetts General Hospital have received injections of uranyl nitrate hexahydrate. All but one have succumbed to the effects of the neoplasm. All fluids and tissues taken at biopsy and autopsy have been analyzed for uranium.

Typical excretion data are shown in Fig. 2. The counts per minute excreted per hour are plotted vs the time of void (corrected for decay). The excretion rate is seen to decrease through 3 orders of magnitude and shows spurious fluctuations from sample to sample.

The application of the model can be illustrated after fitting a curve to the excretion data. Difficulties arise when a graphical method of fitting data as a sum of exponentials is employed. It appears that three terms will not yield a good fit. This, however, is not an adequate test for the number of exponentials required, since it relies upon a free choice of the region described by a single component. The fluctuations in the data also influence the graphical procedure. Consequently, analytical methods have been employed.

Householder's modification[2] of Prony's method[3] affords some help in the solution of this problem. The data in Fig. 2 were interpolated at 50-hr intervals, thus providing the elements of the matrix of linear difference equations required by the Prony method. This is the W matrix, which appears below:

$$
W = \begin{array}{cccccc}
W_0 & W_1 & W_2 & W_3 & W_4 & W_5 \\
\hline
1420608 & 10687 & 2871 & 1412 & 1291 & 1123 \\
10687 & 2871 & 1412 & 1291 & 1123 & 797 \\
2871 & 1412 & 1291 & 1123 & 797 & 723 \\
1412 & 1291 & 1123 & 797 & 723 & 557 \\
1291 & 1123 & 797 & 723 & 557 & 462 \\
1123 & 797 & 723 & 557 & 462 & 270
\end{array}
$$

When W is orthogonalized as prescribed by the Householder procedure, the vector column V_3 of the V matrix is seen to contain the smallest elements. This signifies that only three terms are necessary to fit the data.

[1] S. R. Bernard and E. G. Struxness, unpublished report.

[2] A. S. Householder, "Analyzing Exponential Decay Curves," *Proceedings of the Seminar on Scientific Computation*, International Business Machine Corp., New York, 1949.

[3] Cited by E. T. Whittaker and G. Robinson, *The Calculus of Observations*, 4th ed., Blackie and Son Ltd., London and Glasgow, 1946.

$$V = \begin{array}{c} \begin{array}{cccccc} V_0 & V_1 & V_2 & V_3 & V_4 & V_5 \end{array} \\ \left| \begin{array}{cccccc} 1420608 & -26.709145 & 1.8193559 & -0.0594230 & -11.104810 & 9.3739431 \\ 10687 & 2790.402531 & -415.0656693 & -3.6305357 & 1159.634151 & -980.3519978 \\ 2871 & 1390.347962 & 385.6309315 & 86.4600498 & 571.894343 & -466.4129972 \\ 1412 & 1280.351209 & 291.7617557 & -114.1674027 & 532.096176 & -412.3131088 \\ 1291 & 1113.263747 & 74.1108537 & 50.0849149 & 475.910446 & -389.9031366 \\ 1123 & 788.530742 & 210.5499037 & -24.9372761 & 333.835010 & -369.8452503 \end{array} \right| \end{array}$$

This offers some encouragement for representing the data with three terms even though limited data are employed. This procedure will be programmed for the Oracle in order to permit rapid manipulation of larger matrices.

In the application of the model, the data are bounded by two curves. The equations and curves superimposed upon the data are shown in Fig. 3.

Solving Eqs. 1 and substituting in the integrated equations yield an estimate of the uranium present in blood, bone, and kidney as a function of time. The agreement between such estimates and the observed results is shown in Fig. 4. The best agreement occurs in the period immediately following injection. The estimating functions appear to decrease too rapidly, which indicates that the λ's determined from the excretion curve are too large.

Among the several analytical methods available with which to determine the λ's, two have been tried and found to be unsuccessful. The method

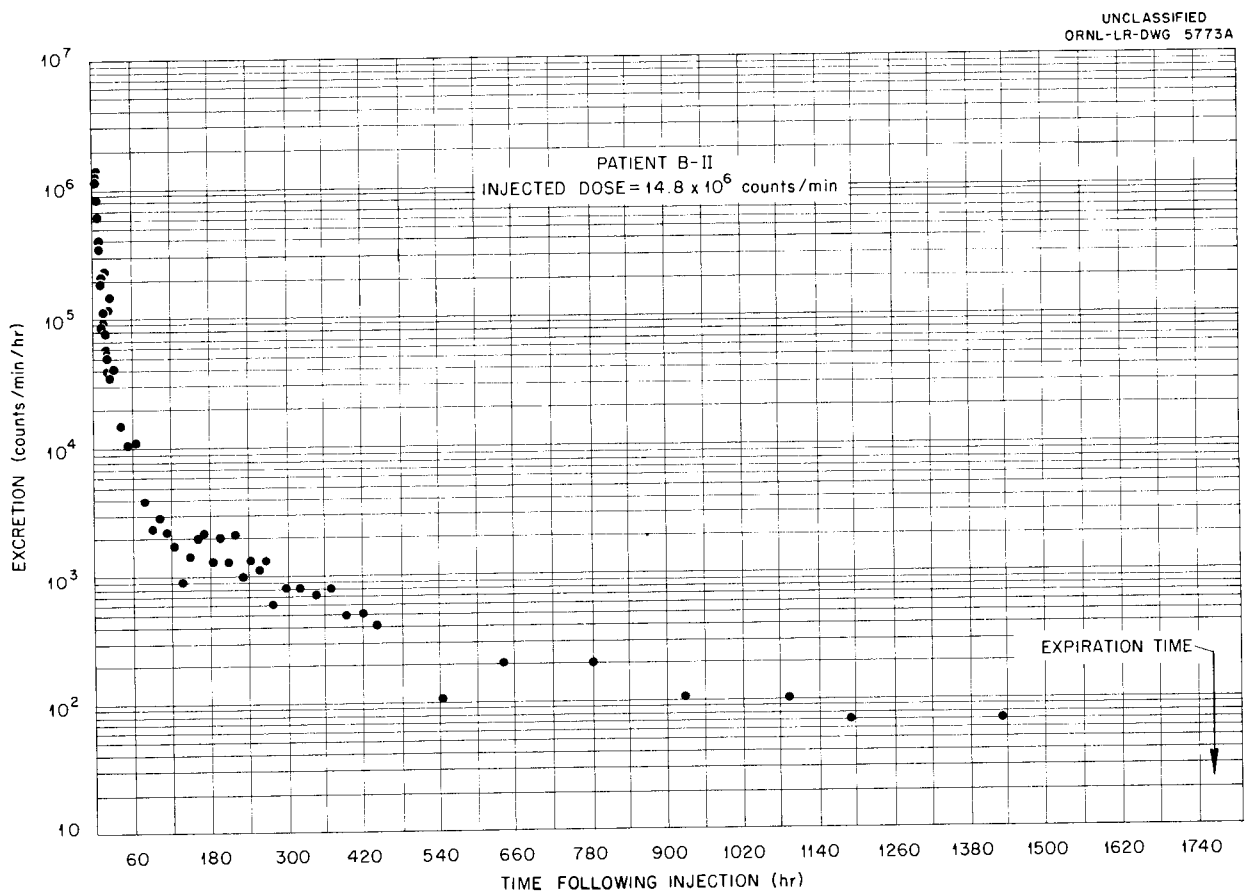


Fig. 2. Excretion of Uranium by a Terminal Brain-Tumor Patient Following an Intravenous Injection of U(VI).

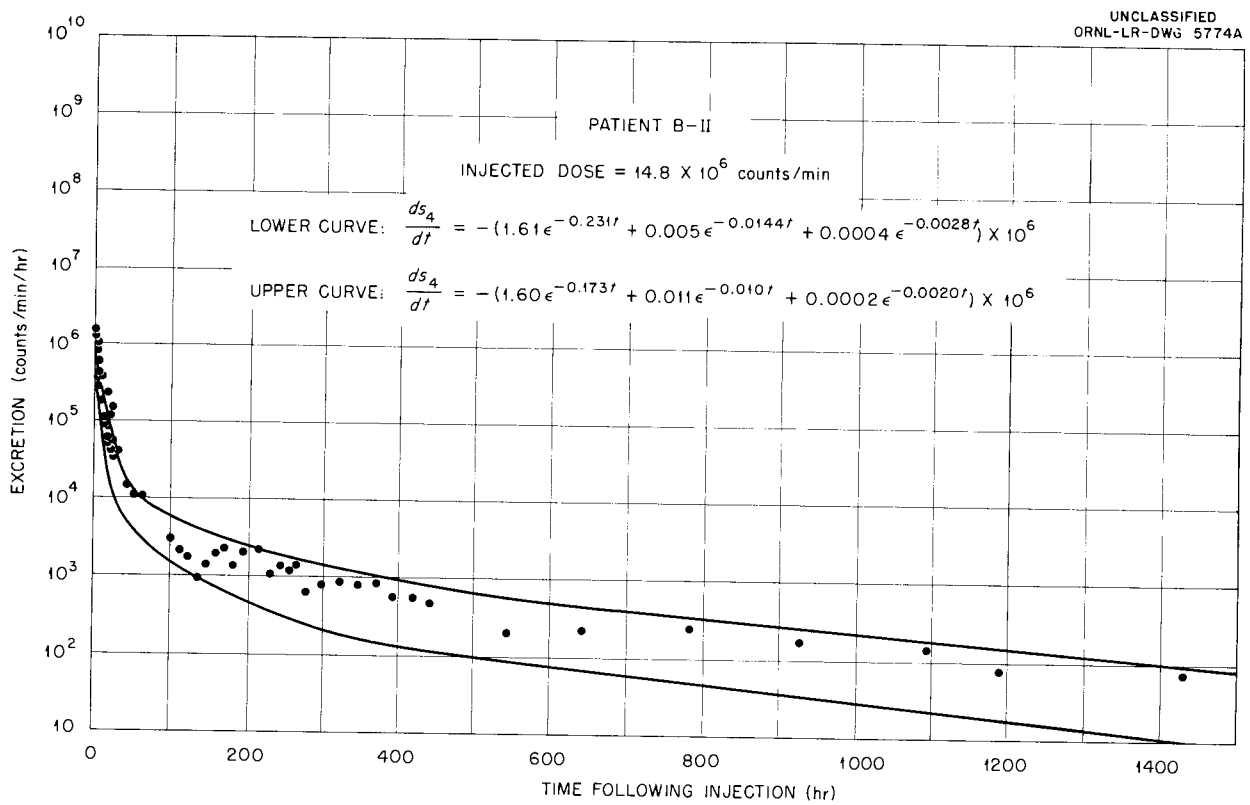


Fig. 3. Excretion Data (Fig. 2) Bounded by Two Multiple Exponential Curves.

of Deming[4] for the treatment of nonlinear functions by a least-squares technique has failed. This method requires initial estimates of the λ's. An iterative procedure described by Householder[5] has been programmed for the Oracle and is employed in conjunction with the Prony method. The program can handle only a limited number of data. A critical factor governing its use is the variance level associated with the data. With the limited number of data points it appears that the variance in the excretion data is too large.

Other methods for the treatment of nonlinear functions are being considered. When a good fit of the excretion curve is obtained, the usefulness of the model can be established.

ECOLOGY

S. I. Auerbach E. G. Struxness
O. Park J. Lynch

Seven samples of tree-hole mold and one sample of log mold with their contained arthropod populations were subjected to various doses of gamma radiation from a Co^{60} source. The tree species utilized were *A. saccharum, Q. alba, U. fulva, L. styraciflua, F. grandifolia,* and *T. americana.* The samples were subdivided into series consisting of several 50- or 100-g fractions. Each of these fractions was irradiated at one of the following doses (in roentgens): $(1.5, 2.5, 5, 7.5) \times 10^4$; $(1, 1.25, 1.5, 1.75, 2, 3.5, 5, 7.5, 8.6) \times 10^5$; and 1×10^6.

The immediate mortality of the contained arthropods was determined by extracting the surviving individuals in Berlese funnels, counting them, and comparing them with controls. Mortality was caused by all doses. It ranged from less than 10% in the lower doses to over 99% at 1×10^6 r. Figures 5 and 6 show the immediate mortality, expressed

[4] W. E. Deming, *Statistical Adjustment of Data,* 1st ed., Wiley, New York, 1943.

[5] A. S. Householder, *On Prony's Method of Fitting Exponential Decay Curves and Multiple-Hit Survival Curves,* ORNL-455 (Sept. 19, 1949).

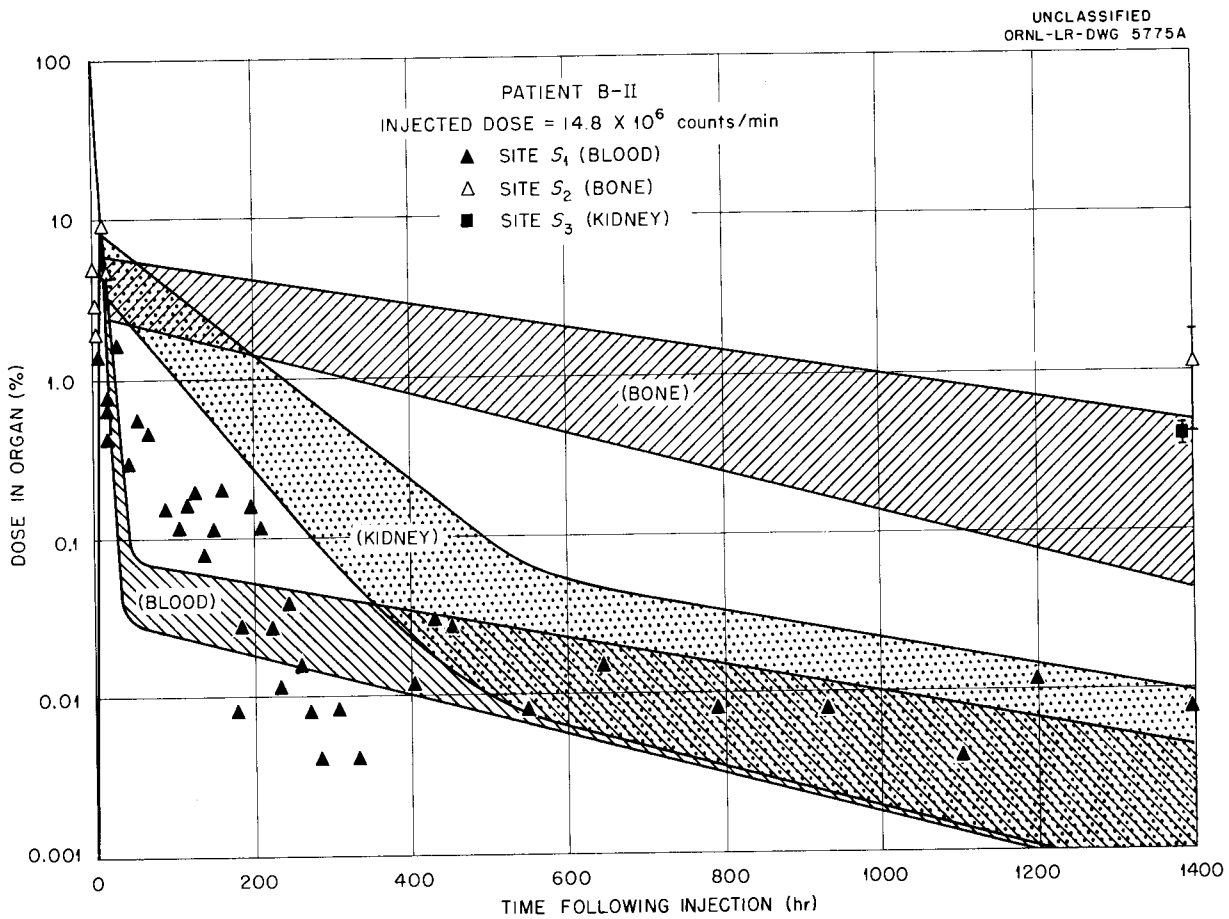


Fig. 4. Comparison Between Estimated and Observed Organ Content.

as per cent of survival, produced by the different doses. Figure 5 shows the curves for the first four series of experimentals, and Fig. 6 shows them for the last four series. In terms of steepness of slope of the curve of per cent survival vs dose, the increments of dose that appeared to be most effective in causing immediate lethality were in the range 50,000 to 200,000 r.

The total arthropod population mortality curve for each tree sample had its own slope. Furthermore, within each sample the curves were not linear. This is not surprising in view of the differences in substrate, the heterogeneity of the species populations within each sample, and the interspecific and intraspecific differences with respect to radiosensitivity.

It is suggested that there is a level of radiation in the range 50,000 to 150,000 r which is of critical biologic significance with regard to the community. If this level is exceeded, the community will undergo breakdown. This hypothetical level has been designated the Manifest Radiation Threshold (MRT).

URINALYSIS RESEARCH

L. B. Farabee

Work continued on the development of an analytical procedure for the determination of radioactive strontium in urine specimens of approximately 1500 ml volume. The essential steps in this procedure were described in a previous progress report.[6] Further studies have been made in order to evaluate the usefulness of the procedure in routine urine analyses. Previous studies at high Sr^{89} tracer levels showed over-all losses of about 2%. The

[6] H. H. Hubbell *et al.*, *H-P Semiann. Prog. Rep. July 31, 1954*, ORNL-1763, p 5.

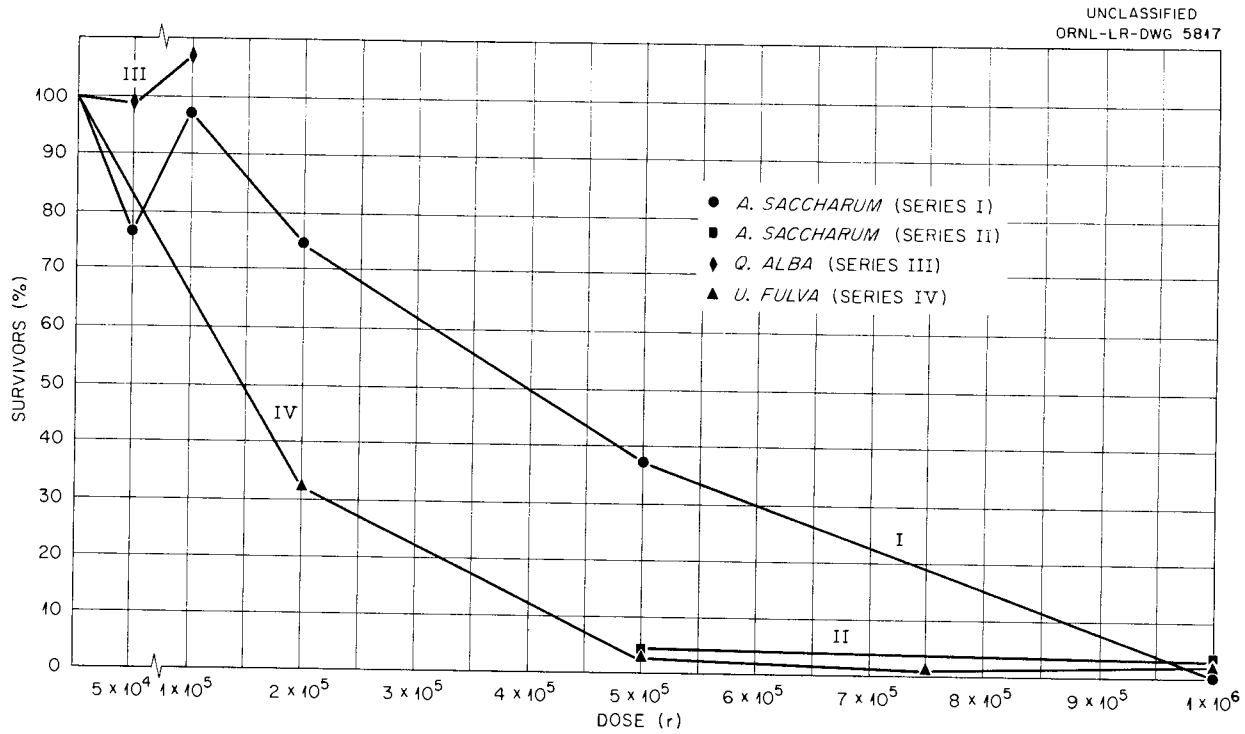


Fig. 5. Mortality of Arthropods Contained in Tree-Hole and Log Mold When Subjected to Various Doses of Gamma Radiation (Series I–IV).

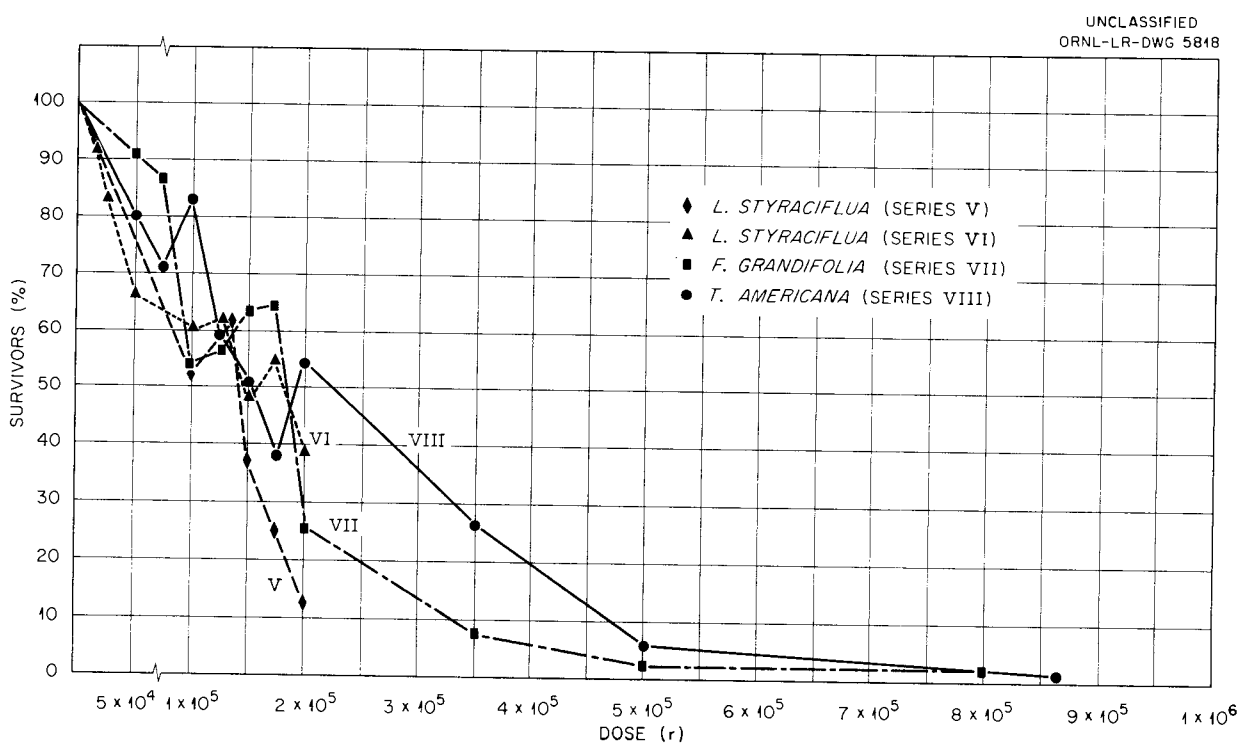


Fig. 6. Mortality of Arthropods Contained in Tree-Hole and Log Mold When Subjected to Various Doses of Gamma Radiation (Series V–VIII).

procedure has been further tested at low tracer levels of approximately 70 counts/min (at 25% geometry) to determine the efficiency at levels that might be expected in some samples in routine analyses. Recovery of added Sr^{89} tracer in urine samples from 22 persons gave an average of 93.3% ± 3.1% (statistical error in counting, 3 counts/min).

Since there is appreciable beta activity from the K^{40} in urine, adequate separation from potassium must be provided by any procedure for analysis for radioactive fission products in urine. This procedure was checked for decontamination from K^{40} by analyses made on 17 urine samples (1500 ml volume) from persons not exposed to radiostrontium. The average beta activity of these samples was 0.73 count/min (25% geometry), with a range of 0.1 to 1.7 counts/min.

This procedure has been used at ORNL since Dec. 1, 1954, for routine analysis for strontium in urine. Although the procedure is not so short as might be desired, the over-all efficiency in routine operations is enhanced by the fact that one operator can carry out eight to ten analyses simultaneously. Since very small amounts of solids are present in the final eluent, which is evaporated and mounted directly for counting, no weighing of the final residue is necessary. Self-absorption of beta activity due to the solids is nil. The procedure provides easy identification of the strontium isotope, since Y^{90}, if present, is separated from Sr^{90} and subsequent counting of the sample will indicate the fraction $Sr^{90}/(Sr^{90} + Sr^{89})$ present by the growth of the daughter Y^{90}. A detailed report of this procedure will be published soon.

DISTRIBUTION OF RADIOISOTOPES IN ANIMAL TISSUE

M. J. Cook A. G. Barkow[7]
K. Z. Morgan

Description of the Experiment

Single-exposure data are currently used to calculate continuous-exposure values for maximum permissible concentrations of radioisotopes in water. A preliminary experiment to test the validity of this practice has been completed.

Male and female C-57 strain mice were divided at random into three principal groups, and all were given Co^{60} as the chloride. The first two groups were treated identically, except for the amount of Co^{60} administered. Each mouse in the first two groups was given a single gavage dose consisting of 0.5 ml of solution. The solution administered to the first group contained 7.2 μc, and that given to the second group contained 32.7 μc. At specified times, ten mice from each group were sacrificed.

The value[8] for maximum permissible concentration in water for Co^{60}, 2×10^{-2} μc of Co^{60} per milliliter, has been estimated to result in a dose rate of 0.3 rep per week to the liver after extended use of the contaminated water. On this basis, 2.25×10^{-2} μc of Co^{60} per millilter was added to the drinking water of the third group. The water was present in the cage at all times in order that the mice might drink *ad libitum*. During a nine-week period these mice were sacrificed – ten at a time – at specified time intervals.

After the animals were sacrificed, they were weighed in tared Lusteroid tubes. Each tube containing a mouse was then placed in a high-pressure ionization chamber, and readings for the total-body burdens of Co^{60} were obtained before the mice were dissected.

Since disagreement exists as to the critical organ for Co^{60}, the organs chosen for investigation were the spleen, liver, kidneys, and gastrointestinal tract with its contents. Each organ was weighed in tared Lusteroid tubes, and the number of microcuries per organ was obtained in the same manner as for the total body. If the amount of Co^{60} in a single organ was too small to be determined, all ten like organs from a sacrificed group were combined to obtain a measurement.

Results of the Experiment

The results of the single-exposure experiments are plotted in Fig. 7. Each point for the total body, liver, and gastrointestinal tract with contents represents the average of ten readings of the per cent of administered dose present in the individual organs. Each point for the spleen and kidneys represents the average reading obtained from a single observation on ten spleens or ten pairs of kidneys.

[7]Summer research participant, Marquette University, Milwaukee, Wis.

[8]United States National Bureau of Standards, *Maximum Permissible Amounts of Radioisotopes in the Human Body and Maximum Permissible Concentrations in Air and Water*, Handbook 52, Superintendent of Documents, Washington 25, D.C.

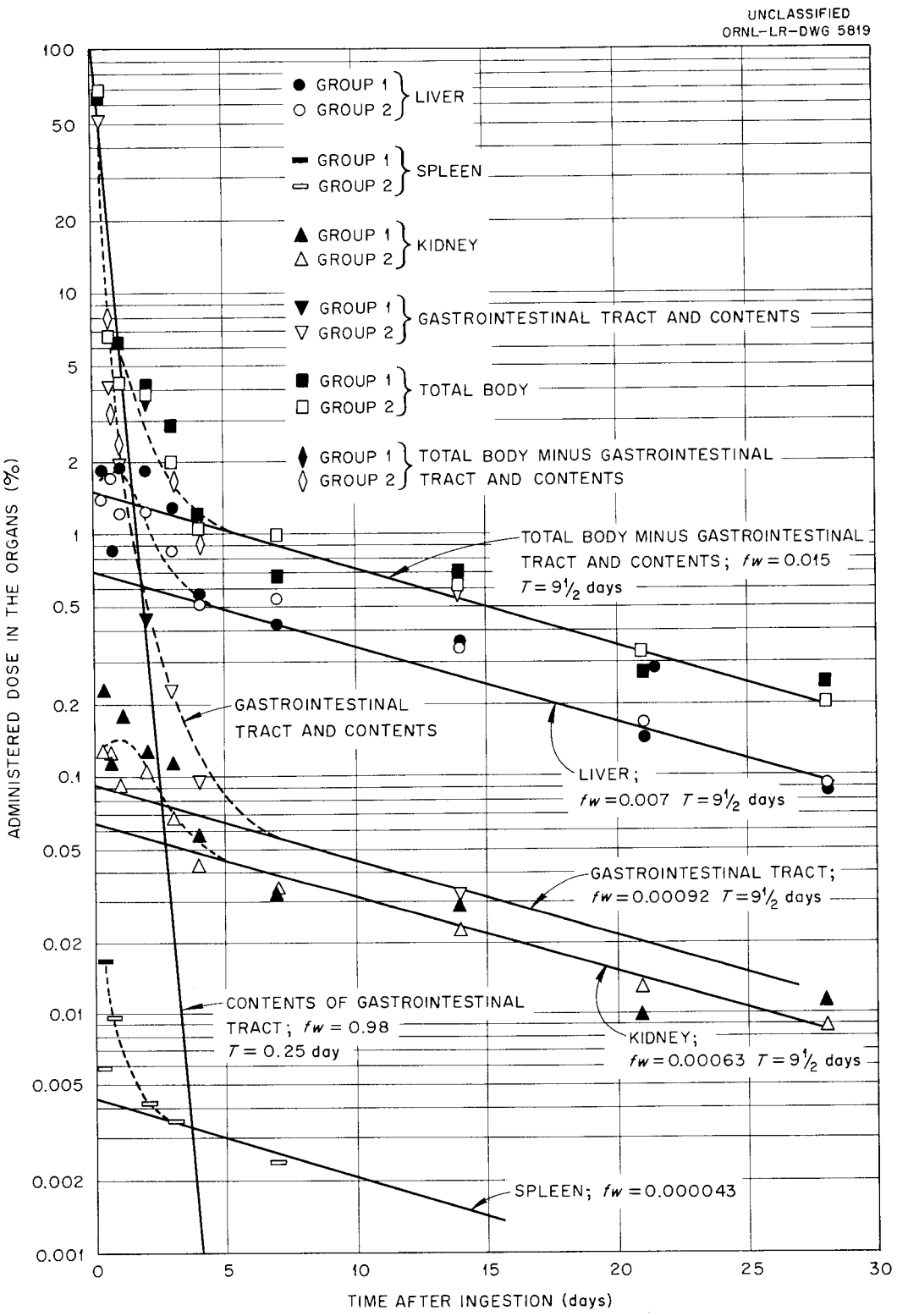


Fig. 7. Distribution of Co^{60} in the Various Organs as a Function of Time After Ingestion. Data from both groups are combined to give the indicated curves.

In Fig. 8 are presented both the experimental points from the continuous-exposure experiments (third group of mice) and the curves calculated by substituting the single-exposure values of f_w and T in the following equation:

$$(1) \qquad qf_2 = \frac{CRTf_w(1 - e^{-0.693t/T})}{0.693},$$

where

q = microcuries in total body,
f_2 = fraction in the organ of the quantity in the total body,
C = concentration of radioisotope in water (2.25×10^{-2} μc of Co^{60} per milliliter),
R = rate of water intake (2 ml/day in this experiment),
f_w = fraction of the radioisotope that reaches the organ after ingestion,
t = period of exposure, days,
T = effective half life, days.

The continuous-exposure curves calculated from single-exposure data show that after 63 days of exposure only 0.000026 μc or about 0.1% of the Co^{60} in the total body is deposited in the spleen. Since the lowest reading obtainable with the high-pressure ionization chamber was about 0.002 μc, the ten spleens combined would not be expected to give a reading. This proved to be the case; no data could be obtained for the spleens in the continuous-exposure experiment. The continuous-exposure data that are plotted in Fig. 8 for the total body, kidney, liver, and gastrointestinal tract plus contents are in agreement, within the limits of error, with the values calculated from the single-exposure data and substantiate the current practice of calculating the maximum permissible values from single-exposure data. The greatest deviation occurred in the case of the liver, for which the values differed by a factor of 2.

The second objective was to determine the critical organ of the body. The liver is recommended as the first choice for Co^{60} in Handbook 52 (ref. 8) and in the 1951 report by the International Commission,[9] but in the 1954 report by the International Commission[10] the gastrointestinal tract is considered to be the critical organ. The maximum permissible concentration in water is 2×10^{-2} μc/ml for the liver and is 4×10^{-4} μc/ml for the gastrointestinal tract, respectively, indicating that the gastrointestinal tract is more critical by a factor of 50. In this experiment the best estimate of the maximum permissible concentration of Co^{60} in water for continuous exposure is 1.4×10^{-2} μc/ml for liver as the critical organ and 3×10^{-4} μc/ml for the gastrointestinal tract as the critical organ. These data are in agreement within the limits of error with the two ICRP values of maximum permissible concentration.

A most striking observation is the large fraction of administered Co^{60} which localizes in the liver. After a five-day period following administration of the dose and during the remainder of the experiment, about 50% of all the administered Co^{60} remaining in the body continued to be in the liver. Figure 9 indicates that the concentration decreases in the following order: gastrointestinal tract with contents, liver, kidneys, and the rest of the body.

The third objective of this experiment was to eliminate the discrepancies between the 1951 report of the International Commission,[9] in which $f_w = 1.00$ and $T = 20$ days for Co^{60} in the liver, and the values given in Handbook 52 (ref. 8), in which $f_w = 0.004$ and $T = 8.4$ days. In this experiment the single-exposure values are $f_w = 0.007 \pm 0.002$ and $T = 9.5 \pm 2$ days.

It is concluded that single-exposure data can be used to obtain continuous-exposure values for approximate maximum permissible concentrations of Co^{60}. This experiment should be repeated for other radioisotopes in order to establish the general validity of using single-exposure data to calculate continuous-exposure values.

ISOTOPIC DISTRIBUTION IN MAN

I. H. Tipton M. J. Cook
D. K. Bowman J. C. Gallimore

Spectrographic Analysis of Human Tissue

The spectrographic laboratory in the Physics Department of the University of Tennessee analyzed

[9] International Congress of Radiology, "Recommendations of the International Commission of Radiological Protection," *Brit. J. Radiol.* 24, 46–53 (1951) or Handbook 47, Superintendent of Documents, Washington 25, D.C. (The meeting of the International Congress of Radiology was held in London, England, July 1950.)

[10] International Congress of Radiology, *Maximum Permissible Internal Dose*, final report of the Congress, December 1954. (This meeting of the International Congress of Radiology was held in Copenhagen, Denmark, July 1953.)

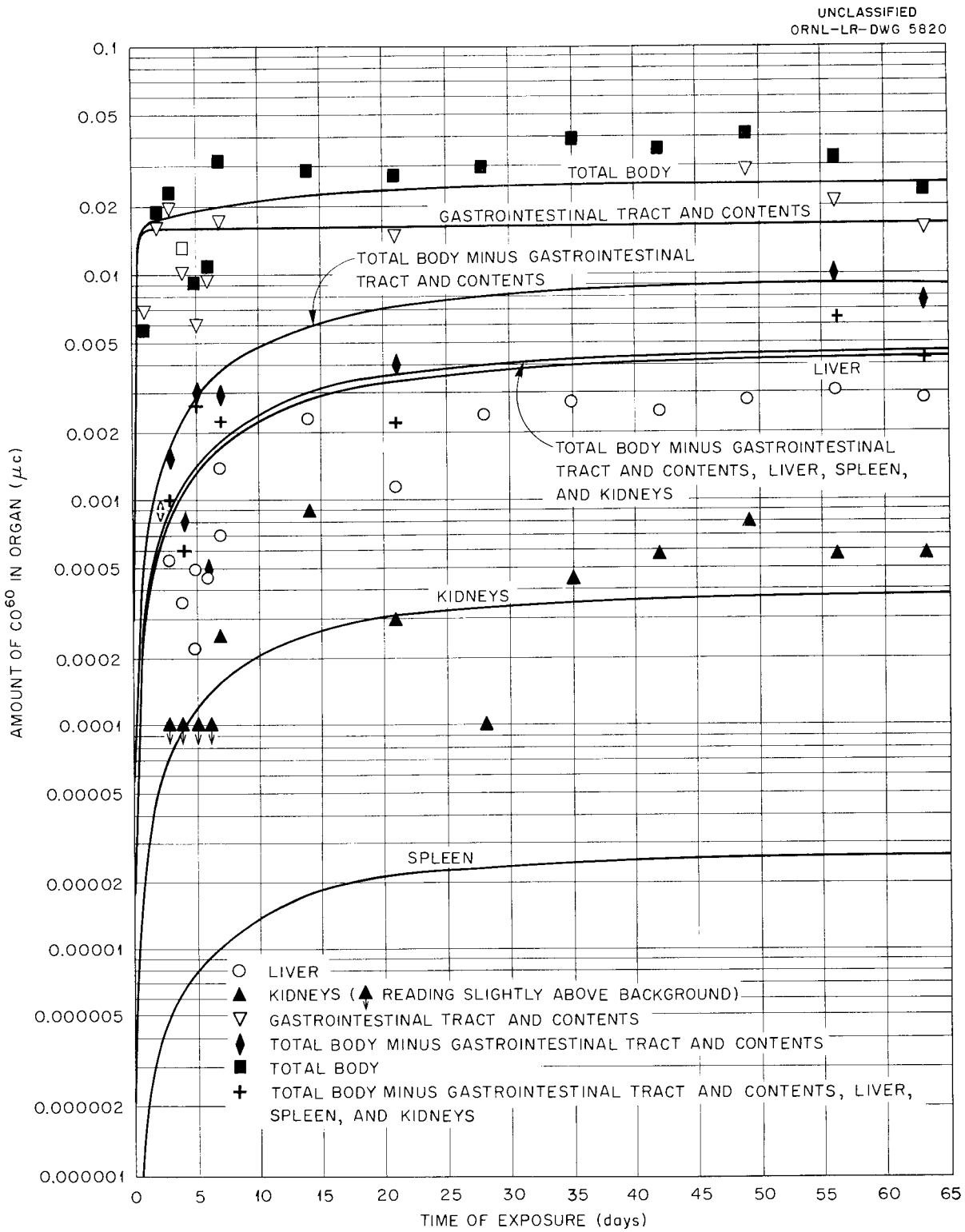


Fig. 8. Relation Between the Amount of Co^{60} Found in the Organs After Continuous Exposure and the Amount Calculated by Use of Eq. 1. The solid lines represent results computed by inserting values of f_w and T as found from single-exposure data (Fig. 7) for various organs in Eq. 1.

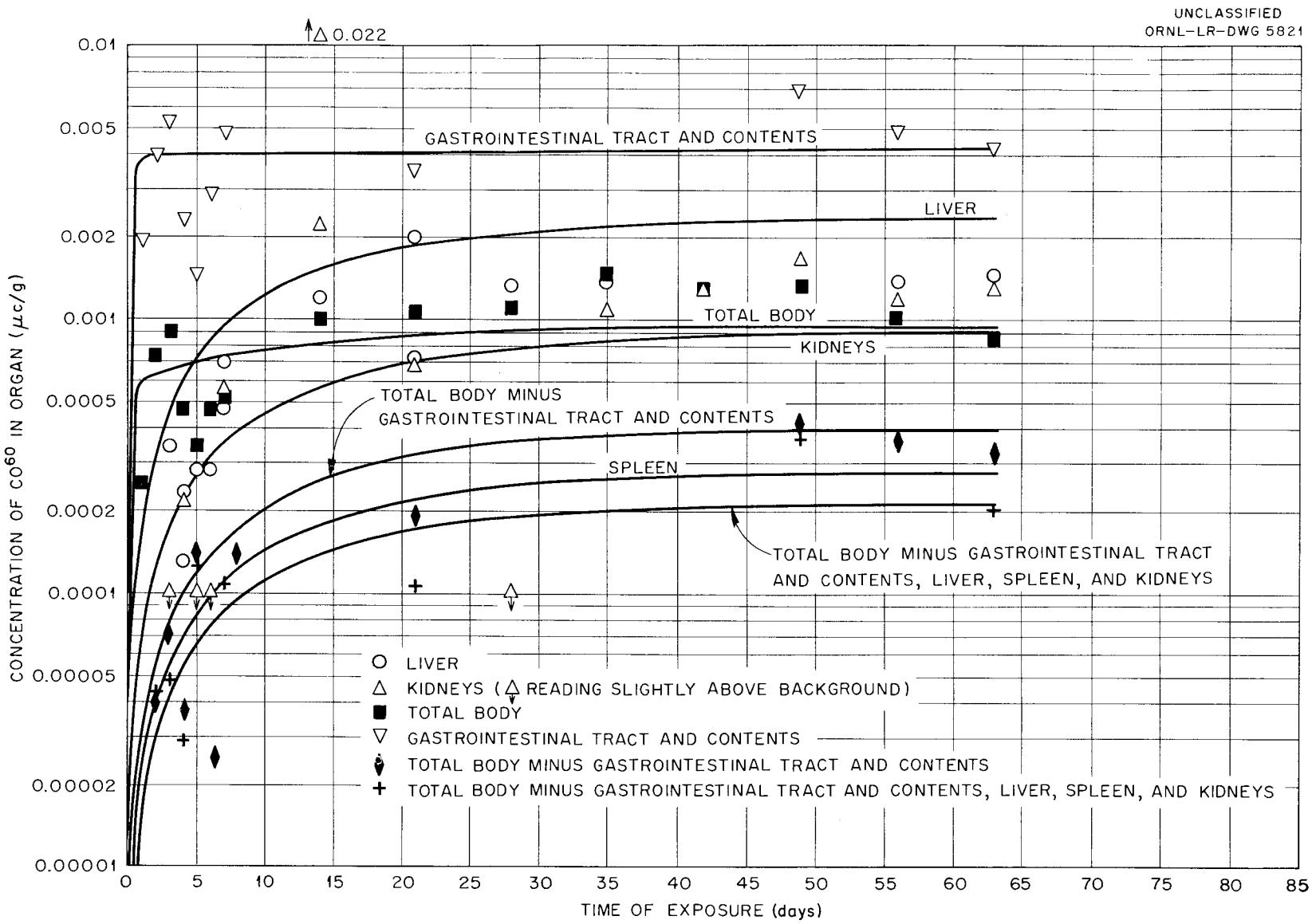


Fig. 9. Relation Between the Amount of Co^{60} Found in the Various Organs Based on Continuous Exposure and the Amount Computed from Single-Exposure Data.

260 samples of wet-ashed tissue from persons who were victims of an instantaneous accidental death, 100 samples of bone and cartilage, and more than 200 other samples of various tissues. Quantitative spectrographic methods for the simultaneous analysis of 21 elements were developed, and a sensitive method for the determination of dilute concentrations of strontium in various biological materials was established.

Since it is desirable to analyze a large number of samples from representative geographical locations and since the collection of accidental-death tissue is tedious and involved, it was decided that the responsibility for collecting and preparing samples should be assumed by the Applied Radiobiology Section. The University was not able to handle this difficult problem, except at the expense of the spectrographic work. A tissue-preparation laboratory has been established, and arrangements with appropriate medical authorities for collection of samples in Boston, New York, Chicago, St. Louis, Denver, Seattle–Tacoma, Los Angeles, Dallas, New Orleans, Miami, and Richmond have been initiated. Samples have been, or are being, received from Boston, New York, Chicago, and Denver. It is hoped that reliable figures for concentrations of more than 20 elements in "standard man" can be established this year.

SANITARY-ENGINEERING RESEARCH

E. G. Struxness

FIELD INVESTIGATIONS AND EXPLORATIONS (LIQUID-WASTE DISPOSAL)

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P. Guinn
H. J. Wyrick
W. D. Laguna (USGS)
E. R. Eastwood
R. Richardson (USGS)
W. J. Lacy (ERDL)
Pfc. L. M. Lawless (ERDL)
M/Sgt. R. R. Rollins (ERDL)

Serial Coagulation Equipment

The ERDL group studied the additive effect of successive coagulations on the removal of radioactive materials from water. Enough radioactive material was added to 2 liters of tap water to give about 1.3×10^{-2} μc/ml. Then 500 ml of this solution was added to each of four 1-liter beakers, the pH was adjusted by the use of either HCl or NaOH, and enough of the desired chemical coagulant combination was added to give 25-25, 50-50, 100-100, and 200-200 ppm. The three coagulant combinations studied were (1) $FeCl_3$-$CaCO_3$, (2) $Al_2(SO_4)_3$-Na_2CO_3, and (3) Na_3PO_4-$Ca(OH)_2$. Hereafter these will be referred to as Fe, Al, and Na, respectively. The pH range used with each coagulant combination was (1) 7.2 to 8.0, (2) 6.2 to 7.0, and (3) 10.2 to 11.0, respectively. After the coagulant was added, the beaker contents were rapidly mixed for 3 min, slowly mixed for 10 min, and then allowed to settle for 20 min. Samples of the supernatant were taken, placed in counting dishes, dried, and counted. Other samples of the supernatant were first filtered and then dried and counted. The remaining liquid was decanted into a 2-liter beaker, the pH was readjusted to the range for the next coagulant pair, and the above procedure was repeated for the second and third coagulants on the same sample. The procedure was repeated with the use of all six possible orders of addition of the chemical coagulants on each of the solutions of the seven radioactive substances.

Table 1 shows the total per cent removal of the radioactivity from the filtered sample for only the 100-100 ppm dosage. Per cent removal was calculated as follows:

$$\text{Per cent removal} = \frac{(\text{activity before first coagulation}) - (\text{activity after final coagulation})}{\text{activity before first coagulation}} \times 100 .$$

TABLE 1. REMOVAL OF RADIOACTIVE MATERIAL BY SERIAL COAGULATION

All removal values are for filtered samples treated with the 100 ppm concentration of chemicals

Radioactive Material	Initial Activity (μc/ml)	Total Removal (%)					
		Method 1 Fe-Al-Na	Method 2 Fe-Na-Al	Method 3 Al-Fe-Na	Method 4 Al-Na-Fe	Method 5 Na-Al-Fe	Method 6 Na-Fe-Al
Ru^{106}-Rh^{106}	0.011	99.8	99.9	99.6	99.7	99.0	99.9
Zr^{95}-Nb^{95}	0.013	99.9	99.9	99.8	99.7	99.9	99.9
Ce^{144}-Pr^{144}	0.013	99.9	99.9	99.9	99.9	99.9	99.9
Ba^{140}-La^{140}	0.012	91.0	90.7	97.1	92.3	89.2	91.5
Sr^{90}-Y^{90}	0.012	80.8	69.8	80.7	82.6	79.0	73.7
MFP-1*	0.013	96.4	97.0	96.4	97.3	97.6	97.0
MFP-2*	0.014	70.5	74.0	73.2	72.5	72.0	69.8

*MFP-1 and -2 are fission-product mixtures.

It will be noticed that the per cent removals agree very closely. However, per cent removals after each coagulation indicated that some radioisotope solutions were as effectively treated by one particular coagulant combination as by the series of coagulations. The serial treatment method was more effective on Ru^{106}-Rh^{106}, Zr^{95}-Nb^{95}, and Ce^{144}-Pr^{144} than was a single treatment. With certain radioisotopes, for example radiostrontium, repeated treatment with the same chemical combination [Na_3PO_4-$Ca(OH)_2$] at high pH (11.0) was found to be most effective. Results reported by McCauley *et al.*[1] have indicated that coprecipitation is the method of removal for radiostrontium when this technique is used.

Field Explorations

Four NX core borings 200 ft deep and one 6-in.-dia churn-drilled well 300 ft deep have been completed at the 4-acre site previously selected for geologic and hydrologic exploration in anticipation of its use for possible disposal of radioactive liquid wastes.[2] Water-level recorders have been installed on the wells to obtain information of the configuration and elevation of the water table in this area. To determine the vertical distribution and degree of interconnection of permeable zones in the rock, each well has been pressure tested, and analysis of the data is in progress.

A deep-well pump and associated equipment have been ordered to conduct pumping tests in this area. The purpose of these tests is to investigate quantitatively the ability of the rocks to transmit fluids.

Single-point electric logging of all wells at this site has been completed. These data will be compared with the recovered cores and with the logs recorded during drilling of the wells to determine whether useful information can be obtained by electric logging.

Preparation of a geologic and hydrologic base map of the Oak Ridge area is in progress.

Experimental Lined Pit

The evaporation study[2] to determine the watertightness of the asphalt-tamped clay liner was completed after a 44-day observation period. This experiment is being conducted as part of a program to develop more effective and economical methods of impoundment of radioactive waste. The data[3] indicate that the liner is leaking at a mean rate of about 0.021 ± 0.017 gal/ft^2/day, amounting to a mean loss of 8.4 ± 6.8 gal/day. Nonuniformity in thickness of the asphalt liner and puncturing of the liner by the tamped shale are deemed responsible for its nonwatertightness and the decrease in its retentive qualities by a factor of approximately 10^2 as compared with the value obtained by laboratory studies. After additional bituminous-membrane studies are completed, it is proposed that the pit be used for confirmation of the studies on a pilot-plant scale.

Experimental Unlined Pit

Another promising method of radioactive-waste disposal involves the use of unlined pits. Prior to the discharge of wastes to one of the experimental unlined pits,[2] water-table contour drawings were developed from the water-level measurements made in the observation wells surrounding the pit. Figure 10 shows the contours before rain accumulated in the pit, and Fig. 11 shows the results of this localized ground-water recharge. From these drawings it is concluded that the movement of waste in the direction of wells U-4 and U-16 would be pronounced, while toward well U-2 it would be less.

The movement of chemical pollution was followed by field nitrate tests (diphenylamine spot-plate method) and by quantitative nitrate and uranium analysis on samples obtained from the wells. A plot of the pit and the direction of travel of nitrates and uranium, as shown in Fig. 12, confirm the direction of travel implied by the rainfall recharge effect on the ground-water table. Uranium in amounts above normal was found in several of the wells and was always associated with a pH less than that of the normal ground water. This is in agreement with the effect of pH on the removal of isotopes by clay as reported in laboratory studies.[4]

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[1] R. F. McCauley, R. A. Lauderdale, and R. Eliassen, *A Study of the Lime-Soda Softening Process as a Method for Decontaminating Radioactive Waters*, NYO-4439 (Sept. 1, 1953).

[2] R. J. Morton *et al.*, *H-P Semiann. Prog. Rep. July 31, 1954*, ORNL-1763, p 15–16.

[3] K. E. Cowser, R. J. Morton, and T. W. Bendixen, *Evaluation of the Watertightness of an Asphalt-Tamped Clay Pit Liner*, ORNL CF-55-3-128 (to be published).

[4] T. W. Brockett, B. Kahn, and C. Straub, *Removal of Radioactive Cations from Solutions by Local Clay-Type Soils*, ORNL CF-54-12-145 (Dec. 17, 1954).

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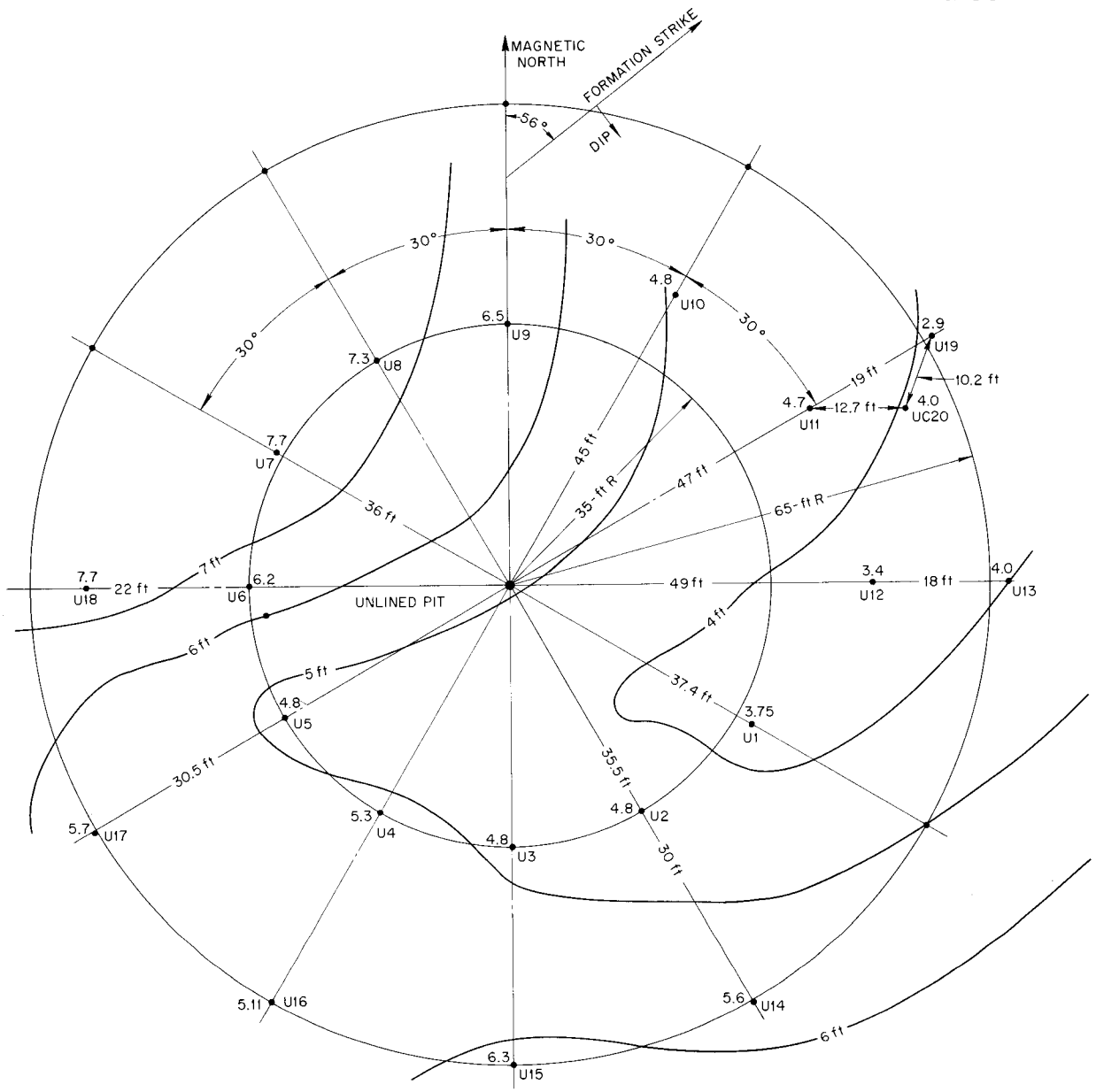


• OBSERVATION AND SAMPLE WELLS (RESULTS OF 5/19/54)
—— RELATIVE WATER-TABLE CONTOURS TO COMMON BASE

Fig. 10. Water-Table Contours Before Rain Accumulated in Experimental Unlined Pit.

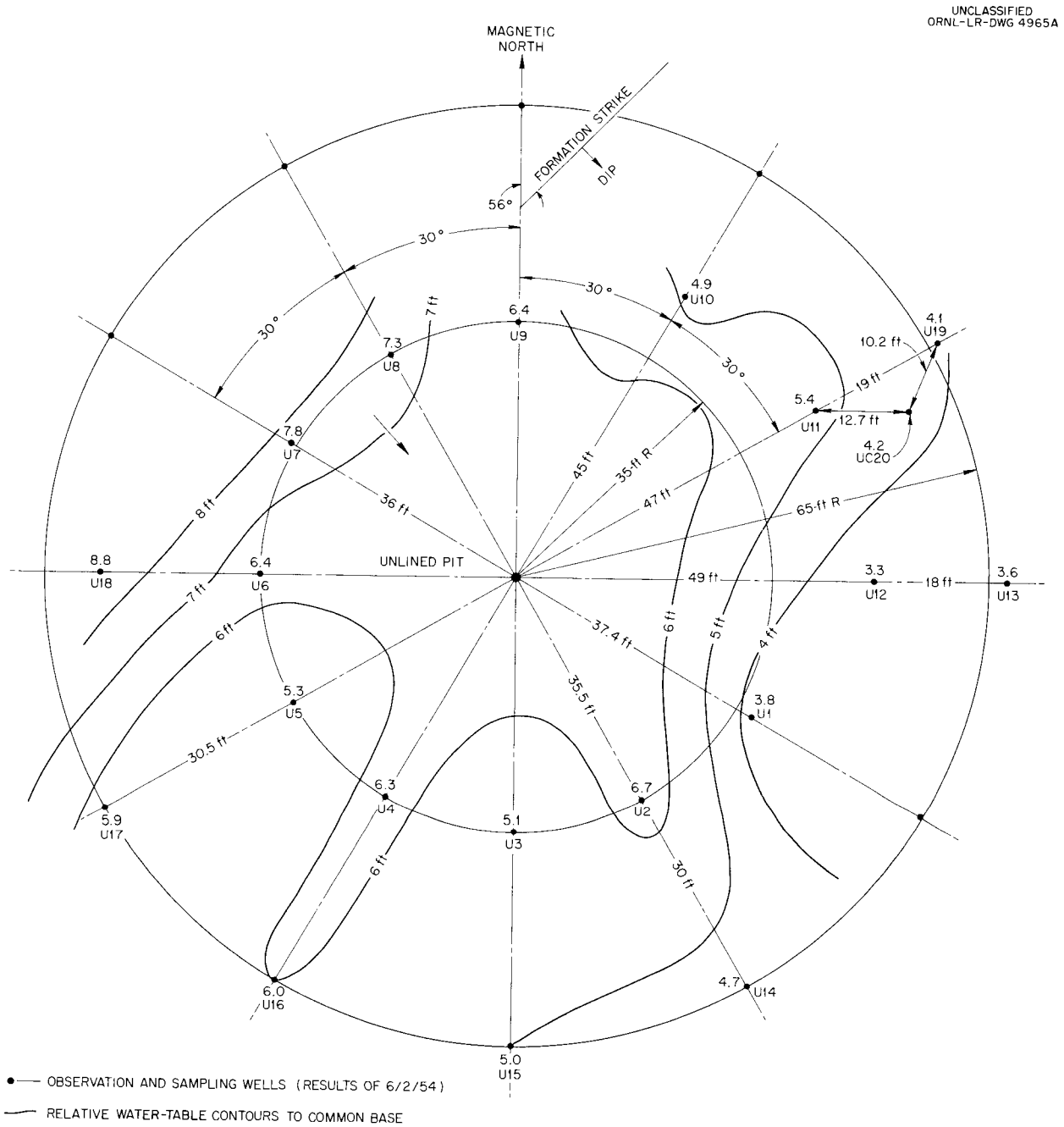
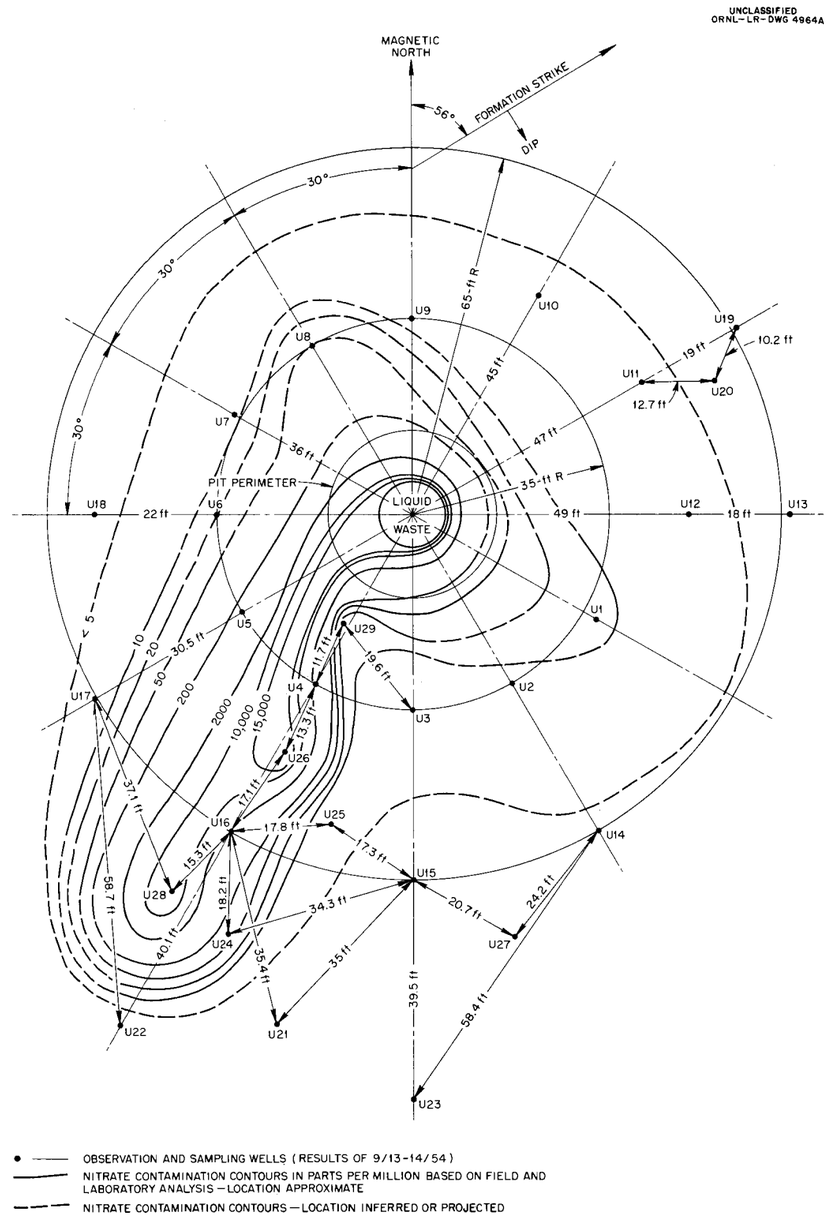


Fig. 11. Results of Localized Ground-Water Recharge on Water-Table Contours.



NITRATE AND URANIUM ANALYSIS

(ALL RESULTS IN PARTS PER MILLION)

WELL	5/21/54 – LABORATORY		9/14/54 – LABORATORY		9/13/54 FIELD NITRATE
	NITRATES	URANIUM	NITRATES	URANIUM	
U1	0.1	1.8	12.0	1.0	10+
U2	0.2	1.1			DRY
U3	0.1	1.8			+
U4	8.0	0.5	1600	0.6	10+
U5	8.4	1.4	214	0.7	10+
U6	0.6	0.9			DRY
U7	0.5	0.8			+
U8	0.2	0.8			DRY
U9	0.3	1.4			DRY
U10	0.5	1.4			DRY
U11	7.0	0.9			+
U12	<0.1	0.4			+
U13	0.4	0.4			+
U14	0.2	0.9			+
U15	0.7	0.9			+
U16	28.0	0.4	1990	9.0	10+
U17	0.1	0.4			+
U18	0.2	0.9			+
U19	0.3	0.9			+
U20	0.2	1.8			+
U21			<1.0	1.1	5–
U22			1.0	1.0	5–
U23			<1.0	1.3	5–
U24			55.0	0.5	10+
U25			<1.0	0.8	5–
U26			19,210	31.0	10+
U27			1.0	2.0	5–
U28			13,000	2.3	10+
U29			17.0	0.6	10+

Fig. 12. Plot of Experimental Unlined Pit and Direction of Travel of Nitrates and Uranium.

Two core borings are being made in order to define down-dip movement, to locate a potential main stream of chemical pollutant, and to provide samples for uranium analyses.

Waste-Storage Pits

A new operational radioactive-waste pit (No. 3) adjacent to waste pit No. 2 was completed and placed into service January 24, 1955. Four wells located around the pit will be used initially for observing the direction and rate of movement of chemical and radiochemical pollution. To detect any down-dip movement of the waste, one well was located normal to the formation strike and drilled to a depth of 172 ft; this depth was necessary to intercept the bedding planes exposed in the pit bottom.

Water samples for chemical analysis have been collected from the four wells. The wells have also been radiologged for background determinations by use of a trailer-mounted G-M probe.

A remote-registering water-stage recorder has been installed to give a continuous record of liquid levels in the waste pit.

To estimate the volume of seepage from the pit, an evaporation pan and a rain gage have been located adjacent to the pit. The difference between the liquid gain by waste input and rainfall and the liquid loss by evaporation will indicate the approximate volume of seepage.

CHEMISTRY AND SOILS ENGINEERING

C. P. Straub (USPHS) E. R. Eastwood
B. Kahn T. W. Bendixen (USPHS)
T. W. Brockett M. I. Goldman (USPHS)
H. L. Krieger (USPHS)

Chemical Laboratory Studies

Procedures have been developed for determining the quantities of cesium, strontium, yttrium, rare earths, ruthenium, zirconium, and niobium radioisotopes adsorbed on soils. The soil is leached repeatedly with the appropriate acid (nitric for strontium, yttrium, and the rare earths; hydrochloric plus oxalic for zirconium and niobium; and sulfuric for cesium and ruthenium), carriers are added, and the radioisotopes are separated and identified by radiochemical methods.

The adsorptive behavior of local soils with respect to the major long-lived fission products was studied. It was found that little adsorption of the isotopes named above occurred on soils saturated with carrier solutions of these isotopes, with the exception of zirconium and niobium, from the 0.2 *M* HNO_3 and 1.6 *M* $Al(NO_3)_3$ solution; but in aqueous solutions (pH >3) removal (with the exception of cesium) followed that predicted from the Hofmeister lyotropic series. For the H^+ saturated soil, for example, the order of removal was $Nb^{95} = Zr^{95} \gg Cs^{137} \gg Ru^{106} \gg Y^{90} \gg Sr^{90}$. The adsorptive capacity of soils for cesium as a function of the cesium concentration was determined in an effort to explain the greater tenacity of cesium retention by soils when cesium is in lower concentrations.

Because of the high cost of making basic the nitric acid–aluminum nitrate solution described above and because of the excessive volume of $Al(OH)_3$ precipitated during neutralization, methods were studied for precipitating in acid solution the various radioisotopes present. It was found that cesium could best be coprecipitated with cold copper ferrocyanide, ruthenium with hot copper ferrocyanide, strontium with cold barium sulfate, and yttrium and the rare earths with cold cerium oxalate from a diluted solution; zirconium and niobium could be carried down by several precipitates. More than 90% of each of the radioisotopes was removed by the designated process.

A study of cesium in low concentrations showed no radiocolloidal properties of cesium. It was found that filter paper had the capacity to adsorb cesium and that this capacity depended on the ionic form of the solution with which the paper is saturated and also on the ionic strength of the cesium solution. This capacity was determined for Whatman No. 40 paper.

Standard radiochemical methods for the determination of barium and strontium were adapted for use in the analysis of low concentrations of these radioisotopes in natural waters and sewage. The sewage is digested with perchloric acid and nitric acid. The strontium and barium radioisotopes are carried on small amounts of strontium and barium carriers and on the calcium normally found in water and sewage, the precipitation being that of the carbonates in basic solution. The strontium and barium are separated from the calcium by treatment with anhydrous acetone.

Soils and Engineering Studies

The use of Tennessee ball clay as a liner material was investigated. With an alkaline waste

solution the permeabilities of the plastic limit pack and dry pack apparently stabilized at k_{20} values of 5×10^{-9} and 1×10^{-8} cm/sec, respectively. As the construction of Lagoon No. 3 progressed, various soil and core samples were collected and tested. Preliminary test results on these samples indicate a permeability coefficient of 3×10^{-3} cm/sec for vertical samples and of about 4×10^{-3} and 1×10^{-3} cm/sec for samples parallel and normal to the dip, respectively. Permeability studies of asphalt liner materials were undertaken, and, after 61 days of testing, these materials were found to have a k_{20} value of about 5×10^{-11} to 10^{-10} cm/sec in either acid or alkaline aluminum nitrate solution.

Field evaluation of some of the liner materials is under way; sections of these liners and other equipment for their study have been built into Lagoon No. 3.

AIRBORNE RADIOACTIVITY STUDIES

J. W. Thomas F. M. Empson
R. L. Bradshaw R. E. Yoder

The use of open pits, provided with impermeable liners, has been proposed as a means of impounding radioactive waste. The pits would be filled with gravel and covered with a bed of sand to prevent contamination of the atmosphere with radioactive aerosols formed by evaporation from the pit. To study the feasibility of this system, a type 347 stainless steel tank, 20 ft long and 3 ft in diameter, equipped with 20 kw of electric heat, has been installed in the ground at a site near the laboratory area. This "entrainment well" will be half filled with coarse gravel, and a radioactive solution will be introduced into the gravel layer. The solution will be brought to a boil by the electric heaters.

The sand will be added in increments so that its effectiveness as an entrainment separator can be determined. Radioactivity will be added initially in the form of short-lived tracers, followed by high-level activity in the form of waste or dissolver solution.

The accessory equipment required for operation of the well consists of a dissolver tank (installed), condenser and cold trap, sampler, air compressor, water tank and pump, refrigeration machine, air filter, and vacuum pump. Installation of this accessory equipment is now in progress.

ORNL-Area Air Contamination

Studies of the distribution of air contamination in the Laboratory area during various hot chemical operations revealed that the vent from a waste storage tank was a source of contamination. Installation of a Fiberglas filter on this vent during the summer of 1954 resulted in a reduction in area-wide ORNL air contamination by a factor of at least 2 during the last two special isotope-recovery operations, in which the tank is used. Air contamination in the immediate vicinity of the tank was reduced by a factor of 100 to 1000. To make and install the Fiberglas filter cost less than $100.

Packed-Bead-Column Method of Particle-Size Determination

Present methods of particle-size determination (owl, diffusion battery, Tyndall effect, gravity settling, etc.) are inconvenient to use for routine measurements over a wide range of particle size, 0.1 to 1.0 μ in radius. To provide a rapid and convenient method of particle-size determination in this range, a glass column, 89 cm long and 3.81 cm in diameter, was filled with 1.47-mm-dia lead beads, and aerosol penetration was determined as a function of particle size by using the standard methods listed above. The results are shown in Fig. 13 for spherical di-2-ethylhexyl particles (DOP). In about 5 min a particle-size determination may be made with an accuracy of about $\pm 10\%$.

The existence of an aerosol size for maximum penetration through a packed column, reported previously,[5] is confirmed by these data. When the air stream is directed down the column, gravity impingement of the suspended particles is assisted by the flow direction; when the flow is directed upward, gravity settling is hindered by the flow direction. As the particle size becomes smaller, the up- and down-direction curves come closer together; this is due to the decreasing influence of gravity. Finally, at about 0.15 μ radius the curves come together and rapidly fall off; diffusion is the important mechanism of particle removal at and below this size.

[5] E. G. Struxness *et al.*, *H-P Semiann. Prog. Rep. July 31, 1954*, ORNL-1763, p 8–11.

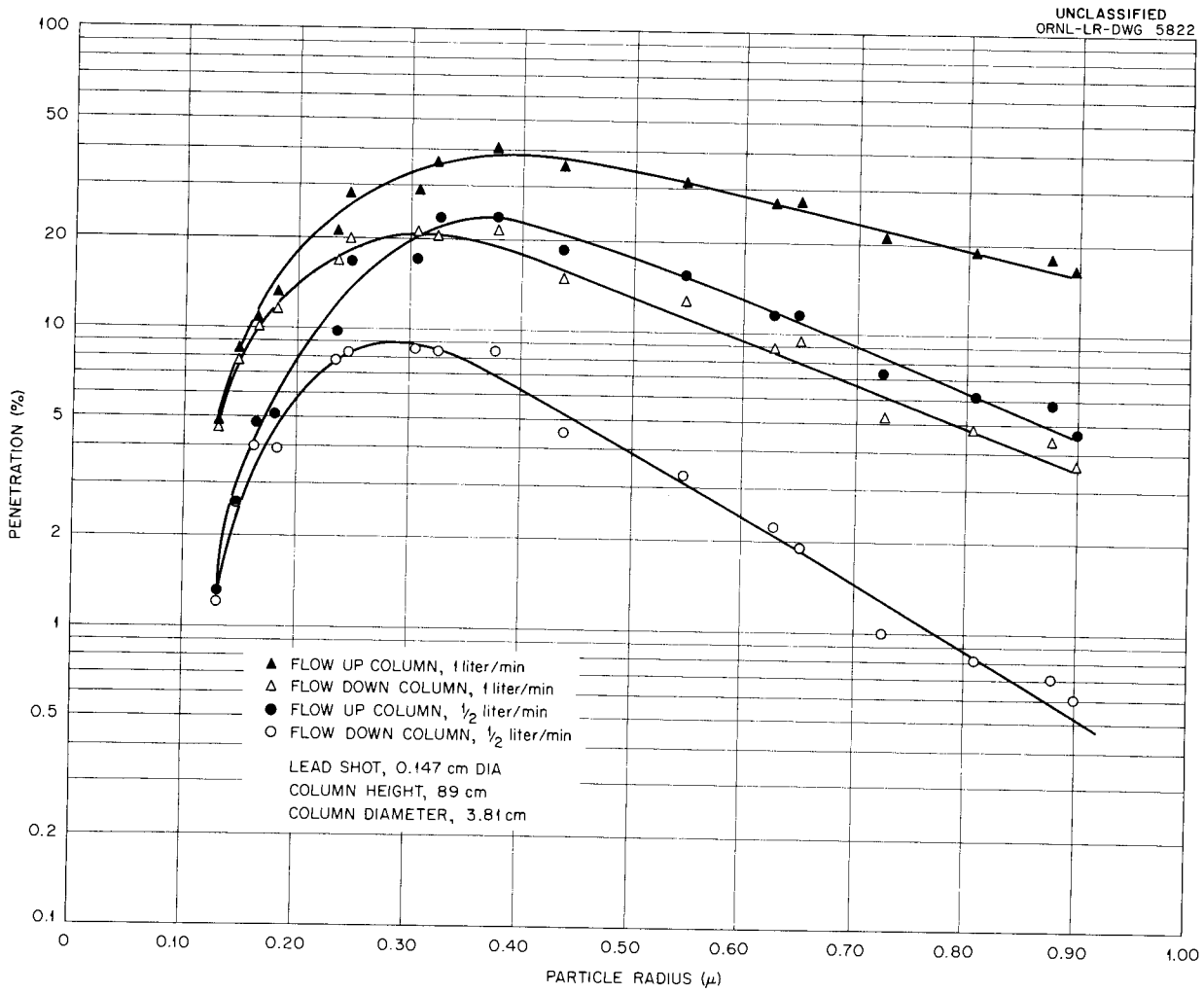


Fig. 13. Aerosol Penetration Through Lead-Shot Column.

RADIATION DOSIMETRY

G. S. Hurst

EXPERIMENTAL PHYSICS OF DOSIMETRY

R. D. Birkhoff, H. K. Richards, T. E. Bortner, B. G. Saunders, J. S. Cheka, W. G. Stone, H. H. Hubbell, F. W. Sanders[1], W. F. Patton[1]

Measurement of Attachment Coefficient

Apparatus has been developed whereby the attachment coefficient for electrons in various gases can be determined. The method involves measuring the decrease in pulse height in an electron-collection pulse chamber with the addition of an electron-attaching gas. Figure 14 shows the effect on the pulse height when oxygen is added to argon in the chamber. It may be shown that the pulse height is a function of electron drift velocity and attachment coefficient. To obtain a unique relation between pulse height and attachment coefficient, the electron drift velocity is measured simultaneously with the pulse height. A very important detail of the experiment is to maintain proper gas purification, especially with such electronegative gases as water vapor and oxygen. Mass spectrographic analyses (performed in the Mass Spectrometry Laboratory) show that the equipment is now capable of holding gas purity to less than 1 ppm of oxygen or water vapor. Under these conditions, since the attachment coefficient for argon is essentially zero, it was found that the variation of pulse height with electron drift velocity agreed with that predicted on theoretical grounds.

The method may be applied to such counting gases as methane, ethylene, nitrogen, and argon, in which oxygen is present in small amounts. In such cases the average agitation velocity of electrons is determined by the main constituent of the mixture. Thus the coefficient for attachment of electrons to oxygen may be determined for electrons in the range from very low energies up to 8 ev. Even though the data on attachment coefficients are obtained with a parallel-plate chamber, they will apply to the high fields that are encountered with most typical proportional or Geiger counters.

[1]AEC Fellows in Radiological Physics.

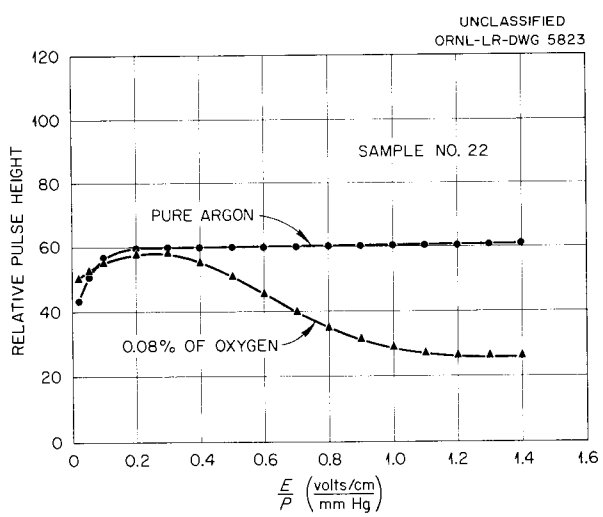


Fig. 14. Pulse Height in Pure Argon and in Argon-Oxygen Mixture.

W Value of 5-Mev Alpha Particles in Water Vapor[2]

Because of its importance in radiobiological studies, the ionization produced by 5-Mev alpha particles in water vapor has been measured. For this purpose a special parallel-plate ionization chamber was constructed in such a way that it could be held at elevated temperatures, thus maintaining a high water-vapor pressure. The ionization current produced was measured as a function of voltage, and, since water is electronegative, the value for the saturation current was determined by means of the Jaffé recombination theory. The *W* value for water vapor was determined by comparison with the ionization produced in nitrogen and ethylene, for which the *W* values had been previously determined. Both methods of calibration gave a *W* value for 5-Mev alpha particles in water vapor equal to 37.6 ± 0.2 ev per ion pair.

To determine the mechanism for the increased ionization and the lowering of the value of *W* of argon due to slight added impurities,[3] two lines of

[2]Thesis work done under AEC Radiological Fellowship, 1953–1954.

[3]C. E. Melton, G. S. Hurst, and T. E. Bortner, *Phys. Rev.* 96, 643–645 (1954).

investigation are being followed. A large parallel-plate ionization chamber with an internal plutonium alpha source is being used to determine the effect of adding various gases to argon at pressures ranging from 750 down to 25 mm Hg. Ethane additions of 1 and 3% have been used, and the increased ionization effect has been found to be non-pressure-dependent. The ionization of argon and of the mixtures is constant down to the pressure at which the alpha particles begin to escape from the sensitive area of the chamber. Below this pressure the amount of ionization drops rapidly. The relative increase due to the added impurity remains fairly constant in the pressure range used. Other impurities will be tested in the same manner.

A spectrometer is used to determine whether any lines of the argon spectrum are attenuated or removed by the addition of the impurity. If either of these occurs, it would indicate that some energy formerly given off as radiation is being expended in ionizing collisions.

Energy Losses of Electrons in Foils

Beta Spectrometer. A technique for making thin gold-ring sources has been developed. Such sources are now irradiated weekly in the LITR and have made possible a study of the internal conversion spectrum from the Hg^{198} gamma ray. Tentative conversion ratios are $K:L:M:N$ of 32.2 : 11.9 : 3.2 : 1 and $L_I + L_{II} : L_{III}$ of 5.9. A report describing the spectrometer and its automatic control features has been written and will be submitted to *The Review of Scientific Instruments*.

Data have been taken on the straggling of the K conversion electrons from Hg^{198} in aluminum and silver. Additional foils of lead and copper have been made in thicknesses useful for measurements in these metals. The automatic controls permit the spectrometer to gather data continuously around the clock.

Accelerator. Experimental work on the excitation of the conduction electron plasma in metals has been completed. Foils of aluminum, magnesium, and copper have been inserted in the electron beam of the accelerator, and the resulting discrete energy losses have been investigated with an energy resolution of 2 in 10^5 for bombarding energies from 15 to 115 kev. The energy necessary to excite the plasma has been measured, and the cross section has been determined as a function of the incident energy of the electrons. Evaluation of data is under way.

Measurements made previously on the distribution of dose as a function of depth for 100-kev electrons striking a slab of aluminum have been continued for very small depths, where the dose is greatest, and for large depths comparable to the range of the incident electrons. When these present measurements on aluminum are completed, the new higher precision ion chamber which has been constructed will be installed. Dose distributions in a variety of materials and at incident electron energies from 10 to 250 kev will then be determined.

X-Ray Exposure Facility

The x-ray exposure facility, mentioned previously, built around a commercial 250-kv constant-potential x-ray machine is now complete and calibrated. The machine can be quickly set for routine exposures at dose rates varying from a few milliroentgens per hour up to several hundred thousand roentgens per hour, at x-ray energies from 5 or 10 kv up to 250 kv. The energy spectrum is accurately known at seven different voltages and can be quickly determined at other voltages by means of a complete set of calibrated filters of aluminum, copper, tin, and lead. Broad or narrow spectral distributions can be easily obtained by the use of these filters.

A standard free-air ionization chamber with its controls, in addition to a large set of Victoreen condenser r-meters, permits quick and accurate dose measurements. A dose-rate meter assists in setting the machine for any dose rate obtainable with the improved x-ray controls, which stabilize the current at any value from 20 μa to 20 ma.

Exposures have been made in the past six months for other members of this section, for the Applied Health Physics Section, and for visitors from the Electric Boat Div. and the U.S. Army.

Film Dosimetry

A series of exposures to x and gamma rays has been made on Eastman type K and Blue Brand x-ray films to determine how the variation in sensitivity of the films with radiation energy compares with that of other types tested previously. A report on all this work is being prepared for publication.

Ion-Recombination Errors in Pocket Chambers

Apparatus has been constructed to determine whether the errors observed by measuring current

flow through an irradiated pocket chamber are the same as those measured by the discharge method mentioned previously.[4]

A study of the theory, carried out with the aid of the Theoretical Physics Group of this section, indicates that the results obtained by the discharge method do not agree with the theory or with results obtained by current-flow methods elsewhere, although the process is too complex for accurate theoretical treatment.

Detection of Ionizing Radiation by Frequency Variation with the Use of the Ferroelectric Effect

In the work on the detection of ionizing radiation by frequency variation, the ion chamber has been replaced by a Geiger counter (Fig. 15). V_1 is a subminiature tube in a Clapp circuit, the frequency of which is controlled by a series-resonance quartz crystal. The circuit contains the ferroelectric capacitance $C_F(I)$ as another frequency-controlling element. The capacitance is connected at one side to the 600-v tap of the voltage supply of the Geiger counter. The other side of $C_F(I)$ is connected over R_2 and R_1 to the 900-v outlet of the voltage supply. Therefore the polarization voltage at $C_F(I)$ is 300 v, producing a capacitance reduction and a frequency increase over the values at zero voltage. When ionizing radiation enters the counter, the current pulses will produce a voltage drop across R_1 and thereby reduce the voltage at $C_F(I)$. By adding a capacitance across a portion of R_2, the pulses can be integrated and produce a nearly constant voltage decrease at $C_F(I)$ and a frequency increase. The leakage of the ferroelectric material becomes unimportant in this construction, and the only undesirable feature remaining is the temperature dependence of barium titanate. New materials with zero temperature coefficient will eliminate this limitation. This circuit is shown in Fig. 15.

Exposure of Quartz Crystals to Neutrons and Co^{60} Gamma Rays

Quartz-crystal blanks without plating or cement were used exclusively in tests on the exposure of quartz crystals to neutrons and Co^{60} gamma rays, since it was suspected that previous results were produced, at least partially, by decomposition of the cement or by oxidation of the silver plating.

[4] H. H. Hubbell *et al.*, *H-P Semiann. Prog. Rep. July 31, 1954*, ORNL-1763, p 7.

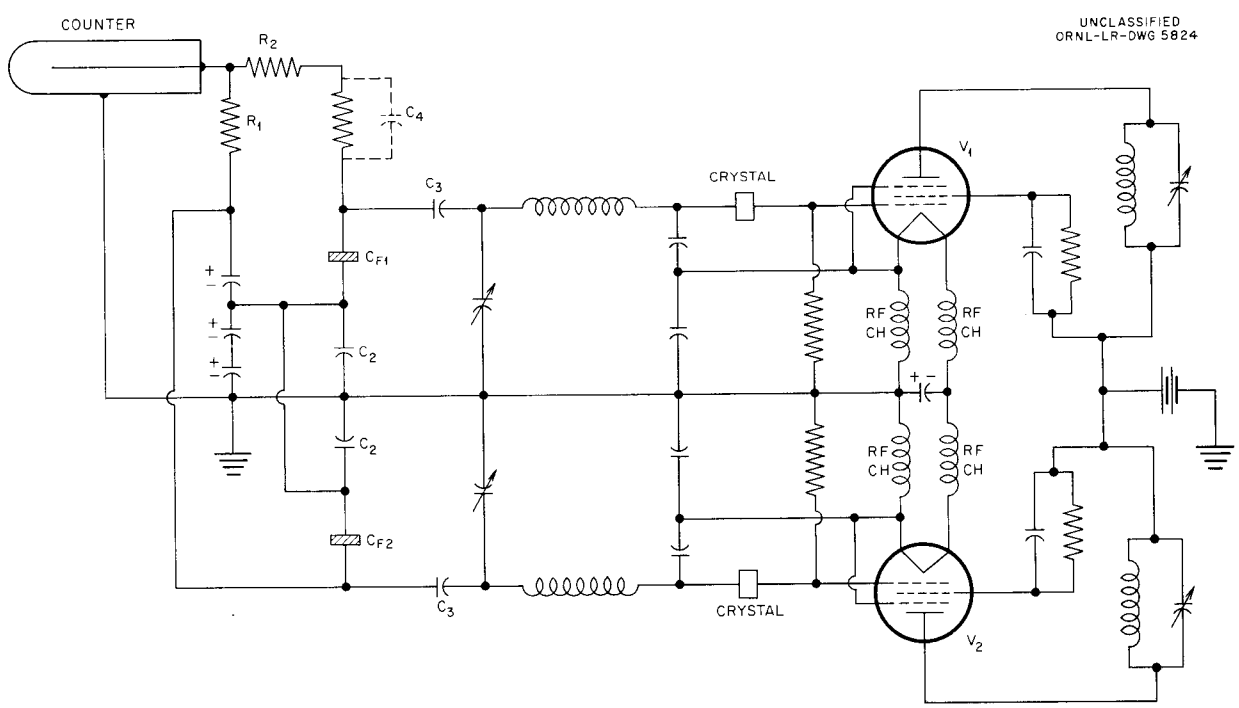


Fig. 15. Frequency-Variation Circuit for Detection of Radiation by Use of the Ferroelectric Effect.

The crystals were placed in a jig between two air-gap electrodes, and a slight pressure was exerted on this assembly and controlled by a positioning screw, thus keeping the pressure constant.

Eight crystals were exposed in the reactor to 1.55×10^{17} fast neutrons, 3.45×10^{17} thermal neutrons, and 10^8 r of gamma rays. All crystals showed a darkening in color. Usually there were certain striated spots which were darker than the rest of the surface. The frequency of all the crystals increased by approximately 300 cps. The lattice constants did not change within the limits of measurement. The optical density [log $(1/T)$, where T = transparency] increased by a factor of 2 to 3. Exposure of the crystals to an ultraviolet lamp did not change the transparency.

After the crystals were annealed at 200°C, the frequency decreased again by 10 to 50 cps. At 250°C another slight annealing effect was found. At 420°C the crystal frequencies returned to approximately their original values.

Another exposure of quartz crystals to 3.9×10^{17} fast neutrons and 2.15×10^8 r of gamma rays resulted in frequency increases of 500 to 600 cps. This time the equivalent resistance was also measured, and an increase of from 30% to more than 100% was found.

Experiments with gamma rays from Co^{60} up to 5.5×10^8 r did not show the significant frequency change of the quartz crystals expected from previous measurements with mounted and silverplated crystals. The experiments are being continued.

THEORETICAL PHYSICS OF DOSIMETRY

J. Neufeld R. H. Ritchie
W. S. Snyder

Path-Length and Energy Distribution for Slowly Moving Ions

The problem of the distribution in path length and energy of heavy, slowly moving atoms or ions [$v \ll (c/137)$] in matter has been treated under the idealized assumption of constant cross section and uniform scattering in relative coordinates. Using the Boltzmann transport equation and assuming that many collisions have occurred, it is found that the flux of particles ψ in ds at s and in du at u is

$$\psi\, ds\, du = \frac{ds\, du}{4M} \sqrt{\frac{3l}{2\pi s}} \exp\left[-\frac{3l}{8s}\left(\frac{u}{2M} - \frac{s}{l}\right)^2\right],$$

where

M = ratio of the mass of the stopping atom to that of the incident atom ($M \ll 1$),

s = path-length variable,

l = mean free path,

u = $\ln (E_0/E)$,

in which E_0 is the energy of the particle at the beginning of its path.

An assumption which is more realistic at somewhat greater energies of the incident particle is that the mean free path for collision varies inversely with the energy. This case may be treated by an immediate generalization of the above equation, if the mean free path does not vary greatly over the collision interval. The results do not differ greatly from those of Bohr[5] for this case. The results have been compared with range-energy data in the literature, and good agreement has been obtained in view of the assumptions made. A program to compute more exact values of the differential cross section for elastic collision of slowly moving ions is planned.

Columnar Recombination

The problem of columnar recombination when diffusion predominates over recombination has been treated by Jaffé.[6] A variational scheme is proposed which gives Jaffé's results with the use of a one-term trial function. The Lagrangian density $\mathfrak{L}$, which yields the partial differential equation describing the density of ions $n(\bar{r},t)$, is

$$\mathfrak{L} = \frac{\alpha}{3}n^3 + n\frac{\partial n}{\partial t} + \frac{\kappa}{2}(\bar{\nabla} n)^2 ,$$

where α and κ are the recombination and diffusion constants, respectively. The process of extremizing the Lagrangian is carried out on the assumption that $\partial n/\partial t$ has its correct value.[7] Numerical work on more accurate trial functions is planned.

Passage of Charged Particles Through a Dispersive Medium

Exact calculations have been made to corroborate the validity of some assumptions made by

[5] N. Bohr, *Kgl. Danske Videnskab. Selskab, Mat.-fys. Medd.* 18, No. 8, 138 (1948).

[6] G. Jaffé, *Ann. Physik* 42, 303 (1913).

[7] P. M. Morse and H. Feshbach, *Methods of Theoretical Physics*, McGraw-Hill, New York, 1953.

Bohr[8] on the basis of some quantitative and intuitional considerations. These assumptions are as follows:

1. The energy loss of the incident particle due to the transverse electromagnetic field surrounding the particle is identical with the energy dissipated as Cerenkov radiation.

2. For an incident particle of relativistic velocity, the electrostatic effect of the surrounding electrons is negligible, and the main factor in the screening is due to the electromagnetic interactions which limit the impact parameter to a value c/Ω, where $\Omega = (4\pi ne^2/m)^{1/2}$ and n is the electron density in the medium.

The calculations substantiate the assumptions made by Bohr.

Neutron-Damage Estimates with RBE Considered as a Function of Linear Energy Transfer

A program has been prepared for computing on the Oracle neutron damage to tissue where the RBE values used are based on the concept of specific ionization or linear energy transfer. The use of these RBE assignments is in accord with the recommendations of the National Committee on Radiation Protection in its Handbook 59, and the project to estimate the damage on the basis of these recommendations has been undertaken at the request of the Committee. The program, as presently constituted, will use the Monte Carlo method of computing the neutron histories and would seem to require about 150 hr of computing time to give estimates of damage for neutrons of energies from 10 Mev to thermal energies.

Depth-Dose Curves in Tissue for Neutrons of Intermediate Energies

Depth-dose curves in a tissue slab irradiated by a normally incident broad beam of neutrons have beem computed for neutron energies of 100, 20, 5, and 0.1 kev. The slab thickness was taken as 30 cm, and the RBE factors used to convert from absorbed energy to biological damage were taken as 1 for energies absorbed from gamma rays, as 10 for energies absorbed from recoil protons, and as 20 for energies absorbed from recoil carbon, nitrogen, or oxygen atoms. The maximum damage was found to be 7.2×10^{-9}, 2.2×10^{-9}, 1.2×10^{-9}, 1.4×10^{-9} rem/neutron for the respective energies. This maximum damage occurred at the irradiated surface for the 100- and 20-kev beams and at a depth of about 3 cm for the 5- and 0.1-kev beams. A report containing a more detailed analysis of the data is being written.

DOSIMETRY APPLICATIONS

F. J. Davis, J. A. Harter, J. M. Garner, W. A. Mills, P. W. Reinhardt

The Division has developed two methods of measuring the fast-neutron tissue dose. The first one of these, employing the proportional counter designed with the Bragg-Gray principle, has been sufficiently described.[9] A later method measures the fast-neutron spectrum, from which tissue-dose interpretation may be made by means of a first-collision curve. This method uses activation and threshold detectors and is described elsewhere.[10]

Recent comparisons of the two methods at ORNL and at LASL indicate that the two methods of dosimetry give dose measurements which are in excellent agreement. The proportional counter is a fundamental instrument which may be designed to fit any application ranging from the measurement of dose rates less than the maximum permissible flux of neutrons to give 0.3 rem per 40 hr to applications in measuring the dose in radiobiological experiments, even with the cyclotron or other high-intensity neutron sources. The threshold-detector method in its present form can be applied with great advantage to extremely high bursts of neutrons – for example, weapons testing – where other methods of fast-neutron dosimetry fail. An additional advantage of the threshold-detector method is that spectral measurements are obtained which permit not only a calculation of the dose but also an interpretation of the energy-distribution function vs specific ionization or linear energy transfer (LET).[11]

[8] A. Bohr, *Kgl. Danske Videnskab. Selskab, Mat.-fys. Medd.* 24, No. 19, 1–52 (1948).

[9] G. S. Hurst, *Brit. J. Radiol.* 27, 353–357 (1954).

[10] G. S. Hurst *et al.*, ORNL-1671 (March 30, 1954) (classified).

[11] J. W. Boag, *Radiation Research* 1, No. 4, 323 (1954).

EDUCATION, TRAINING, AND CONSULTATION

E. E. Anderson

AEC FELLOWSHIP PROGRAM

M. F. Fair M. R. Ford

The 1953–1954 group of 21 AEC Fellows in Radiological Physics completed their training in applied health physics at the Laboratory on August 27, 1954. Two of the fellows, who were granted six-month extensions of their fellowships, remained at the Laboratory to engage in research to fulfill the requirement for a master's degree. W. F. Patton has completed his problem, on the W values in water vapor; F. W. Sanders is working on the problem of determining the mechanism by which the value of W of argon is lowered when slight impurities are added.

The new group of 21 AEC Fellows (1954–1955) began their training under the fellowship program at Vanderbilt University on September 27, 1954.

OTHER TRAINING ACTIVITIES

M. F. Fair M. R. Ford

One member of the Education, Training, and Consultation Section is conducting two courses (each 1 hr per week) for nine months in apprentice mathematics for the Training Division.

The weekly and special orientation lectures in health physics are the responsibility of the Education, Training, and Consultation Section of the Division.

Two courses of five weeks each in internal dose were given for members of the Health Physics Division.

Special lecture and discussion periods in health physics were held for: (1) members of the Chemical Technology Division, (2) a group of aircraft engineers, and (3) representatives from Bendix Aviation Corp., Detroit.

A two-week advanced course in health physics was held for three members of the Nautilus crew, one member of the Health Physics Staff of Electric Boat Div., and one U.S. Army officer from Fort McClellan, Alabama.

One laboratory experiment on health physics instrumentation was conducted for ORSORT.

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