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WHOLE-BODY COUNT OF TUNGSTEN-187 IN PHS PERSONNEL FOLLOWING THE SCHOONER EVENT

by

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The SCHOONER Event, conducted at the Nevada Test Site, December 8, 1968, released radioactive effluent into the environment. Whole-body counts were performed on thirty-one Public Health Service personnel who participated in this cratering experiment with tungsten-187 appearing in the resultant spectra as the only contaminant.

Repeated whole-body counts were performed during the week following exposure to determine the magnitude of individual burdens. The maximum burden measured, 25 μCi, correlates to an estimated dose to the large intestine of approximately 1 rad. Absorbed dose calculations, based on physiological parameters taken from the International Commission on Radiation Protection Manual II, indicate a dose conversion factor of 32 mrad per μCi tungsten-187 ingested. A whole-body scan performed eight hours after exposure confirmed the presence of tungsten-187 in the GI tract of one individual and yielded an upper limit calculation on the maximum possible absorbed dose to the lung of 6 mrad/μCi ^{187}W retained.

Spectra obtained on all subjects were carefully analyzed to detect any iodine-133 that could be masked by the relatively large amounts of tungsten-187. The attributable dose due to iodine-133 in the person showing the highest burden of tungsten-187 was estimated to be less than 20 mrad. External exposure was determined from results obtained on thermoluminescent dosimeters worn by all personnel participating.

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Project SCHOONER was a nuclear cratering experiment conducted on December 8, 1968, at the Nevada Test Site as part of the Plowshare Program. The yield of the device was approximately 35 kilotons and it produced a crater 63 meters deep and 260 meters in diameter. In accordance with a Memorandum of Understanding with the Atomic Energy Commission, the U. S. Public Health Service (whose activities in this area have now been taken over by the Environmental Protection Agency) conducted a program for documenting the extent and location of radioactive debris leaving the boundaries of the Nevada Test Site. This task was accomplished through the use of a number of sampling networks including ground monitoring with hand survey instruments, fixed position Thermoluminescent Dosimeter networks, air samplers, milk collection, some vegetation sampling, and the whole-body counting of personnel known to have been in the path of the debris.

Altogether 107 whole-body counts were obtained from 39 individuals involved in the SCHOONER EVENT. With the exception of cesium-137 and

potassium-40, components of all background whole-body counts, no isotopes could be identified in any spectra except tungsten-187. A typical whole-body counting spectrum can be seen in Figure 1. Thirty-one of the subjects counted were U. S. Public Health Service personnel and eight subjects worked for other government agencies. No activity could be detected in any individual after December 16 (D+8), and all counting was terminated on December 20, 1968.

Fourteen individuals were counted on the day of the release including personnel flying in monitoring aircraft and several individuals occupying ground positions in the path of the cloud on the highway immediately north of the test site and approximately 55 miles from the point of detonation. A ground monitor positioned on the highway had the highest measured burden observed during the first day of counting and was chosen to serve as a "standard" against which other individuals would be compared. About 11 hours after exposure of this subject, herein referred to as Subject A, a whole-body scan was performed. The results of this scan are shown in Figure 2. Activity was detected in the nasopharyngeal area, the GI tract, and the bladder. Most of the activity was concentrated in the region of the large intestine. These results are consistent with the inhalation and subsequent ingestion of large insoluble particulates.

Subject A was counted repeatedly during the two-week period following the event and his initial burden of tungsten-187 is estimated to have been 75 μCi tungsten-187. The whole-body counter used to perform the measurements uses an 11 by 4 inch NaI (Tl) crystal positioned over a .6 meter arc bed. This geometry was originally selected to minimize calibration errors with an unknown source location in the subject. Scan information suggested that most activity was in the lower GI region; therefore, calibration was performed by using a urine sample in a 400 ml container positioned approximately where the lower GI region would be with respect to the whole-body counter arc. To insure consistency in results, the urine sample was cross-calibrated with other systems at the laboratory used to count milk and air samples. A tungsten-187 standard purchased from Amersham of London was used to calibrate these other systems.

External contamination was evident on the skin, hair, and clothing of subjects arriving at the facility. Decontamination was performed by showering. In order to maintain the integrity of the very sensitive counting facility, extreme caution was exercised to insure that no subjects were admitted to the whole-body counting area with external contamination. The chamber background in the energy band corresponding to the tungsten-187 peak is also shown. Little change in background occurred during the two-week counting period. Counting results on Subject A as well as counts on the urine sample serving as a calibration source are shown in Figure 3. Counting on this subject continued until December 20 when no activity could be detected. Figure 4 is a retention plot of Subject A. The plotted points have been corrected for the physical half-life of the tungsten-187 (23.7 hours) and represent the actual biological retention of the nuclide. The plot is characterized by a rather sudden drop between the 51st and 75th hour after exposure and an apparent long-lived component (160 hour half-life).

Estimates of the absorbed dose due to tungsten-187 were made considering the GI tract, the lungs, and the maximum possible thyroid dose that could have occurred from iodine-133 masked by the tungsten-187. The model used to estimate the dose to the GI tract is discussed in the appendix and is derived from physiological parameters taken from I.C.R.P. II. The critical part of the GI tract based on these assumptions is the large intestine and the dose conversion figure derived is 32 mrad per μCi ingested. Subject A obtained an estimated dose of 1 rad to the lower large intestine based on this conversion factor. The assumption that the large intestine can be considered as the critical organ for tungsten-187 is supported by a paper in Health Physics, Vol. 15 by Kaye, which reports on rat experiments.

There was a question at the time that the critical organ might actually be the lung based on a lack of knowledge of particle size and the possible retention of a small particulate in the lungs. A conservative model was chosen to compute the maximum possible dose based on information gathered in the scan taken 11 hours after the exposure of Subject A. The model is explained and derived in the appendix. The maximum credible dose based on this model is estimated to be 6 mrad/μCi tungsten-187 retained. This value

compared to the 32 mrad/uCi dose to the lower GI region clearly points to the ter as the critical organ.

Because of the relatively large organ dose that can be obtained from the inhalation of small amounts of iodine isotopes, it was necessary to make some estimate of the possible iodine-133 that could have been masked in the spectra by the presence of the tungsten-187. The theoretical location of an iodine-133 peak is shown on the spectrum illustrated in Figure 1. The physical half-life of the two nuclides are quite similar; tungsten-187, 23.7 hours and iodine-133, 20.8 hours; however, it was thought that the much slower elimination of the iodine isotope from the thyroid (biological half-life 138 days, I.C.R.P. 2) might change the ratio of the two isotopes in pairs of spectra taken on individuals where significant elimination of the tungsten-187 was known to have taken place. The latter of the pair of spectra was stripped from the former to try to enhance the counts in the iodine-133 region. This technique was used on a number of pairs of spectra but no iodine-133 peak was observed. Maximum values for iodine-133 were finally estimated by assuming that should a peak be present in a given spectrum the peak would be identifiable by visual inspection if the counts in the iodine-133 peak region exceeded the counts in the spectrum by an amount equal to three standard deviations of the counting error; $\sigma = \sqrt{N}$. The maximum size iodine-133 peak would then be just 3 σ. To find the maximum possible dose due to iodine-133 the maximum possible burden hidden in a given spectrum was extrapolated back to time of exposure and the factor 1.39 mrad/nCi was applied to the extrapolated result. This conversion factor is also derived in the appendix. Maximum computed thyroid dose due to possible iodine-133 inhalation was estimated to be 39 mrad.

Counting results on all individuals are shown in Figure 5. The plot reveals considerable variation between individuals with respect to the retention of the isotope. The graph not only demonstrates the difficulties of constructing valid dose models when dealing with the GI tract but points out a problem of even assigning relative doses when multiple counts are taken on individuals. Note in the figure that initially Subject A's burden exceeded that of Subject B by a factor of 2.4, but on the 6th day following the event Subject B's burden exceeded Subject A's by a factor of 1.2.

Relative burdens were actually assigned by considering the initial counts as indicative of the isotope passing through the GI region. Four or more counts were taken on three individuals, Subjects A, B, and C in the figure. Retention graphs were plotted comparing the three subjects correcting the data for the physical half-life of the isotope. One such graph, shown in Figure 6, is based on 100% being the amount in the subjects on the counts taken on December 9. The plots represent the biological retention of the isotope after this date. Note that no apparent similarity in the retention pattern exists except that the retention decreased as a function of time.

Six radiation monitors who were whole-body counted to determine tungsten-187 burdens were also wearing Thermoluminescent Dosimeters. The Thermoluminescent Dosimeter used was an EG&G Model TL-12 which is enclosed in a glass envelope and has a low energy cutoff of 50 kev. The response of the device at energies higher than 50 kev is essentially independent of the energy of the incident gamma ray. Figure 7 is a map showing the location of the monitors, their Thermoluminescent Dosimeter readings, and their respective estimated GI tract doses. Figure 8 shows a comparison of Thermoluminescent Dosimeter readings versus estimated doses to the large intestine due to the inhalation of tungsten-187. A linear least squares fit of the data suggests that the ratio of Thermoluminescent Dosimeter reading to estimated internal dose was on the order of 0.41. The remaining U. S. Public Health Service personnel were either in unusual exposure situations; for example, crewing aircraft, were not stationary during cloud passage or were wearing some sort of protective respiratory device and a comparison of TLD readings versus tungsten-187 burdens is of little value.

REFERENCES

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(3) HINE, G.J., BROWNELL, G.L., Radiation Dosimetry (1958).

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(6) Environmental Protection Agency, Final Report of Off-Site Surveillance for Project Schooner, December 8, 1968 (1971 in press).

TYPICAL WHOLE BODY COUNT SPECTRUM

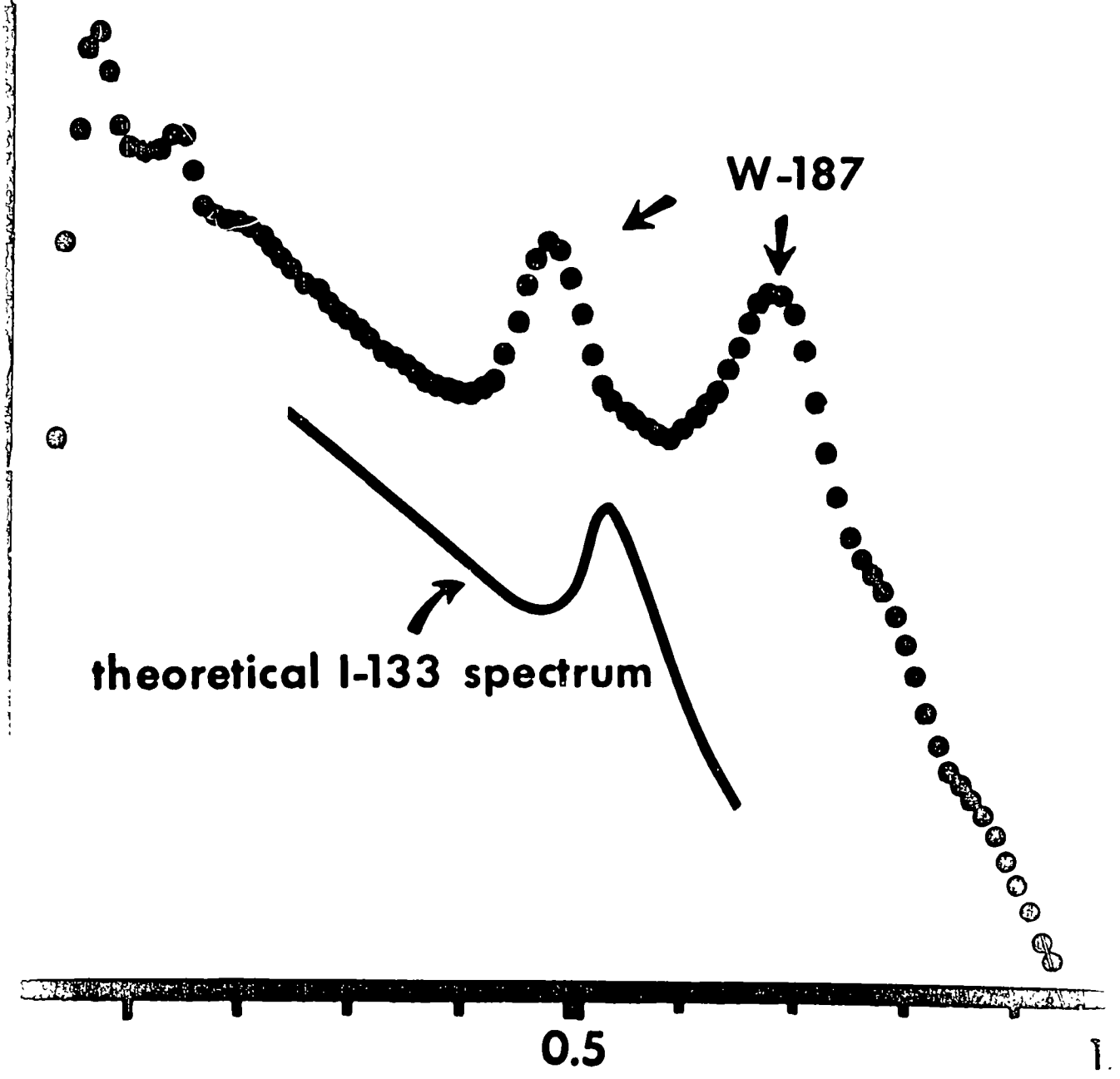


Figure 1

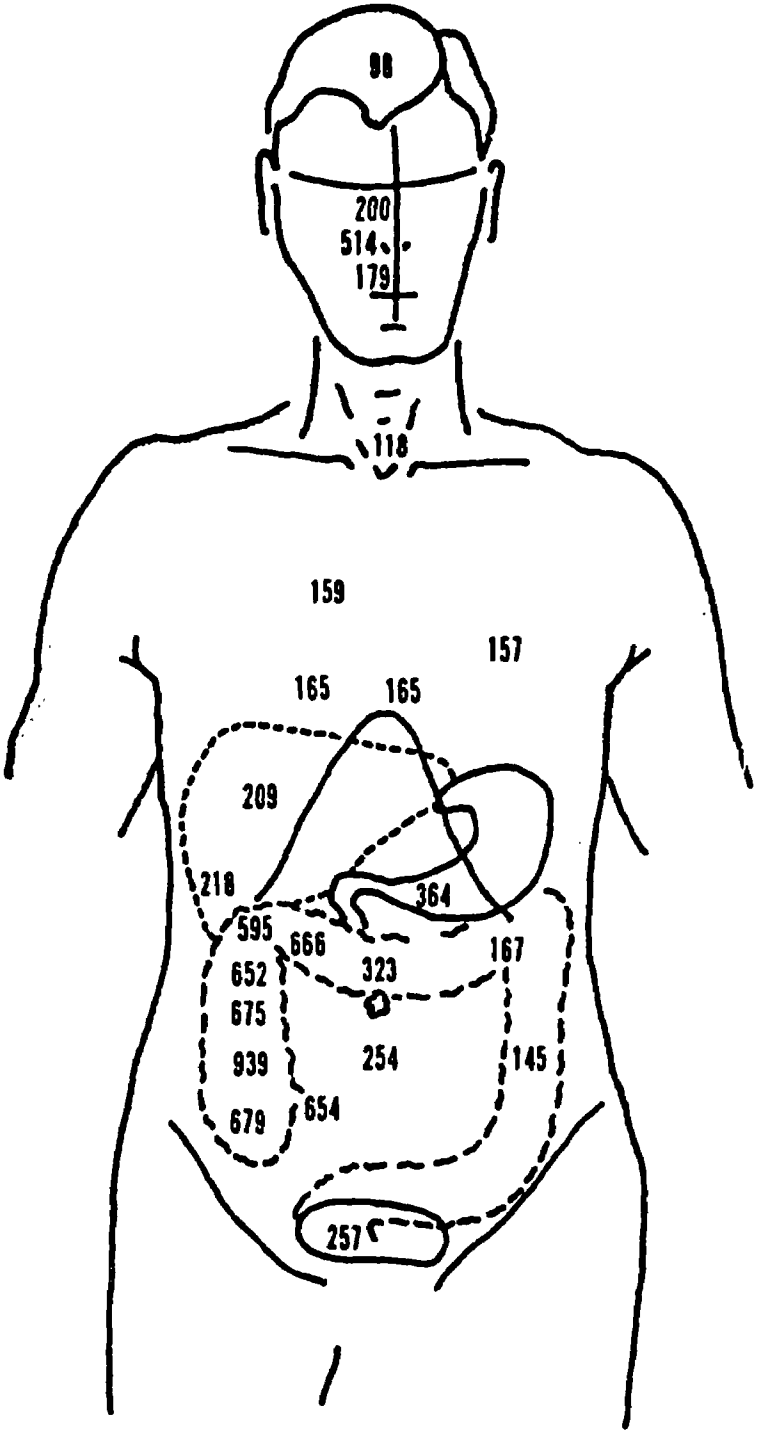


Figure 2 WHOLE BODY SCAN H+11 HOURS
counts per minute over region indicated

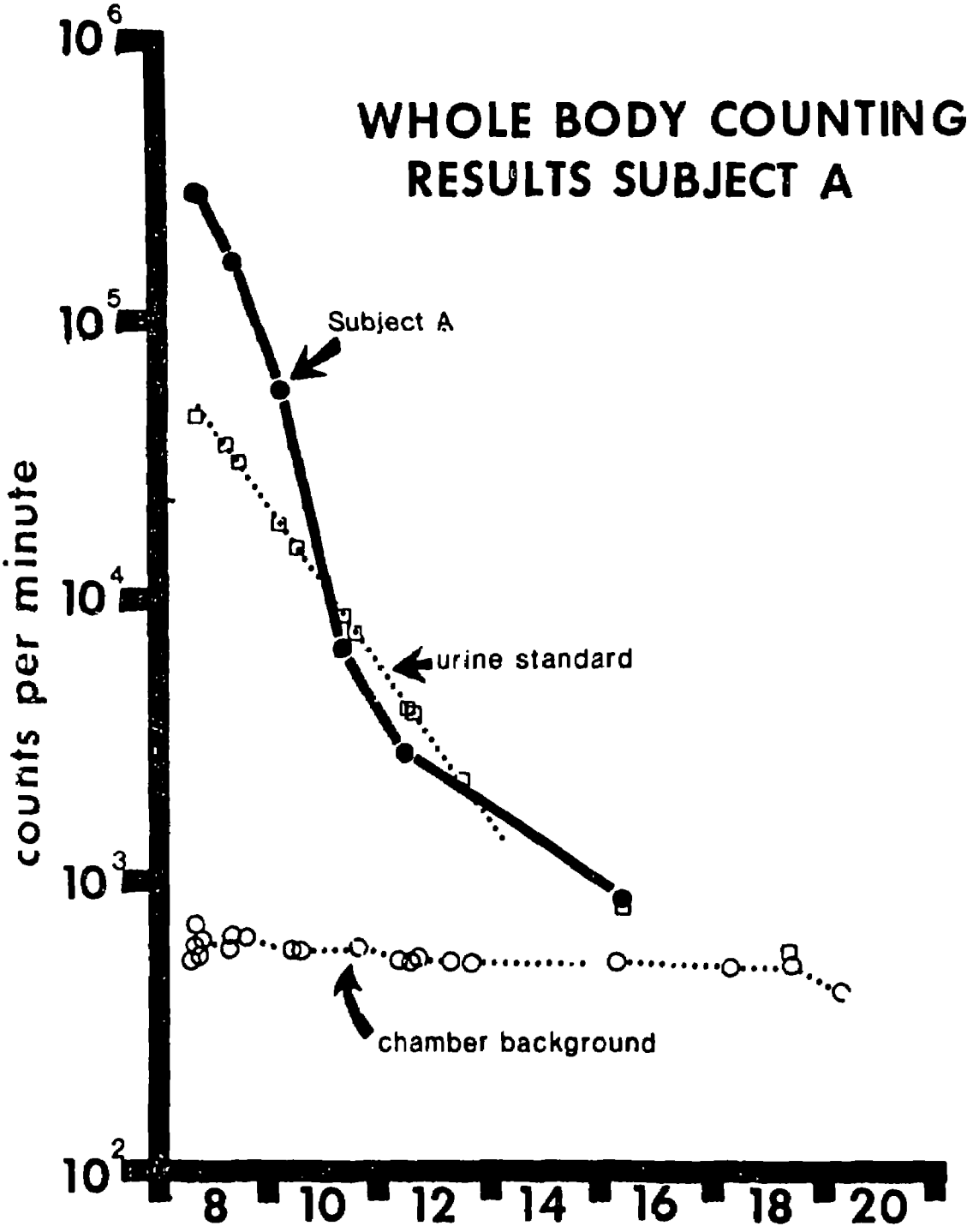

WHOLE BODY COUNTING
RESULTS SUBJECT A
counts per minute
10^6
10^5
10^4
10^3
10^2
Subject A
urine standard
chamber background
8
10
12
14
16
18
20
date

Figure 3

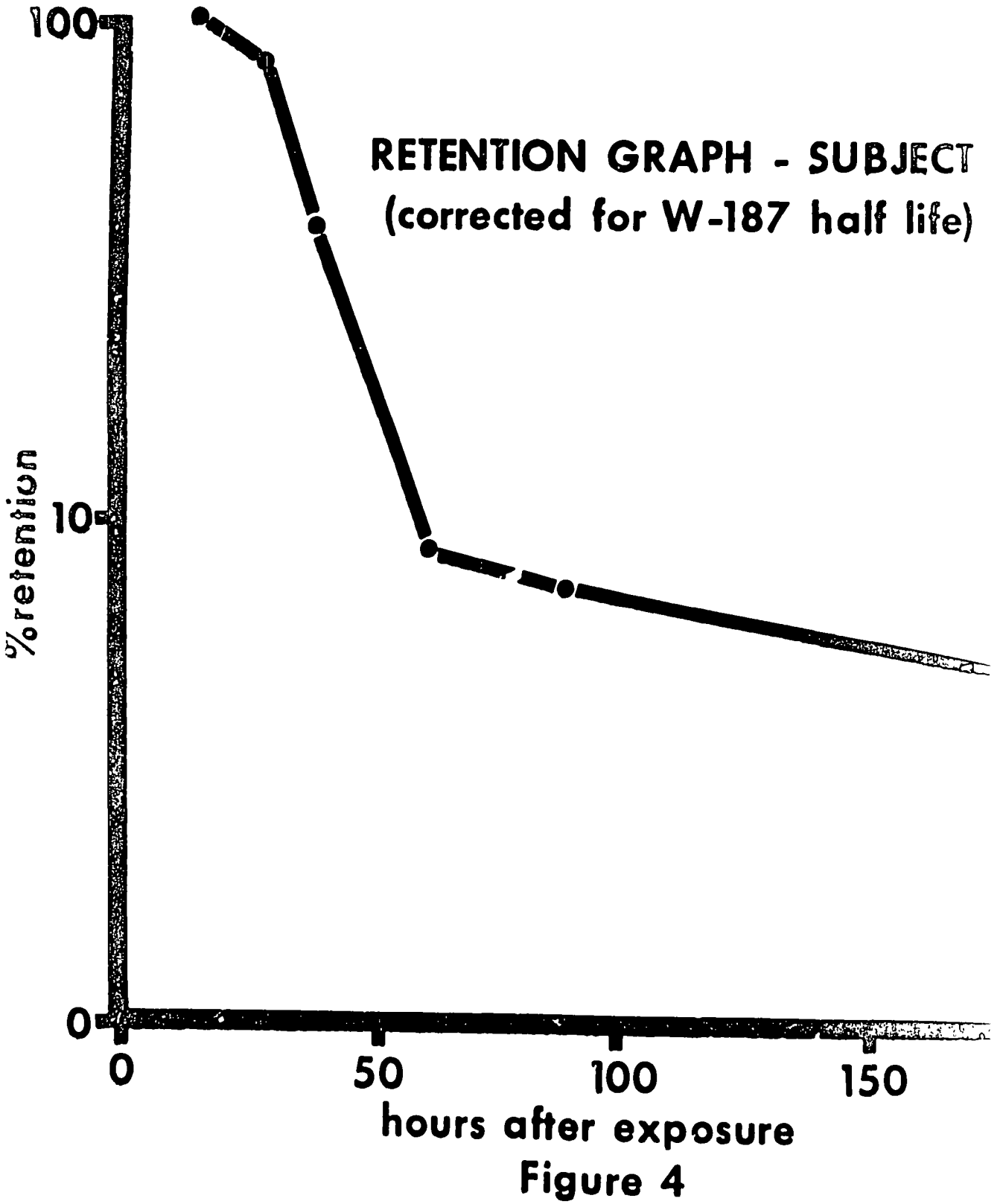

RETENTION GRAPH - SUBJECT
(corrected for W-187 half life)
100
10
0
%retention
0
50
100
150
hours after exposure

Figure 4

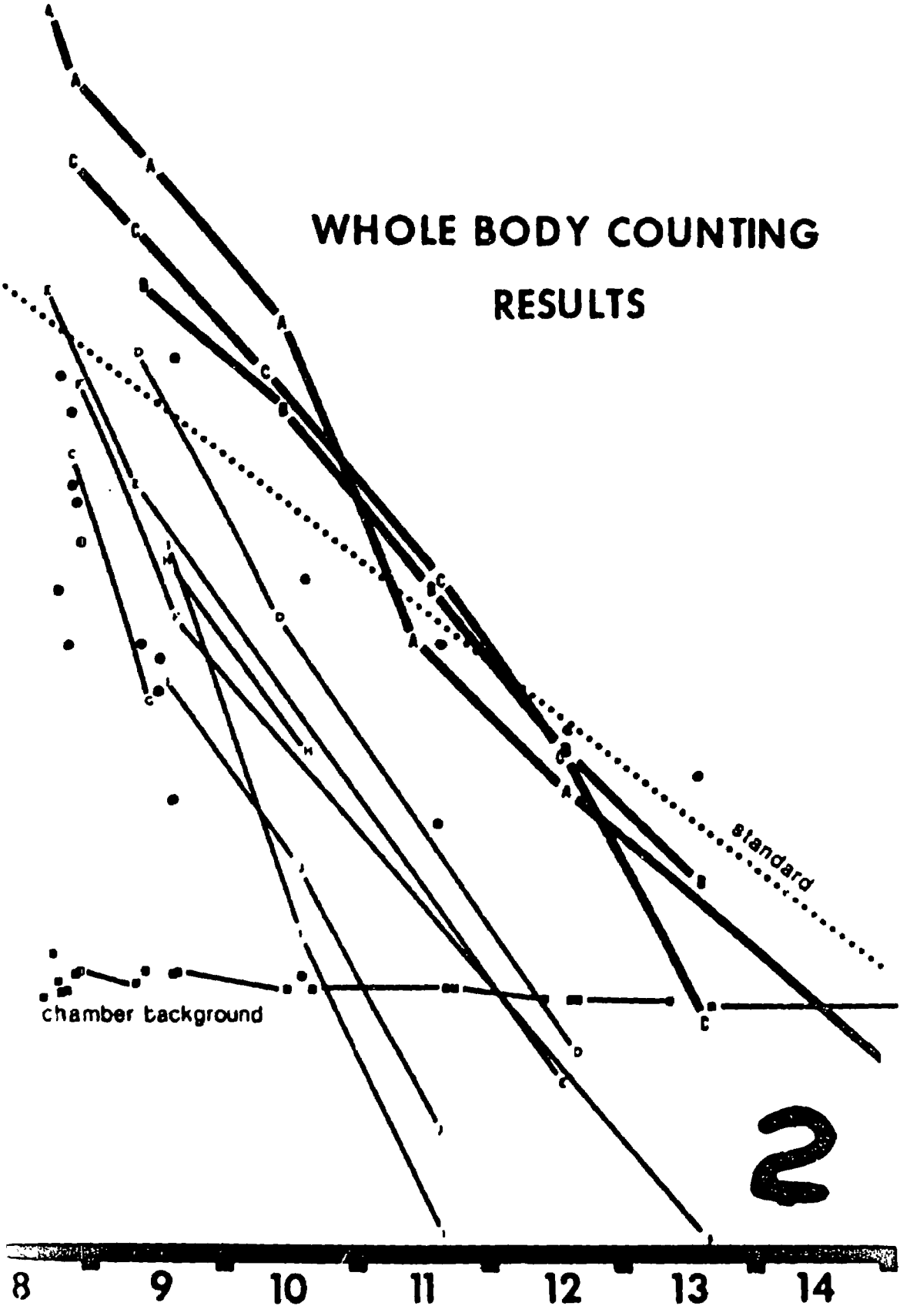

WHOLE BODY COUNTING
RESULTS
standard
chamber background
2
8
9
10
11
12
13
14
date

Figure 5

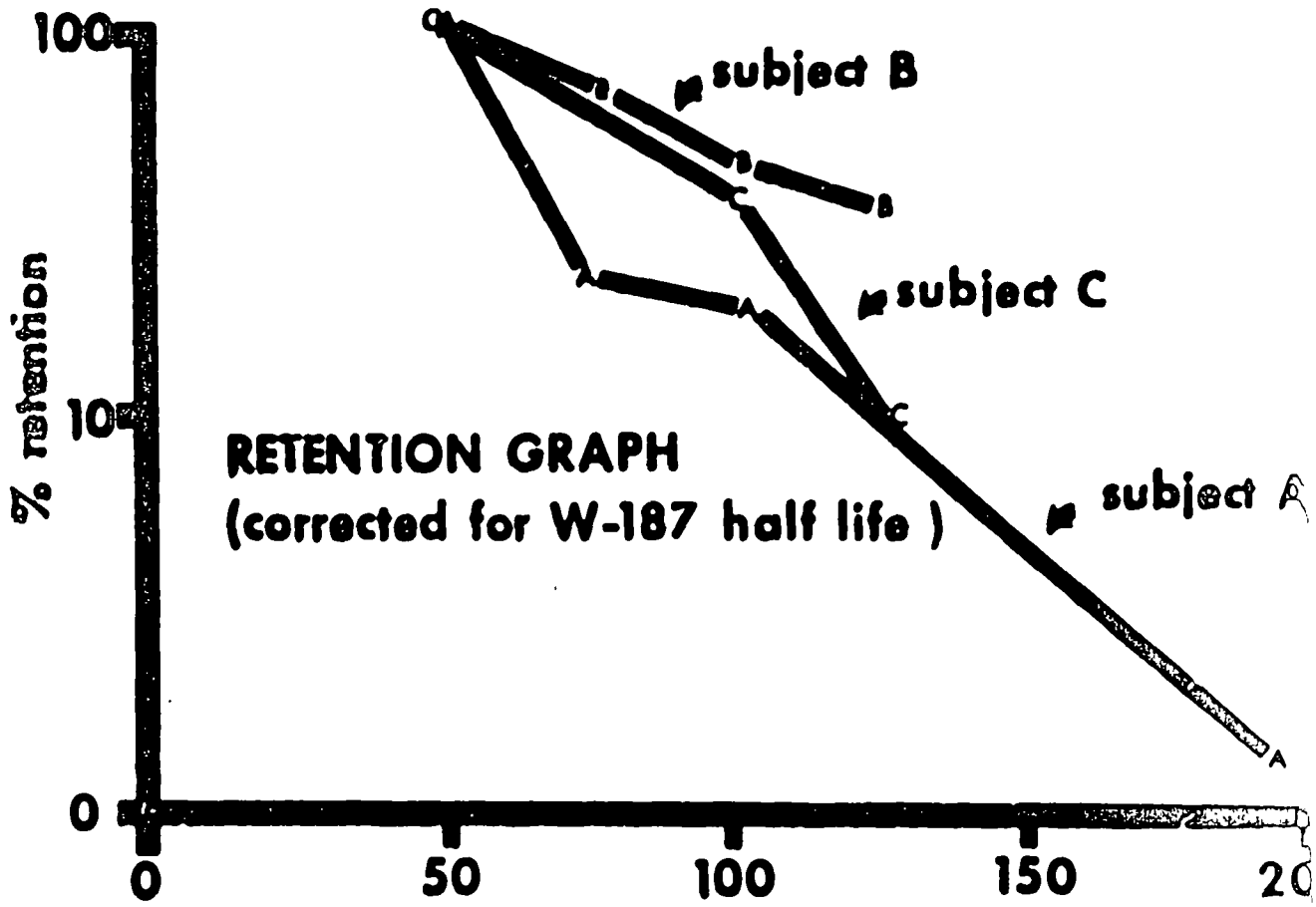
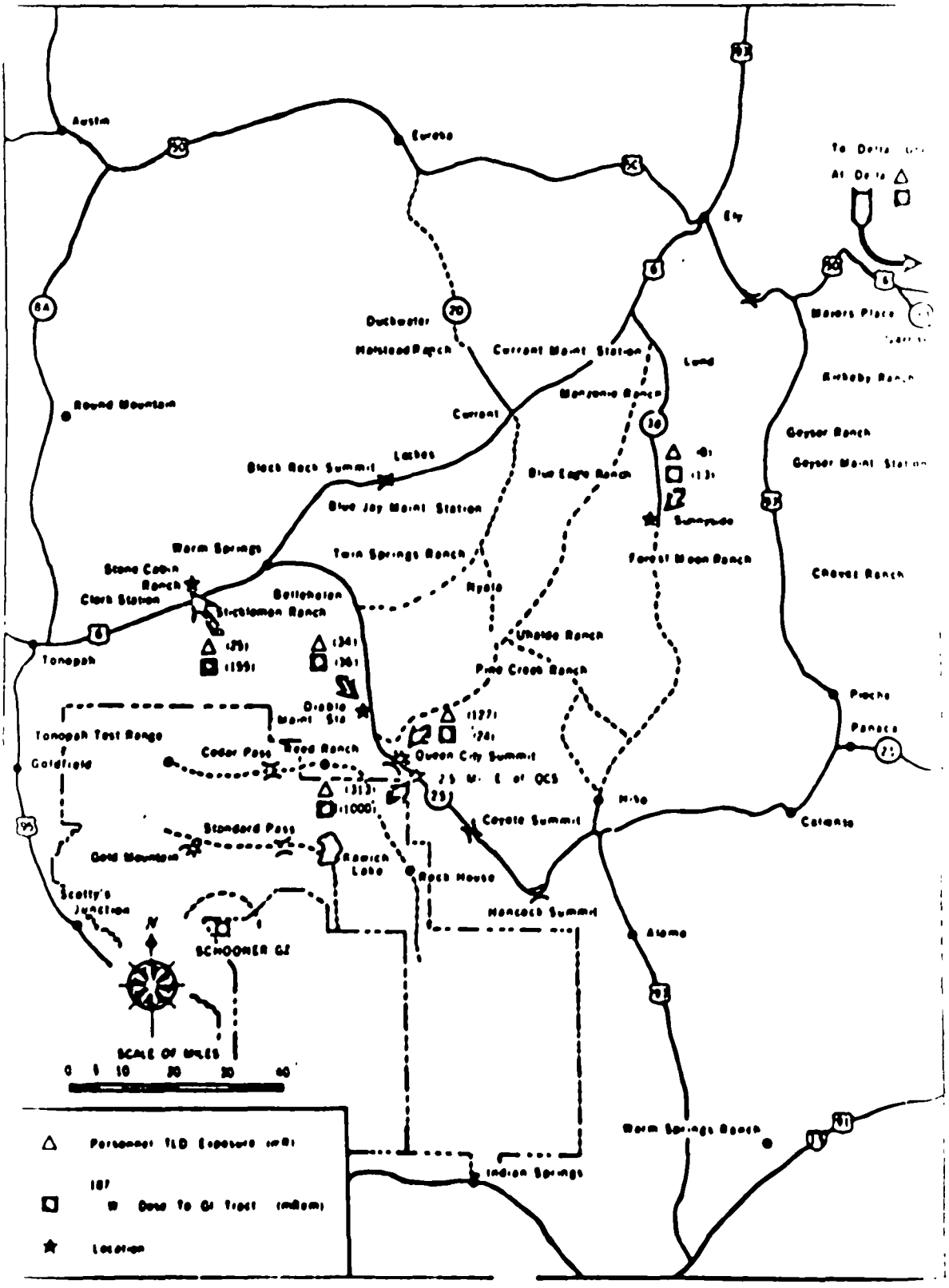

100
10
0
% retention
subject B
subject C
subject A
RETENTION GRAPH
(corrected for W-187 half life)
0
50
100
150
hours after exposure

Figure 6



igure 7 T.L.D. READING AND DOSE ESTIMATE TO LLI VS. LOCATION OF PHS MONITORS

T.L.D. RESULTS VS. ESTIMATED G.I. DOSE

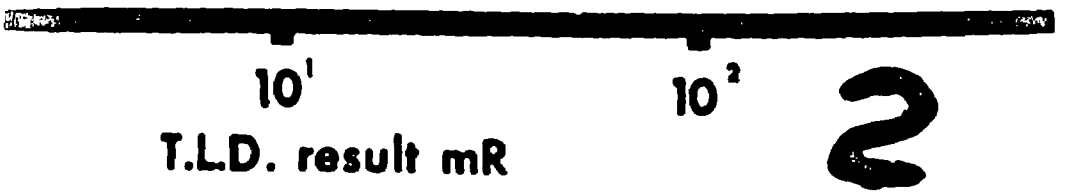


Figure 8

APPENDIX

THEORETICAL ABSORBED DOSE TO LOWER LARGE INTESTINE FROM ^{187}W

From I.C.R.P. 2, use Equation 14.

$$R = (q\ f_2)\ \frac{3.7 \times 10^4 \times 24 \times 3600 \times 7 \times 1.6 \times 10^{-6} E\ dt}{2 \times 100\ m \times dt/t}\ \text{rems/week}$$

Divide by 7 to obtain dose in rad/day

Multiply by 1000 to obtain mrad

Consider $q\ f_2$ as the input to the lower large intestine in μCi.

From I.C.R.P. 2, Table II the time elapsed from ingestion until isotope reaches the lower large intestine is 13/24 days. The physical $T_{\frac{1}{2}}$ of ^{187}W is 23.9 hours. Therefore, the amount of ^{187}W reaching the lower large intestine per μCi ingested is .687.

E = .36 MeV effective energy

m = Mass organ
= 150 grams

t = Time for passage
= 18/24 days (I.C.R.P. 2)

Inserting these values;

R' (mrad) = μCi ingested x 31.7

APPENDIX

THEORETICAL ABSORBED DOSE DUE TO ^{187}W IN LUNGS

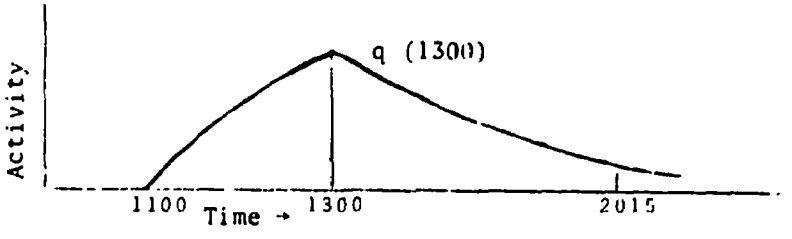
Dose (in mrad) = Q x 51.2 x $\frac{E}{m}$ (from I.C.R.P. 10, Equation 1).

m = Mass lungs
= 1000 grams (I.C.R.P. 2)

E = Absorbed energy/disintegration
= .44 MeV

Q = Time integral of contamination nCi - days

Calculation is based on scan information of Subject A. It is assumed that the count rate over lungs initially would equal the count rate observed over the lower GI region in the scan (+8 hrs) and that the lung turnover function was a simple exponential. Further it is assumed that the intake function was a constant 25 μCi/hr between 1100 and 1300 hours with the fraction retained equaling .5 (I.C.R.P. 2).



Activity in Lungs

From scan

Background = 80 counts

Lower GI = 939 counts
= 859 net counts

Lung = 157 counts
= 77 net counts

$$77 = 859 \exp(-.693 \cdot 8/T_{\frac{1}{2}})$$

$$T_{\frac{1}{2}} = 2.28 \text{ hrs}$$

$$\lambda = .3$$

$Q = \int_0^t q(t)\,dt$ (I.C.R.P. 10, Equation 2)

Neglecting physical $t_{\frac{1}{2}}$ of ^{187}W

from 1100 - 1300 hrs $q(t) = \frac{1}{\lambda}\left[\ \ - \exp(-\lambda t)\right]$

from 1300 hrs → ∞ $q(t) = q(1300) \exp(-\lambda t)$

APPENDIX

from 1100 - 1300 hrs Q = 42 μCi - hrs

q (1300) = 38 μCi

from 1300 hrs → ∞ Q = 125 μCi hrs

Q = 167 μCi - hrs

= 7 μCi - days

Dose = 7 x 51.2 x .44 ÷ 1000 = 158 mrad

= 6.3 mrad/nCi ^{187}W retained

APPENDIX

THEORETICAL ABSORBED DOSE TO THYROID DUE TO INHALATION OF ^{133}I

Dose (in mrad) = $Q \times 51.2 \times \frac{E}{m}$ (from I.C.R.P. 10, Equation 1).

m = Mass thyroid
= 20 grams

E = Absorbed energy/disintegration
= .54 MeV

Q = Time integral of contamination nCi - days

Calculation based on amount of ^{133}I in thyroid extrapolated back to time of exposure.

$$Q = \int_0^\infty [\exp(-\lambda_{eff} t) - \exp(-\lambda_{uptake} t)]dt$$

$$= \frac{1}{\lambda_{eff}} - \frac{1}{\lambda_{eff} + \lambda_{uptake}}$$

$\lambda_{eff} = .7996$ (I.C.R.P. 2)

Assume 5 hours uptake

$\lambda_{uptake} = .333$

$Q = 1.008$

Dose = $1.008 \times 51.2 \times .54 \div 20 = 1.39$ mrad/nCi ^{133}I