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ABSTRACT

Enewetak Atoll is one of the Pacific atolls used for atmospheric testing of U. S. nuclear weapons. Beta dose and gamma ray exposure measurements were made on two islands of the Enewetak Atoll during July-August 1976 to determine the beta and low energy gamma contribution to the total external radiation doses to the returning Marshallese. Measurements were made at numerous locations with thermoluminescent dosimeters (TLD), pressurized ionization chambers, portable NaI detectors, and thin-window pancake GM probes. Results of the TLD measurements with and without a beta attenuator indicate that approximately 29% of the total dose rate at 1 meter in air is due to beta or low energy gamma contribution. Studies on the effect of ground cover on this contribution indicate that it is relatively insensitive to thickness of ground cover.

Integral 30-year external shallow dose estimates for future inhabitants were made and compared with external dose estimates of a previous large scale radiological survey (EN73). Integral 30-year shallow external dose estimates are 25 to 50% higher than whole body estimates. Due to the low penetrating ability of the betas or low energy gammas, however, several remedial actions can be taken to reduce the shallow dose contribution to the total external dose.

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Introduction

Enewetak Atoll is one of the Pacific atolls used for testing of U. S. nuclear weapons. A large-scale radiological survey was conducted in 1972-1973 (EN73) to determine dose estimates for future inhabitants (NA75). Those whole body dose estimates are due primarily to energetic gammas, primarily from ^{137}Cs and ^{60}Co. A subsequent radiological survey of Bikini Atoll (another former U. S. nuclear weapons testing site) indicated, however, that perhaps as much as 25% of the total external exposure rate is due to beta or low energy gamma radiation (GU75). In August, 1976, beta and gamma dose measurements were made at Enewetak Atoll to determine the beta or low energy gamma contribution to the total external dose, its dependence on ground cover, and the impact on external dose estimates for future inhabitants.

Enewetak Atoll is located in the northern part of Micronesia about 3,800 km southwest of Honolulu. Forty islands on a coral reef ring a lagoon of approximately 40 km diameter (Figure 1). The largest islands and consequently most important for future villages and agriculture, are Enjebi (Janet) and Bokambako (Belle) in the northern half of the atoll, and Enewetak (Fred), Medren (Elmer), and Japtan (David) in the southern half.

Most of the more than 40 nuclear weapons tests were conducted in the northern region of the atoll, with approximately half tested over the lagoon or ocean areas and the remainder tested on several northern islands. Therefore, the major radioactive contamination and hence radiological impact was to the northern half of the atoll.

Two of the largest northern islands (Enjebi and Bokambako) were used for this study because of their higher soil radionuclide concentrations and the potential use of Enjebi as a residence and agricultural island. Comparative beta and gamma dose measurements were made at a total of 87 locations on these two islands with thermoluminescent dosimeters, pressurized ionization chambers, portable sodium iodide detectors, and pancake GM probes. Locations were carefully selected to represent a wide range of exposure rates and variety of ground cover.

Measurement Methods

A portable instrument with a 2.5 cm diameter x 3.8 cm NaI crystal and ratemeter readout was used primarily for selection of measurement location. External exposure rate measurements were made at a height of 1 meter at 67 locations with a pressurized ionization chamber which consists of a stainless steel sphere filled with high pressure argon, connected to an electrometer with digital readout. Calibration of this instrument was verified by DOE laboratories prior to the survey. Although insensitive to beta or low energy gamma radiation, it is sensitive to cosmic radiation. It has a relatively flat energy response over the gamma ray energy range encountered in this survey (NA75).

The primary technique used to determine beta or low energy gamma contribution to the external dose rate was measurements made with thermoluminescent (TLD) dosimeters. LiF(TLD 700) previously matched to within ±2% were used. The dosimeters were annealed at Enewetak Atoll immediately prior to placement on the two islands. Three TLD dosimeters were placed in the Lawrence Livermore National Laboratory (LLNL) personnel dosimeter badge with a blank badge fastened on top for improved protection from the environment (rainfall, dirt). A calibration of the dosimeters was made with a ^{137}Cs source prior to deployment. At each of 80 locations, two TLD badge sets were positioned 1 meter above the ground on a slotted crossbar mounted on a wooden stake. One of these sets at each location was surrounded with an additional 860 mg/cm^2 aluminum attenuator to allow only the energetic gamma component to be recorded by the dosimeter. An array of TLD dosimeter badges surrounded by various attenuator thicknesses was also positioned at a height of 1 meter at each of seven locations to determine the effect of ground cover on the beta contribution. An aluminum framework 46 cm wide, 92 cm long and 1 meter high was used for these experimental stands. Three pieces of aluminum bar stock were each drilled to house four sets of TLD badges with various amounts of aluminum shielding, and bolted across the top of each stand. Twelve TLD badge sets were therefore used at each location, shielded top and bottom by various aluminum absorber thicknesses. Control TLD sets were stored inside a lead pig on a southern island with minimal radioactivity. All TLD badge sets were retrieved approximately three months later and transported back to Lawrence Livermore National Laboratory inside a lead pig for evaluation. A second calibration was carried out before evaluation to determine fading and transit exposure.

A pancake GM probe with a 7.62 cm diameter thin window, lead gamma shield and digital readout was used for comparative purposes. Measurements with this portable active instrument were made at 34 locations. At each location, two measurements were made at 1 meter height; one with no attenuator and one with an 860 mg/cm^2 attenuator over the window.

Results

Figure 2 shows the comparison of gamma exposure rates at 1 meter in air measured with LiF TLD dosimeters and a pressurized ion chamber. The TLD dosimeters were shielded against betas, and their responses reduced for background (mostly cosmic) as measured by controls. The ion chamber readings were reduced by 3.3 μR/hr, the cosmic contribution at that latitude (GU75). The dashed line represents a 1:1 relation between the two measurement techniques. The solid line is a linear regression of the data corrected for background, and yields agreement between the two methods within 4%. There is an offset of about 3 μR/hr between the data regression and a 1:1 relation, which probably indicates a difference of background subtraction methods between the two measurement techniques.

Similar measurements made with a GM pancake probe shielded against beta contribution and compared with ion chamber readings resulted in a much wider data spread than for the TLD, due to poor statistics in the pancake probe readings (approximately 200 cpm/25 μR/hr). The linear relationship in the data does, however, indicate that the hand carry pancake GM probe could be used with some loss of precision in areas inaccessible to the ion chamber.

The beta attenuation measurements made at seven locations are shown in Figure 3. Two experimental stands were placed in very thickly vegetated areas, such as closely packed clumps of grass 15 cm or more in height or thick patches of large-leaf vines. The top curve in Figure 3 represents these two stands; extrapolation of the data shows that only about 20% of the dose rate in air at a height of one meter is due to beta contribution. Two stands were placed in areas of medium vegetation (15 cm or less in height, but mostly covered).

These data extrapolate to a beta contribution of about 30%. Three stands, located in areas of minimal or no ground cover, resulted in the lower two curves of Figure 3; the beta contribution varies from about 50% (lower curve) in a completely bare location, to about 40% in two areas with minimal ground cover. Although the general shape of the attenuation curves is similar for all ground cover conditions, there is considerable difference in relative response for greater than about 1000 mg/cm^2 of absorber. The difference in beta attenuation between thick and medium ground cover is not so distinct as the difference between medium and minimal ground cover, indicating that a relatively small amount of ground cover reduces the beta contribution at 1 meter considerably (i.e., from 50% at bare locations down to about 30% at medium locations, then down only to 20% at thickly vegetated locations).

The ratios of TLD responses for attenuated dosimeters were determined at 80 locations in an attempt to correlate these ratios with vegetation (Figure 4). The measured contributon of beta or low-energy gamma to the total exposure rate varied between 16% and 59%, with a median of 29%. Although a wide variety and extent of ground cover were represented in these 80 locations, the deviation in the data is less than 13% at 1σ, suggesting that a median of 29% of the total dose rate at 1 meter can be used with sufficient accuracy for estimates of doses to the skin and eyes of future inhabitants. Attempts to categorize TLD locations with respect to vegetation and beta contribution were unsuccessful, partly due to differing concentrations of ^{90}Sr and ^{137}Cs in the soil, but largely due to changes in the nature and extent of vegetation over a three-month period. Locations originally categorized as thickly vegetated did have a slightly lower median beta ratio (25%), but these differences are not large enough to warrant categorizing projected beta doses according to vegetation.

Conclusions

Previous soil surveys indicated the primary radioisotopes contributing to the external does rate are ^{137}Cs and ^{60}Co for gammas, and ^{90}Sr for beta contribution (EN73, p. 103). External dose estimates for future inhabitants were based on aerial gamma surveys and did not include beta contributions and shallow dose estimates. The major finding of the work reported herein is that approximately 29% of the total external dose rate on Enewetak Atoll is due to beta or low-energy gamma radiation. While marked deviation from 29% can be found, especially at locations with little or no vegetation, the beta contribution is surprisingly insensitive to extent of ground cover typically found on these islands.

The impact of such a significant fraction of the total external dose rate resulting from beta or low-energy gamma radiation is illustrated in Table 1, where integral 30-year shallow dose estimates are compared with 30-year whole body doses reported in the 1972 survey. Living patterns and external dose estimates represent assumptions of village location, visitation, and agriculture patterns (EN73). They are listed in Table 1 and can be located on the map in Figure 1. Living patterns I and II are for residence in the southern islands, and patterns III through VI are for residence in the northern part of the atoll. External dose rates are much lower in the southern part of the Atoll. The living patterns include approximately 20% of the time spent on other islands for agricultural purposes, except for pattern III, in which residence, visitation and agriculture are confined to one island.

The estimated beta or low-energy gamma doses are listed in Table 1 as "shallow" doses, in keeping with the concepts set forth in ICRU 25 (CO76). The energy deposited by ^{90}Sr in tissue is predominantly within the first centimeter (HA75). The integral 30-year external doses due to betas or low-energy gammas vary from 1/4 to 1/2 of the total external integral doses, depending on the living pattern chosen. The variability is due to differences in ^{137}Cs, ^{60}Co, and ^{90}Sr soil concentrations as a function of time on different islands. The integral external doses in Table 1 include no assumptions about modifications which could be made to reduce external dose rates; remedial actions, such as providing gravel around villages or plowing the islands, could very substantially reduce the external shallow dose contribution.

TABLE 1. 30-Year Integral External Dose Comparisons

Living Pattern	†External Whole Body Doses (rem) from reference (EN73) with natural background* subtracted	Shallow External Doses (rem)
I	0.030	0.010
II	0.80	0.44
III	3.2	1.1
IV	9.2	2.4
V	2.1	0.73
VI	3.6	1.5

Assumed Living Patterns for Future Enewetak Atoll Inhabitants

Case	Village Island	Visitation Area	Agricultural Area
I	Enewetak/Medren	Jinedrol-Kidrinen (Keith)	Jinedrol - Kidrinen (Keith)
II	Enewetak/Medren	Bokoluo -Billae	Mijikadrek - Billae + Biken
III	Enjebi	None	Enejebi
IV	Bokambako	Bokoluo - Billae	Bokambako
V	Enjebi	Mijikadrek - Billae	Mijikadrek - Billae + Biken
VI	Enjebi	Bokoluo - Boken	Bokoluo - Boken

Fishing from entire Atoll assumed for all cases.

†From Table 204, page 613 of reference (EN73).

*Natural background ~0.027 rem/yr or 0.80 rem/30 years.

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Figures

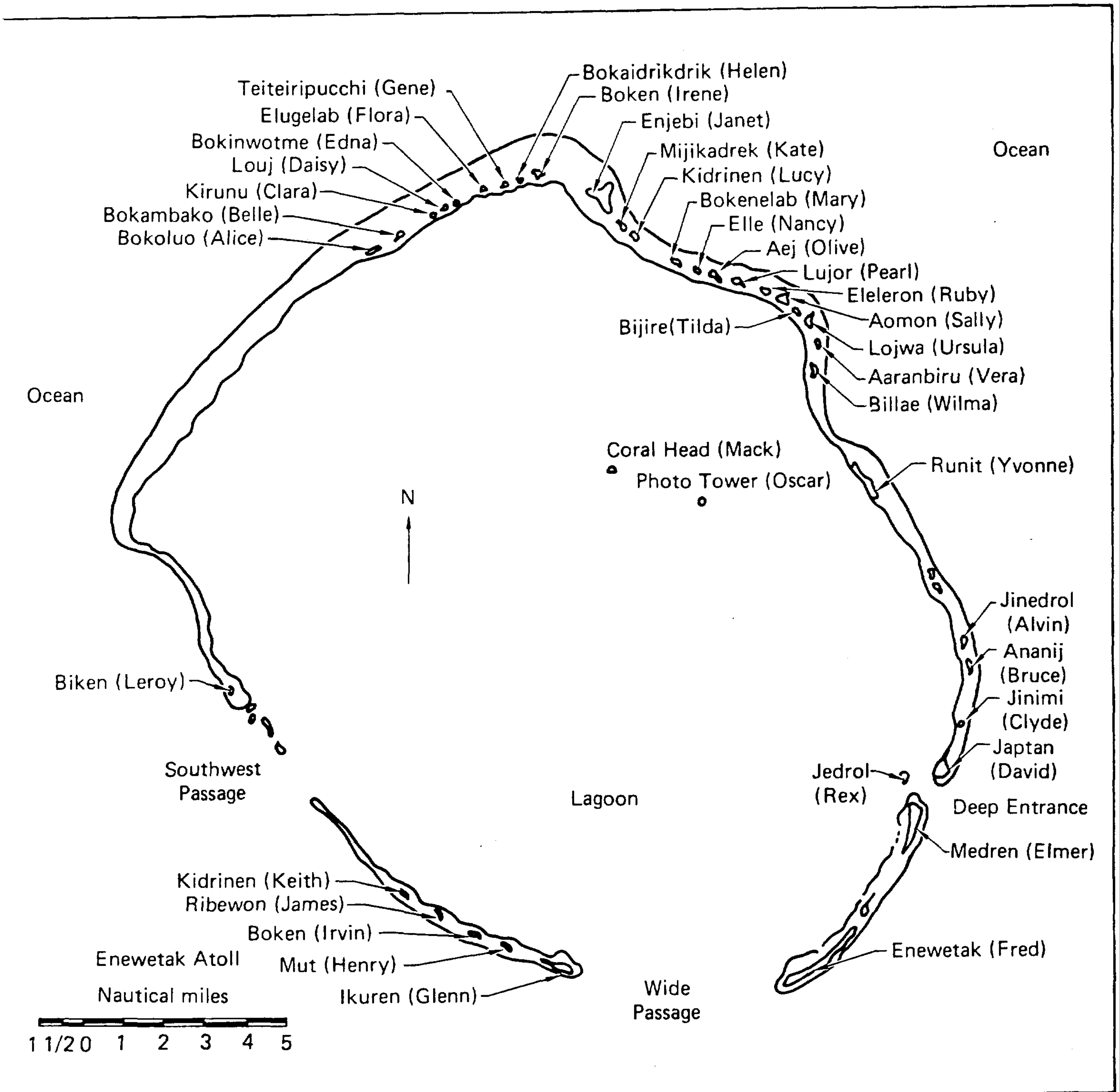

Fig. 1

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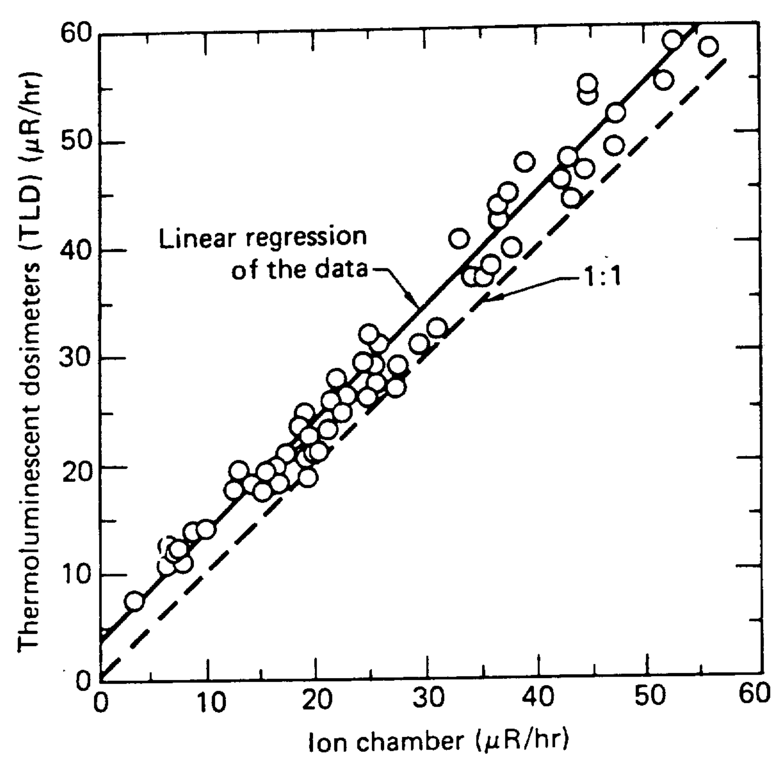
Thermoluminescent dosimeters (TLD) (μR/hr)
Ion chamber (μR/hr)
Linear regression of the data
1:1
0
10
20
30
40
50
60

Fig. 2

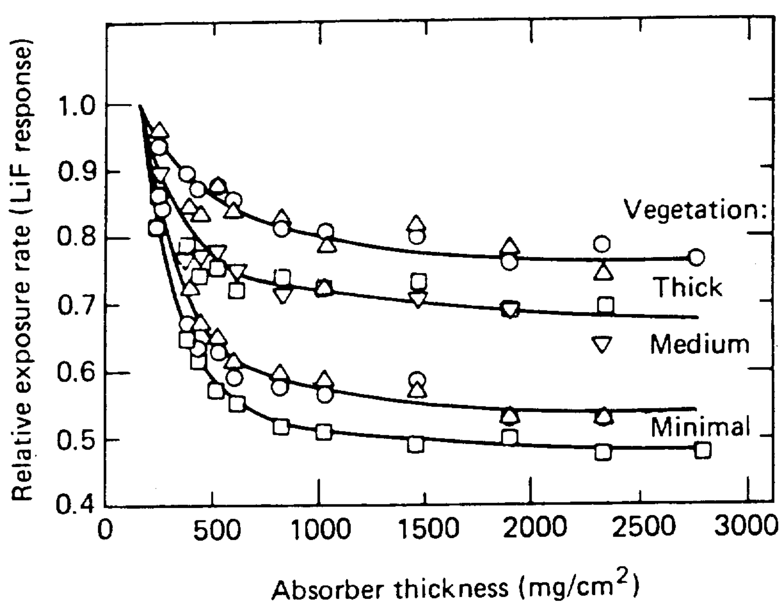

Fig. 3

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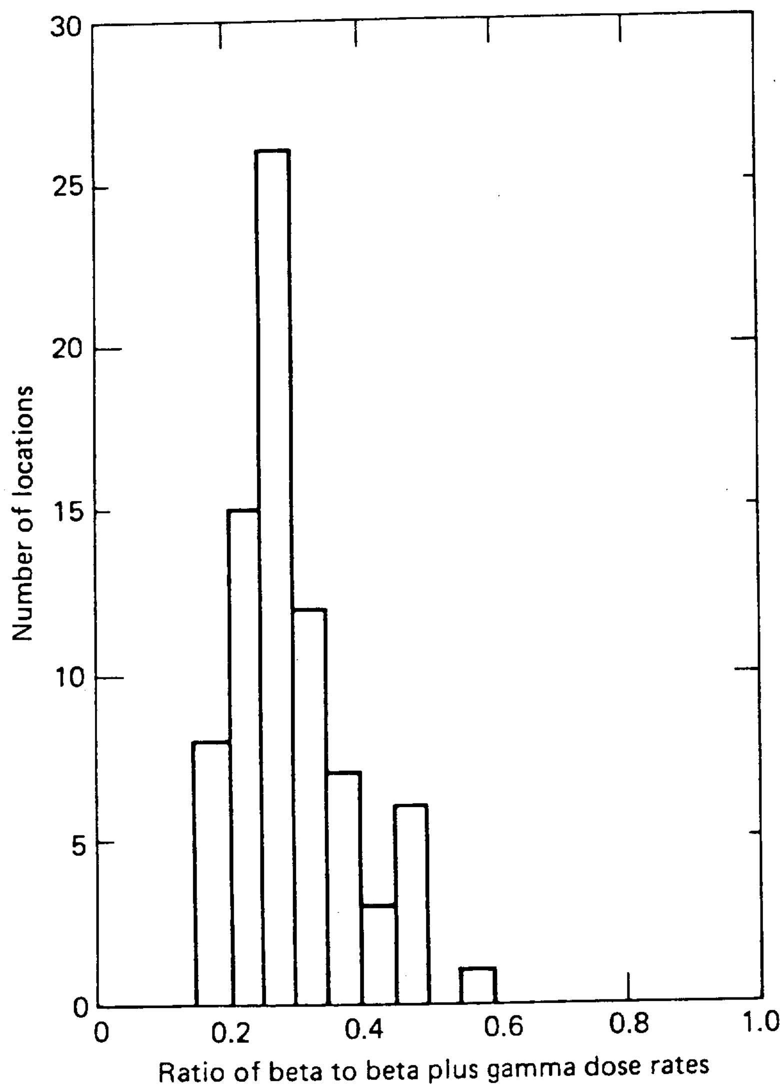

Fig. 4

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