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THE EFFECTS OF A TROPICAL RAIN FOREST COVER ON AIRBORNE GAMMA-RAY SPECTROMETRY

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Theoretical calculations have been made to estimate the attenuation and the generation of gamma photons by a model of a tropical rain forest environment. For typical flight altitudes of 100 meters, it is shown that a 35 meter high canopy can attenuate from 40% to 60% of the original gamma photons, depending on the energy considered. It is also shown that the 1.46 MeV photopeak of 40-K measured at flight altitudes is completely dominated by the forest generated component, whereas this effect is negligible for the 2.62 MeV of 208-Tℓ and the 1.76 MeV of 214-Bi. Of major importance are the effects of forest clearings on the gamma-ray spectrum which can lead to serious misinterpretations of aerial profile data if not taken into account. A short review on the biocycles of potassium from the soil to the biomass of the tropical rain forest is included in the article. A simple experiment has also been made to demonstrate the attenuation due to a forest biomass on the gamma radiation emitted by the soil.

A atenuação e a produção de fótons de radiação gama em um modelo de ambiente de floresta tropical úmida, foram calculadas teoricamente. Para alturas típicas de vôo de 100 metros, demonstrou-se que uma cobertura de floresta de 35 metros pode atenuar de 40% a 60% da radiação gama original, dependendo da energia considerada. Além disso, o fotopico de 1,46 MeV do ^{40}K determinado para a altura típica de vôo, foi completamente dominado pela fração gerada pela floresta. Esse efeito foi desprezível no caso dos fotopicos de 2,62 MeV do $^{208}Tℓ$ e 1,76 MeV do ^{214}Bi. Os efeitos do desmatamento no espectro de radiação gama não devem ser desprezados e pode-se incorrer em graves erros na interpretação dos dados nos perfis aéreos caso esses fatores não sejam considerados. Uma revisão sucinta sobre os biociclos do potássio do solo para a biomassa na floresta tropical úmida foi incluída no artigo. Finalmente, foi montada uma experiência simples a fim de demonstrar o fenômeno da atenuação da radiação gama na presença de uma cobertura de floresta.

INTRODUCTION

The problem of the effect of the presence of a forest cover on the airborne measured gamma-ray spectra of the ground has received little attention by the exploration geophysicists. Israel et al. (1962) and Kogan et al. (1971) have approached this problem theoretically for some temperate forests of the Northern Hemisphere. They have shown that a 30% to 50% decrease in the total radiation dose is due to the attenuation of the gamma photons by the forest biomass. These authors have also considered the effects of the anisotropy in the gamma field caused by the heterogeneous distribution of the biomass and the potassium immobilization in the forest biomass, which can lead to an excess of 15% or less in the dose rate measured at 50 meters ground clearance.

Recently, Travassos (unpublished thesis) and the authors have returned to this problem applying it to a very peculiar and little studied environment: the tropical rain forest. The tropical rain forest is unique insofar as the biomass content and nutrient cycles are concerned. A large volume of mature forest, totalling a biomass over 50% larger than that found in most temperate forests, grows and recycles itself very rapidly in a nearly self sustained environment.

About 10% of the whole land area of the world is covered by this type of forest, most of it concentrated in the Amazon basin. For some countries, like Brazil and many other countries of South and Central America, Africa and Asia, tropical rain forests may represent if not all, a significant fraction of their entire virgin territory. This fact itself justifies a more through study of the influences of this type of forest on the collection of airborne geophysical data, in particular gamma-ray spectrometric data. These effects are studied and discussed here not only from the point of view of the interactions of gamma photons with the forest biomass, but also taking into account some of the biochemical cycles that are characteristic of this environment and considering the increasing influence exerted by man in developing areas of the forest.

DESCRIPTION OF THE MODEL

We follow here the simplest approach by describing our system as a homogeneous, isotropic and layered medium. The four layers, described next are primarily based on chemical and physical propertier considered in airborne gamma-ray spectrometry, which do not necessarily agree with the layers, stages, or levels described in the other sciences (soil science, forestry, etc.).

The physical layered model:

1 – The mineral soil, for the purpose of this work, consists of a semi-infinite layer of altered rock underlying the entire system. This is essentially what the geophysicist senses with the airborne gamma-ray detectors.

2 – The organic soil layer is composed of about the same mineral components as the mineral soil layer but has an additional highly variable content of decomposed organic matter plus live roots. This layer is of particular interest for the present study since it plays an important role in the recycling of several plant nutrients, particularly of potassium. Although it is usually a very thin layer (about 86% of its biomass content is located within the first 30 centimeters; Holdridge et al., 1971), here we find the most important characteristics of the majority of soils of tropical rain forests: the high leaching rate of soluble cations, the rapid turnover of the biomass, and the rapid absorption of essential cations by the living root system.

Birot (1965) states that the volume of dead biomass returning to the top soil is 2 to 4 times larger here and the rate of decomposition of the fallen biomass about 5 to 10 times greater than for most forest in temperate regions. He also concludes that about 1/3 of the potassium content of the living biomass in tropical rain forests (0.05 to 0.1 kg/ha) returns yearly to the top soil, that represents 5 to 8 times the amount found in forests of temperate zones. However, most of this potassium, as well as other soluble plant nutrients, is promptly absorbed by the root system of the forest thus closing a chemical cycle that has a net effect of concentrating the potassium in this thin organic soil layer and in the associated vegetation cover. The rate of absorption of potassium cations by the roots of a tropical rain forest can be about 20 times greater than the losses by leaching (Golley et al., 1975). A small amount of soluble potassium can be furnished by the mineral soil, from the altered rocks, and from the water comming from frequent rains thus counterbalancing the losses by leaching. The problems of mineral nutrient balances in tropical rain forests are treated more throughly by Richards (1952), Stark and Jordan (1978), and Jordan (1982a). Table 1 shows a compilation of the concentration of potassium in the top soil layers of some tropical rain forests.

3 – The stan forest layer comprises all aboveground live biomass. There is a large number of references describing the tropical rain forest cover in many places of the Earth (Richards, 1952; Holdridge et al., 1971; Golley et al., 1975; Klinge et al., 1975; and Jordan, 1982b). Although the type of forest cover may vary from place to place, there is a certain number of important features

Table 1 – Natural potassium in top soils of some tropical rain forests.

location	exchangeable potassium (PPM)	source
Amazonian Forest. Brazil:		
red-yellow lateritic	3.9 to 35.	
yellow lateritic	16. to 82.	
red-yellow podzol	23. to 78.	Malavolta (1976) (1)
other soils	8. to 136.	
Amazonian Forest. Venezuela:	9.4 (average)	Jordan (1982a,b)
Panama:	17. to 117.	Golley et al. (1975) (2)
Costa Rica:	7.8 to 1174.	Holdridge (1971)
several places:	41. to 1271	compiled by Golley et al. (1975)

(1) these soils represent about 80% of all brazilian tropical rain forest soils.

(2) total potassium measurements.

that can be generalized and will adequately characterize a tropical rain forest for the purposes of the present study.

This type of forest is composed chiefly of an extremely large number of species of woody plants, most of them with dimensions of trees. Due to competition for light, these trees are generally straight and slender, branching only at the top. The forest is divided into two or three levels according to the height of the trees, plus the undergrowth which is not very dense. The height of the upper level is very likely within the range of 20 to 50 meters. The weight of leaf biomass is only a small fraction (1 to 13%) of the total dry biomass, nevertheless it can be 2 to 8 times larger than that of temperate zone forests, as stated by Birot. This is also supported by the data on leaf area in tropical rain forests when compared with that for temperate forests; an 8 to 5 ratio according to Jordan (1982b). If one considers this and the higher water content of leaves with respect to the stalk and branches of a tree (about 68% water content in leaves against 52% to 59% for the rest of the tree; Odum, 1970), one sees that the biomass of leaves cannot be neglected for the present study. Table 2 presents a short compilation of the total biomass content in some tropical rain forests.

The forest cover is not being considered here only as an absorbing medium for gamma-rays but also a source of radiation, mainly through the decay of the radioactive potassium (40-K, isotopic abundance of 0.01%) in solution with sap. In Table 3 we present a short compilation of the potassium content in dry biomass for some tropical rain forests.

Table 2 — Biomass content in some tropical rain forests.

location	dry biomass (kg/m^2) above ground	dry biomass (kg/m^2) roots and litter	source
Brazil	10. to 35.		several sources
Venezuela	33.2 to 34.9	4.8	Jordan (1982a,b) and Jordan and Escalante (1980)
Panama	26.3 to 36.8	1.9 to 2.7	Golley et al. (1975)
general	>41.	>9.	Rodin and Basilevič (1968)
general	12.2 to 37.0	2.5 to 9.0	Golley et al. (1975)
general	15. to 40.		Birot (1965)
general	6. to 80.		Lieth and Wittaker (1975)

Table 3 — Natural potassium in dry biomass of some tropical rain forests.

location	total potassium (PPM) (dry biomass)	source
Ghana	2,600	derived from data in Ovington (1968)
Panama, Brazil, Porto Rico and others	3,100 to 12,900	compiled or measured by Golley et al. (1975)
general	1,300 to 6,700	derived from data in Birot (1965)

By comparing these data with those of Table 1, and also taking into account the water content, we see that the potassium in the living biomass can be several orders of magnitude larger than the soil potassium concentration. Due to their chemical properties there is no enrichment of uranium and thorium in the living biomass. As a general rule, the concentration of these radioisotopes in the biomass parallels the concentration in the soil (Miller et al., 1980). On the other hand radium, which is chemically similar to calcium, can and does accumulate in the living biomass. An extreme of this effect was reported in 1968 by Penna Franca and collaborators for the "Castanha do Pará" (Brazil nuts found in the amazonian forest), where the radium concentration was between 273 and 7100 pCi/kg. It represents two to three orders of magnitude larger concentration than the average radium concentration found, (for example, in some tree and plant species reported by Kogan et al. (1971), Maslov et al. (1980) and Titaeva et al. (1980) or in some cereals, seeds and vegetables as reported by Eisenbud (1973). Nevertheless, due to the high transpiration rate through the leaves, the gaseous radioactive daughters in the uranium and thorium series (radon) are lost to the atmosphere, resulting in a 214-Bi and 208-Tℓ depleted biomass.

4 – The atmosphere fills every empty space between the soil and forest canopy and has to be considered when calculating the effective density and attenuation coefficients of all previously described layers. For our first order model, we will assume the atmosphere as an absorbing medium rather than a gamma-ray emmitter.

Table 4 shows a compilation of the selected parameters describing the standard tropical rain forest of the present model. We will assume the parameters of Table 4 throughout this paper unless specifically stated.

Table 4 – Selected parameters describing the adopted model of a tropical rain forest.

altitude of the detector		100 m
height of forest canopy (Hf)		35 m
depth of organic soil layer (Hr)		0.5 m
total forest dry biomass (Bi)		50 kg/m^2
fraction of total biomass which is underground		19%
water content of above ground biomass		58%
water content of underground biomass		61%
average density of the forest biomass		750 kg/m^3
mass attenuation coefficients in dry biomass for gamma photons of energy:	0.61 MeV	8.9×10^{-3} m^2/kg
	1.46 MeV	5.8×10^{-3} m^2/kg
	1.76 MeV	5.2×10^{-3} m^2/kg
	2.62 MeV	4.2×10^{-3} m^2/kg

THE MATHEMATICAL MODEL

The four layer model employed in this work is depicted in Fig. 1. An elementary volume dv of soil will produce an intensity of primary gamma photons of energy E through an unit cross section detector given by:

$$\delta\phi_r(E) = \frac{q_r}{4\pi\rho^2}\, e^{-\mu_r(\rho-\rho_r)}\, e^{-\mu_s(\rho_r-\rho_s)}\, e^{-\mu_f(\rho_s-\rho_f)} e^{-\mu_a\rho_f}\, dv \qquad (1)$$

which can be written as:

$$\delta\phi_r(E) = \frac{q_r}{4\pi\rho^2}\, e^{-(\mu_r\rho+\mu_1\rho_f+\mu_2\rho_s+\mu_3\rho_r)} dv \qquad (2)$$

where q is the source activity per unit volume, μ is the mass attenuation coefficient (see Fig. 1), and

$$\begin{aligned} \mu_1 &= \mu_a - \mu_f \\ \mu_2 &= \mu_f - \mu_s \\ \mu_3 &= \mu_s - \mu_r \,. \end{aligned} \qquad (3)$$

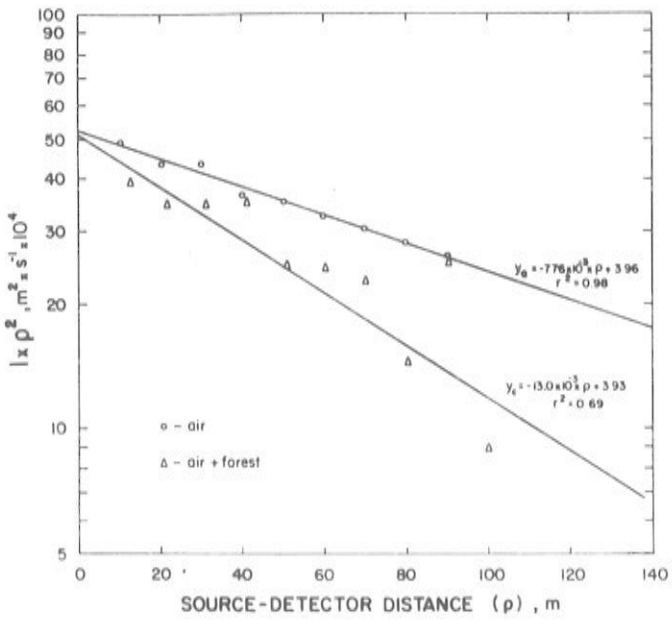

Figure 1 — Diagram showing the four layer homogeneous and isotropic model.

Similarly, the organic soil layer and the forest cover will produce gamma photon intensities given respectively by:

$$\delta\sigma_s(E)=\frac{q_s}{4\pi\rho^2}\,e^{-(\mu_s\rho+\mu_1\rho_f+\mu_2\rho_s)}\,dv \qquad (4)$$

$$\delta\phi_f(E)=\frac{q_f}{4\pi\rho^2}\,e^{-(\mu_f\rho+\mu_1\rho_f)}\,dv \qquad (5)$$

By using the following trigonometric relationship

$$\frac{\rho_f}{Z_f}=\frac{\rho_s}{Z_s}=\frac{\rho_r}{Z_r}=\frac{\rho}{Z} \qquad (6)$$

with Z_i (i = f,s,r) being the vertical distance from the detector to each layer interface, we can place all exponents in equations (2), (4) and (5) as functions of ρ only by employing the following expressions:

$$\rho_f=\left[\frac{Z_f}{Z}\right]\rho\;;\quad \rho_s=\left[\frac{Z_s}{Z}\right]\rho \text{ and } \rho_r=\left[\frac{Z_r}{Z}\right]\rho \qquad (7)$$

Substituting the above relationships into equations (2), (4) and (5):

$$dv = 2\pi x\,dx\,dZ \text{ and } xdx = \rho d\rho \qquad (8)$$

After a few simplifications we finally arrive to:

$$\delta\phi_r(E)=\frac{q_r}{2\rho}\,e^{-[\mu_r+\mu_1(Z_f/Z)+\mu_2(Z_s/Z)+\mu_3(Z_r/Z)]\rho}\,d\rho dZ \qquad (9)$$

$$\delta\phi_s(E)=\frac{q_s}{2\rho}\,e^{-[\mu_s+\mu_1(Z_f/Z)+\mu_2(Z_s/Z)]\rho}\,d\rho dZ \qquad (10)$$

$$\delta\phi_f(E)=\frac{q_f}{2\rho}\,e^{-[\mu_f+\mu_1(Z_f/Z)]\rho}\,d\rho dZ \qquad (11)$$

Recalling that $Z = \rho\cos\theta$ we can integrate the above equations with respect to ρ for θ in the interval between zero and a given angle θ. This corresponds to ρ in the interval between Z and a given value of ρ. This results in:

$$d\phi_r(E)=\frac{q_r}{2}\{\epsilon_1(\mu_r Z+\mu_1 Z_f+\mu_2 Z_s+\mu_3 Z_r)+$$
$$-\epsilon_1[(\mu_r Z+\mu_1 Z_f+\mu_2 Z_s+\mu_3 Z_r)/\cos\theta]\}\,dZ \qquad (12)$$

$$d\phi_s(E)=\frac{q_s}{2}\{\epsilon_1(\mu_s Z+\mu_1 Z_f+\mu_2 Z_s)+$$
$$-\epsilon_1[(\mu_s Z+\mu_1 Z_f+\mu_2 Z_s)/\cos\theta]\}\,dZ \qquad (13)$$

$$d\phi_f(E)=\frac{q_f}{2}\{\epsilon_1(\mu_f Z+\mu_1 Z_f)+\epsilon_1[(\mu_f Z+\mu_1 Z_f)/\cos\theta]\}\,dZ \qquad (14)$$

with ϵ_1 being the exponential integral for $\eta = 1$ given by

$$\epsilon_\eta(\xi)=\int_1^\infty \frac{e^{-\xi t}}{t^\eta}\,dt. \qquad (15)$$

Equations (12), (13), and (14) are now to be integrated with respect to the variable Z in the intervals: Z_f to Z_s, Z_s to Z_r and Z_r to infinity. After the integration and rearranging termos we finally get:

$$\phi_r(E)=\frac{q_r}{2\mu r}\{\epsilon_2(\mu_s Z_r+\mu_1 Z_f+\mu_2 Z_s)+$$
$$-\cos\theta\,[\epsilon_2\,(\mu_s Z_r+\mu_1 Z_f+\mu_2 Z_s)/\cos\theta)]\} \qquad (16)$$

$$\phi_s(E) = \frac{q_s}{2\mu_s}\{[\epsilon_2(\mu_f Z_s + \mu_1 Z_f) - \epsilon_2(\mu_s Z_r + \mu_1 Z_f + \mu_2 Z_s)] + \cos\theta[\epsilon_2(\mu_f Z_s + \mu_1 Z_f)/\cos\theta + (\mu_s Z_r + \mu_1 Z_f + \mu_2 Z_s)/\cos\theta]\} \quad (17)$$

$$\phi_f(E) = \frac{q_f}{2\mu_f}\{[\epsilon_2(\mu_a Z_f) - \epsilon_2(\mu_f Z_s + \mu_1 Z_f)] + \cos\theta[\epsilon_2(\mu_a Z_f/\cos\theta - \epsilon_2(\mu_f Z_s + \mu_1 Z_f)/\cos\theta)]\}. \quad (18)$$

There is a more easily workable form for the second order exponential integral ϵ_2, which is very useful when employing a digital computer to evaluate the above equations (Abramowitz and Stegun, 1972):

$$\epsilon_2(\xi) \cong e^{-\xi} + \xi\left[0.5772157 + \ln(\xi) + \sum_{\eta=1}^{\infty} \frac{(1)^{\eta}\,\xi^{\eta}}{\eta \cdot \eta!}\right]. \quad (19)$$

Therefore, the total number of primary gamma photons of a given energy E passing per unit of time through a detector of unit cross section area is given by:

$$\phi(E) = \phi_r(E) + \phi_s(E) + \phi_f(E) \quad (20)$$

which thus includes both the absorption and the generation of photons in any of the four layers described in the previous section.

We have collected a total of 26 data points for several distances between source and detector (ρ) up to about 100 meters, including duplicate measurements. The results are presented graphically in Fig. 2, curve (a). An identical experiment was performed without a forest cover. The results are also graphically presented in the same figure, curve (b). The least square fits to data points in each curve furnish the attenuation equations:

$$I_c = \frac{50.9}{\rho^2}\exp(-13.0 \times 10^{-3} \times \rho)\ s^{-1} \quad (21)$$

$$I_a = \frac{52.5}{\rho^2}\exp(-7.76 \times 10^{-3} \times \rho)\ s^{-1} \quad (22)$$

The coefficients in the exponents of the equations are the linear attenuation coefficient: for the composite medium air plus forest (13.0×10^{-3} m^{-1}) in equation (21), and for the air (7.76×10^{-3} m^{-1}) in equation (22).

AN EXPERIMENTAL ASSAY TO MEASURE THE ATTENUATION IN THE BIOMASS

The attenuation of gamma photons within the range of energies usually found in the natural Earth environment, was measured in a well known reforested area in order to estimate the effect of a living biomass. The area chosen for the experiment had a flat topography and was planted with 4-year old *Eucalyptus saligna* trees in a regular 2 x 1.5 meter grid pattern. The total above ground biomass estimated by the standard forestry techniques[1] was 5.62 kg/m^2.

A NaI(Tℓ) detector was assembled on the top of a 9 meter steel frame and connected by cable to a remote pulse height analyser with associated electronics. Gamma photons were provided by a 100 mCi point source of 60-Co shielded by depleted uranium inside a lead case.

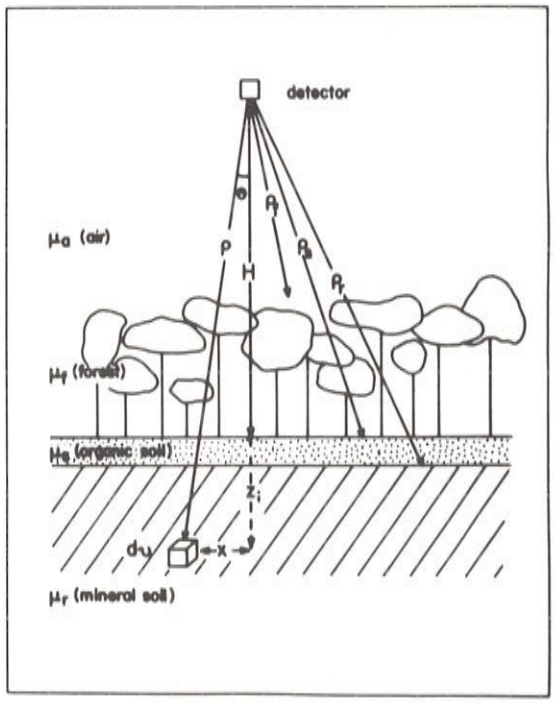

Figure 2 — Plot of experimental data for source — detector distance versus the product photon intensity x distance squared. The adjusted linear regression coefficients of determinations for each set of data points are indicated in the figure.

(1) The average diameter at breast height and canopy height are 18.7 cm and 7.83 m, respectively. For biomass calculations, see Veiga and Brazil (1981) for example.

The photopeak studied was the 1.33 MeV, which is the closest to the 1.46 MeV photopeak of 40-K.

The presence of the thin forest cover in the experiment has caused a 40% relative change of the linear attenuation coefficient.

It is also possible to estimate the effect of the biomass for the 1.33 MeV energy of 60-Co by recalling that the mass attenuation coefficient is primarily a function of the effective atomic number of the medium. In this case, since the effective atomic numbers of the air and of the composite medium are nearly the same ($Zeff_{(air)} = 8.2$; $Zeff_{(composite)} = 7.9$) we can compare:

$$\frac{\mu_a^{\ell}}{d_a} \cong \frac{\mu_c^{\ell}}{d_c} \tag{23}$$

with μ^{ℓ} being the linear attenuation coefficient, and d_a and d_c the densities of the air and the composite medium, respectively. By rearranging the terms we obtain:

$$d_c \cong \frac{\mu_c^{\ell}}{\mu_a^{\ell}} d_a = 2.10 \text{ kg/m}^3 \tag{24}$$

We are dealing with a fixed volume above the ground which contains air, air plus forest, or sole forest. This allows us to obtain the density d_f of the forest cover alone by simply putting:

$$d_f = d_c - d_a = 0.84 \text{ kg/m}^3 \tag{25}$$

Now, multiplying the density d_f by the average measured height of the forest (7.83 meters) we obtain an estimate for the total above ground biomass of 6.58 kg/m^2, which is very close to the 5.62 kg/m^2 measured directly by the DBH technique.

DISCUSSION AND CONCLUSIONS

Fig. 3 shows the variation of the intensity ratios Th:K and U:K with the height of the forest canopy, as would be measured at constant ground clearence from the detector. The curves show different behavior for different concentrations of potassium in the above ground biomass. All other parameters are kept constant and are listed in Table 4.

In order to better understand these curves we shall calculate the change in the intensity ratio caused by a unity change in the altitude of the forest. This is given by the slope of each curve at 35 meter. Taking, for example, the curve for U:K intensity ratios corresponding to a biomass potassium concentration equal to the soil

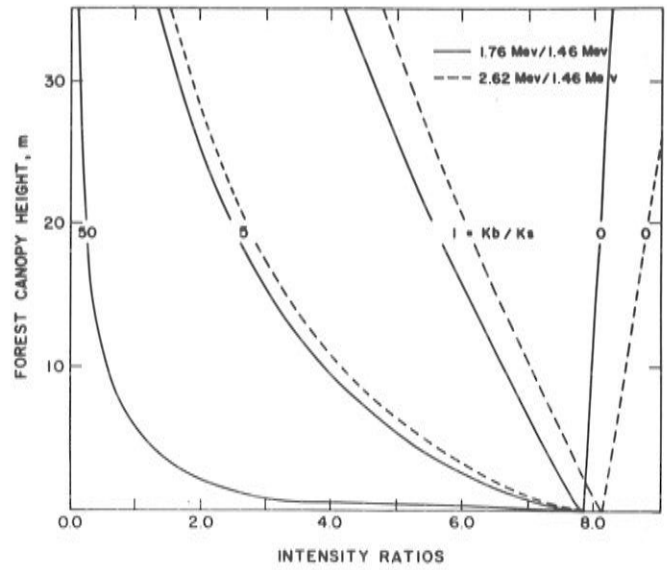

Figure 3 — Calculated intensity ratios versus height of forest canopy for some typical ratios between potassium concentration in total dry biomass (Kb) and in the mineral soil (Ks). For these curves Ks is constant and equal to 0.01%. Both eU and eTh are taken to be 1 PPM in the mineral soil and zero in the entire biomass.

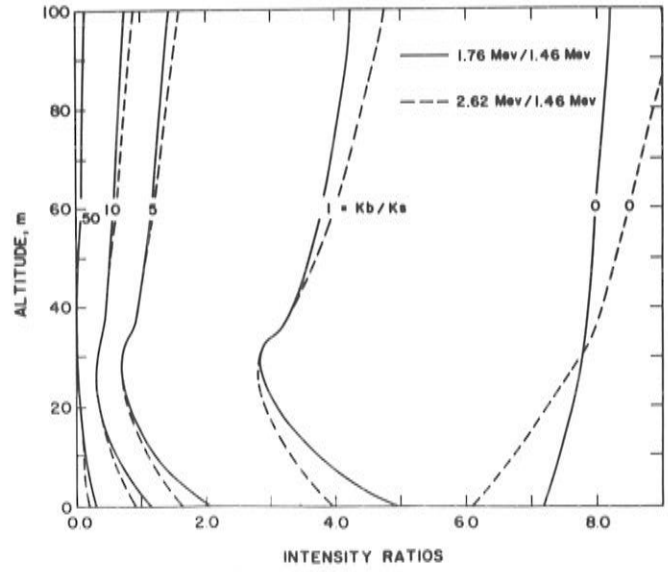

Figure 4 — Calculated intensity ratios versus altitude of detector for some typical ratios between potassium in total dry biomass (Kb) and mineral soil (Ks). For these curves we considered the same concentrations employed for Figure 3.

potassium concentration (Kb/Ks = 1), the calculated slope is 0.06 m^{-1}. On the other hand, for a 50 times enrichment of potassium in the biomass (Kb/Ks = 50), the slope is 0.005 m^{-1}, therefore one order of magnitude smaller. In other words, the larger the potassium concentration in the above ground biomass with respect to the soil, the lesser will be the effects of small changes of the forest canopy height in the intensity ratios. These ratios will rather be more sensitive to changes in the net potassium concentration of the biomass. We will return to this problem further in this article.

Fig. 4 shows how the intensity ratios change as a function of the altitude of the detector above the ground and as a function of the potassium concentration ratios between the mineral soil and the total forest. The discontinuity observed in all curves at H = 35 meters in the air-forest canopy transition. It is our feeling though that the experimental data for an altitude profile would show a smoother change at the interface.

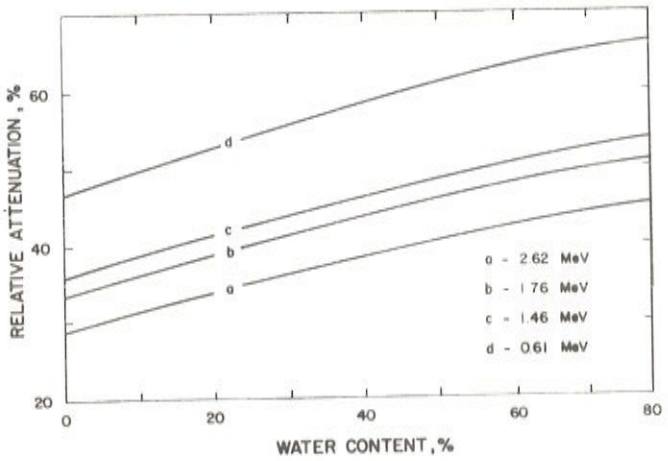

Figure 5 — Calculated relative attenuation of gamma photons versus water content of stand forest and roots. For calculating these curves the radioisotopic concentrations were taken as zero in the total biomass, and unit in the mineral soil.

The relationship between the total attenuation and the water content of the living biomass is nearly linear within the range from zero to 70% water content and is shown in Fig. 5. A change of 10% in the water content of the living biomass will cause only about 3% relative change in the attenuation within the range of energies of interest. Golley et al. (1975) observed that the water content in the total forest biomass of a tropical rain forest ranged from 51.8% to 65.7% in dry and rainy seasons, respectively. Considering that one of the dominant climate features of most of the tropical rain forests is heavy rainfall evenly distributed over the greater part of the year, we conclude that the water content of the biomass cannot be a major cause of fluctuations in gamma ray spectrometric data, except perhaps immediately after a rainfall when a significant volume of water will be trapped in the foliage. The problems caused by the water accumulated in the top soil, although being important in airborne gamma-ray spectrometry, are beyond the scope of the present work and will not be discussed here. For a careful consideration of this problem see Carroll (1981), for example.

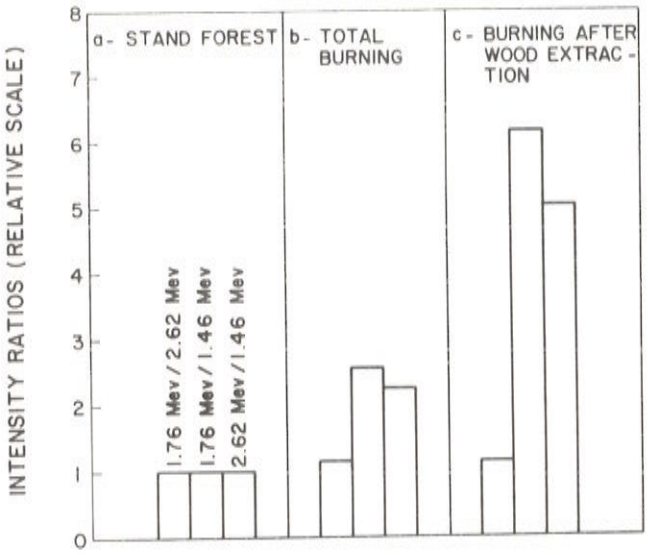

Figure 6 — Calculated effects of forest clearings on the airborne measured gamma-ray intensity ratios. For the calculation we have assumed eU and eTh concentrations of 1PPM in the mineral soil and zero in the biomass. Potassium was taken as 0.001% in the mineral soil and 0.1% in the biomass. The intensity ratios shown here are all normalized for the stand forest values.

We have also demonstrated that the airborne gamma-ray spectrometric data is greatly influenced by natural and man-made forest clearings. The forest clearence in the brazilian amazonian forest is commonly practiced by burning, generally with a previous exploitation of wood. This practice is nowadays becoming more and more frequent in Brazil and its effects are shown here to produce large changes in the measured gamma intensity ratios. Fig. 6(a,b,c) presents the calculated changes in the intensity ratios when passing from a standing forest cover to a completely burnt area and, finally to an area that has had the wood exploited before clearing by fire. To calculate Fig. 6(b), we assumed that the above ground biomass was totally burnt and reduced to a 1 centimeter thick ash layer containing all non-volatile nutrients that once composed the original forest, including potassium.

In Fig. 6(c), we first subtracted the biomass equivalent to the trees whose diameter at breast height was larger than 20 centimeter, and then proceeded as in the previous calculations. We can see here that the resulting anomalies in the three intensity ratios can be easily misinterpreted by an U and Th enrichment in the ground. What happened, in fact, was the removal of the attenuation layer by burning the standing forest cover while placing the potassium originally distributed through the entire biomass, at a larger distance from the detector. The net effect is an increase in the Th:K and U:K intensity ratios and a minor increase in the U:Th intensity ratio.

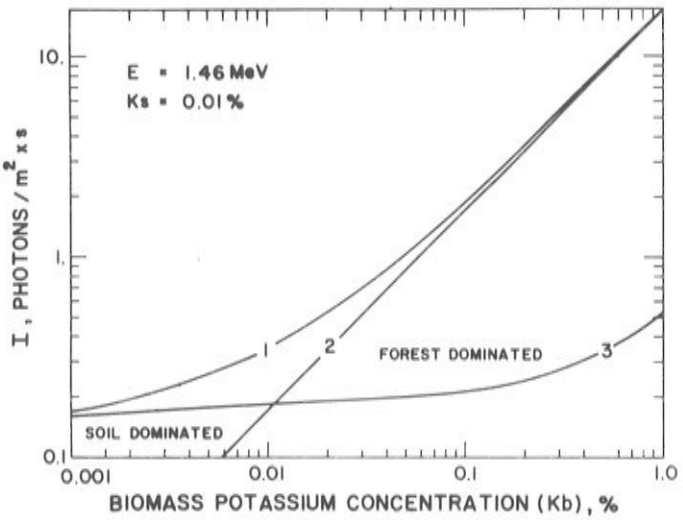

Figure 7 — Intensity of 1.46 MeV photons calculated for 100 meter flight altitude versus concentrations of potassium in total dry biomass. Curve 1 shows the total intensity, curve 2 represents the forest generated component and curve 3 shows the soil generated component (including roots and dead biomass).

The separate contributions of 1.46 MeV gamma photons generated in the organic soil plus mineral soil and standing forest, and the total intensity are shown in Fig. 7. In this figure we can see that the contribution of the soil to the total 1.46 MeV intensity is dominant up to a certain value of Kb/KS (~ 1) when the forest begins to dominate. This masking effect of the forest in the 40-K energy is very important when interpreting airborne gamma-ray data. Further studies on the fluctuations of the potassium content in the tropical rain forest biomass is needed in order to properly interpret and correct experimental data for this effect. The biomass is most probably too depleted in the other two relevant isotopes (214-Bi and 208-Tℓ) as compared to the soil, to cause any similar effect on experimental data. A strong reason supporting this conclusion is the easy escape of radon through leaves and branches of trees, thus preventing accumulation of 214-Bi in the above ground biomass.

If the potassium content in the forest is relatively constant, as it is in the opinion of the authors, then all the intensity ratios with respect to the 1.46 MeV photopeak will be directly proportional to their concentrations in the soil and independent of such parameters as the flight altitude and the physical changes of the atmosphere along the flightline, or any other time dependent features.

Finally, the changes in the shielding effect on the 0.5 centimeter thick soil layer containing organic matter (both live and dead biomass) have also been studied. An increase of organic matter from zero to 10 kg/m^2 has produced a calculated maximum net decrease in the shielding effect of only 1.7%. Such a minor variation can be neglected for the purposes of airborne gamma-ray spectrometry.

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