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HYDROLOGICAL EVALUATION OF RADIOACTIVE WASTE DISPOSAL SITE AT IPEN: STUDY OF MOVEMENT OF SOIL MOISTURE AND GROUND WATER RECHARGE BY ARTIFICIAL TRITIUM TAGGING METHOD

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RESUMO

A disposição de resíduos radioativos no subsolo, requer o estudo preciso do movimento da água através das formações locais e do aquífero. O presente estudo refere-se a uma avaliação hidrológica do local do IPEN destinado a depósito de resíduos radioativos.

Analizou-se a migração da umidade na zona não saturada, utilizando-se como traçador trítio artificial, na forma de água tritiada. A infiltração vertical da água de chuva foi estudada durante o período de um ano, mediante amostragem periodica do solo, a diferentes profundidades.

As amostras de solo foram submetidas a destilação em vácuo, para extrair delas a umidade. O teor de trítio na água do solo foi medido com um contador líquido de cintilação. Obteve-se, assim, informação sobre o movimento de umidade na zona não saturada no local do depósito.

A técnica de marcação com trítio artificial usou-se, também, para calcular a taxa de recarga com base na infiltração das precipitações pluviais.

INTRODUCTION

It is economically attractive to dispose radioactice wastes of nuclear industry into ground or into bodies of water. The natural features determinimg the suitability of a site for ground-disposal of radioactive wastes include, the climate, type of soil, sub-surface geology, hydrology- particularly in relation to underground water sources and proximity to population centre.

Where the climate is considerably damp, there is obviously greater likelihood that radioactive materials released to the ground will be leached. As the moisture, from rainfall, infiltrates through the soil at waste disposal site, it may come in contact with buried wastes or elute radionuclides already sorbed by the mineral components in the soil. A study to measure infiltration and moisture movement in the waste disposal site should therefore be made prior to disposal operations.

Disposal of radioactive wastes into ground demands precise study of movement of liquid through porous media. Monsoon water infiltrates downwards through the partially dry soil untill it eventually reaches the saturated zone. Contamination of ground water may originate either from infiltration leaching the burried wastes or from effluents discharged directly into the soil. In normal case, contaminated liquid would mix with natural water in the unsaturated zone and infiltrate through the soil. It would next enter the capilary zone and where it would be influenced by pronounced horizontal flow before it enters the fully saturated zone. At this stage the transition from predominantly vertical flow to predominantly horizontal flow would be complete. This necessiates accurate determination of vertical infiltration rate in the areated zone and horizontal velocity of ground water in saturated zone. Determination of these parameters constitutes the basic work of hydrological evaluation of a radioactive waste disposal site.

This paper presents the study of infiltration in the unsaturated zone of the radioactive waste disposal site at IPEN. Movement of water or soil moisture can best be studied by application of radioactive tracer. In this study tritium has been used as the tracer.

USE OF TRITIUM AS TRACER FOR WATER

Tritium has been used as water tracer in investigations of river flow measurements. The problem of absorption or loss of tracer for moisture movement studies can be avoided by using tracers which are isotopes of hydrogen and oxygen. Thus, tritium is a unique tracer (IAEA,1968). It fulfills almost all the requirements of a water tracer except that it undergoes isotopic exchange with the hydrogen of the clay matrix and organic matter generally present in the cultivated soils. Also because of its low beta radiations it cannot be detected in-situ. Samples have to be brought for analysis in the laboratory. Injections of tritiated and deutiriated waters have been applied to study the water movement in the unsaturated zone (Zimmerman et al.,1967; Smith et al.,1970).

PRINCIPLE OF THE METHOD OF DETERMINING SOIL MOISTURE MOVEMENT AND GROUND WATER RECHARGE BY TRITIUM TAGGING METHOD

One of the most important hydrological parameter which can be computed by studying the vertical movement of tritium tagged moisture in the unsaturated soil zone is the amount of recharge taking place to the ground water. The method of determing recharge is based on monitoring the movement of a layer of moisture, tagged with tritiated water, downward in the soil on its way towards the water table. Studies in the past (Zimmerman et al.,1966;1967) have shown that the ground water recharge process is essentially a piston-like propagation of soil water through the unsaturated zone and that much of the water eventually being added to ground water is therefore not directly derived from the incident precipitation but is soil water released after successive exchange of the percolating water, layer by layer with the moisture already held in the unsaturated zone.

If tritiated water is injected well below the root zone (say at 70 cm below surface) and away from any tree, it will move as cloud of labelled moisture in due course of time towards the water table due to influence of percolating rain water. The cloud during its movement may show some vertical spread due to microscopic velocity variations and molecular diffusion. After some time the maxima of the cloud will get displaced further down and the distribution would still be broader. The maxima of the cloud can be located by estimating tritium in the moisture of the soil obtained from different depths. The moisture content of the layer displaced during the period between the time of injection of tritium and the time of soil sampling represents the net recharge during the period. Thus, the net recharge in cm can be expressed by the following expression:

$$\text{Recharge to ground water} = \frac{m \cdot D \cdot X}{(1+m)}$$

Where,

m = average moisture content of the soil between point of injection and tritium peak/centre of gravity. This is the weight of water per unit weight of dry soil

D = bulk density of soil mass. This is weight per unit volume of the soil mass

X = displacement of tritium peak/centre of gravity (cm)

The experimental approach of the tritium tagging method is a direct one and is more reliable, convenient and does not involve uncertain computations as compared to conventional classical methods. The accuracy obtained while estimating moisture penetration or ground water recharge depends on the velocity of moisture movement which is proportional to the ground water recharge rate and inversely proportional to the field capacity of the soil. For a typical soil where the velocity might be 1 m/yr (field capacity 20 per cent by volume;ground water recharge rate 200 mm/yr), the ground water recharge rate will come out with a limit of error of 10 per cent or better (IAEA,1968). Very low recharge rates or those measured for shorter time interval are less accurately determined by this method, since the broadening of the tracer peak becomes more pronounced in comparison with the depth of displacement. By this method it is also possible to detect lateral movement of soil moisture caused by horizontal or inclined soil layers of low permeability.

Concentrations of naturally occurring tritium in precipitations seem to be of the order of 10 T.U., but from 1953 the tritium content in precipitation has increased. Consequently, precipitation has been labelled with an amount of tritium which can be relatively easily measured. The tritium input from the precipitations can be used to compute recharge by environment tritium tagging method(Smith et al.,1970;Bedenkamp et al.,1974;Allison et al.,1974;Sukhija and Rama,1973). The application of environmental tritium has the advantage of giving an avergae result over many years, although not as accurate as using artificial tritium. The disadvantage of environmental tritium method is that sometimes the tritium profiles obtained are confused and not easy to interpret. This mehtod could be applied best in soils where infiltration velocities are very small and the peak bomb-tritium has not reached the water table.

AREA OF INVESTIGATIONS

The radioactive waste disposal site of Instituto de Pesquisas Energéticas e Nucleares is situated in the western part of the Institute and lies within topographic contours of 750 m and 735 m of the Butanta hill where the Institute is located Ground topography slopes in the north-west direction towards the course of old Jaguare stream which is about 450 m away from the disposal site. The site is characterised by good soil cover. Ground water table at about 850 m away from the site in the north and at a lower topographical level of 710 m has been found to be 3.2 m below ground. Monitoring wells at the disposal site are planned to be drilled to establish local water table,but the water table at the site, in view of of the local topography, is likely to be about 15-20 m below ground.

The area-soil consists of quarternary alluvial sediments with clay, thickness of these sediments is variable within 10 m. The site is devoid of significant vegetation and the local area suffers erosion after heavy spell of rain. Local drainage system and levelling up of the area is underway to avoid disturbances of the local topography due to erosions.

FIELD WORK AND LABORATORY INVESTIGATIONS

a) Injection of tritium and soil sampling

Injections of tritiated water were carried out at the levelled area of the disposal site which was devoid of vegetation. Earlier investigators employing artificial tritium(Zimmerman et al., 1966;1967) have used line or planer injection pattern but in the investigations reported here the pattern of injection differed in the following way:

i) Injections were made at depth well below the root zone of vegetation. The soil moisture movement and ground water recharge thus estimated would be expected to be affected by evaporation/evapotranspiration to a negligible extent.

ii) Five point injections were made at 10 cm radial distance in the form of a cross. This way the the displacement or diffusion of tritium cloud could be taken more uniform around the central point of injection.

Four sets of injections were made, each set having five point injections. This ensured that four samplings of soil could be carried out at different intervals of time without affecting natural soils and flow conditions around the unsampled set. The injection operation was as follows : five drive rods were pushed into the soil, so as to make holes - 70 cm deep and 7 mm in diameter. The rods were pulled out and brass injection tubes were gently inserted. 2.5 ml of tritiated water (≈ 1 μCi/ml) was injected into each hole. After injections, the holes were filled with the soil. Iron bolts were hammered one foot deep at either end of the line of injection to serve as markers for subsequent location of the injection points. The erea was left completely undisturbed. The depth of sampling for obtaining tritium profiles were decided by previous experience and site conditions.

The injections were carried out on 24 May 1979 and following shedule of sampling of soil from the individual set of injections was carried out:

Set No.	Date of Sampling	Time Elasped Since Injection
1	24/08/79	3 Months
2	28/11/79	6 Months
3	25/02/80	9 Months
4	28/05/80	12 Months

Soil samples were taken with 3" diameter hand auger in successive depths of 10 cm from various depths. Adequate amounts of soil samples were stored in well capped glass containers and brought to laboratory for tritium estimation. At the same time, soil samples after every 20 cm depth interval were packed separately for moisture determinations.

b) Determination of bulk density of local soil

Measurements of bulk density were carried out in the field itself. The entire soil from the auger hole was weighed at the site. The volume of the hole was then measured by filling it with fine sand which was already contained in a graduated cylinder. The data of bulk density thus measured are shown in Table-1.

c) Determination of soil moisture content

Moisture contents were measured by accurately weighing the soil samples before and after drying them at 110 °C. This yielded moisture content by weight % .

d) Extraction of soil moisture for tritium assay

For extraction of moisture, the soil samples were subjected to vacuum distillation. Heating of the soil samples was carried out by regulable heating mantles. The distilled moisture was collected in moisture traps which were cooled by dry ice-acetone slurry.

e) Estimation of tritium content

The estimation of tritium was carried out by liquid scintillation counting. The counting vial contained 20 ml of the solution consisting of 1,2 or 10 ml of extracted soil water; 9,8 or 0 ml respectively, of distilled water and 10 ml of aquasol. The vials were then counted in the liquid scintillation counter.

DISCUSSION OF RESULTS

Table 1 summarizes the results of the investigations carried out. It shows the interval of soil sampling,displacement of peak and centre of gravity of the tritium profile,the bulk density of the soil as measured in the field and calculations of recharge to ground water.

Movement of soil moisture and its leading to recharge is controlled by following factors:

- frequency and amount of rainfall during the period of investigation
- temperature,humidity,evaporation/evapotranspiration rates over the period of investigation
- soil type,presence of clay-its extent,depth of occurrence

The experimental data obtained so far indicate that:

- from May '79 to May '80, bulk of moisture has migrated vertically only upto 70 cm.
- rate of migration of the bulk of moisture(which evidently depends upon rainfall) during May '79 to May '80, has been rapid during the initial six and nine months. After nine months, vertical movement of moisture slowed down. This should be explainable by the soil moisture deficiency and pattern of rain during the period of investigation .
- the soil moisture profiles need to be studied along with the the data of sand,silt and clay contents at various depths. At the waste disposal site, layer of soil between 160-180 cm depth shows the maximun soil moisture content(see Fig.3 and 4). This indicates presence of clayey layer which can contain water, but cannot easily transmit it. Presence of clay band will hinder vertical movement of soil water and will cause horizontal spread of the tritium tracer. Heterogeneity of the soil,thus is responsible for irregular soil moisture distribution and diffused tritium profiles as encountered in the present investigation (see specially Fig. 3 and 4).

It is to be noted that ground water recharge does not occur immediately with the commencement of the rain since the portion of the rainfall reaching the water table is dependent upon the balance, if any, left after evapotranspiration and soil moisture replenishment. During the period May '79 to May '80, vertical movement of soil moisture in the radioactive waste disposal site appears to lead to a recharge of about 19 cm. This value approximates the net recharge as tritium was injected well below surface i.e. at 70 cm depth- a zone where direct evaporation and evapotranspiration effects may not be very significant. However, it is necessary to verify this by studying the upward and downward fluctuations of soil moisture at the site by installing tensiometers at different depths. This study will throw more light on the cause of diffused tritium profiles which are characteristic of the area.

Further sudies at the radioactive waste disposal site are in progress to investigate the vertical movement of tritium tracer. Reprentative data of rainfall and evaporation for the waste disposal site are being obtained from Centro Tecnológico de Hidráulica,Departamento de Águas e Energia Elétrica (CTH/DAEE). The soil samples from various depths are being analyzed in the laboratory to obtain data on sand/silt and clay contents. These data, when used in conjunction with the data of soil moisture and tritium contents, will yield information on pattern of recharge in relation with rainfall,evaporation and soil moisture deficiency.

CONCLUSION

As a part of hydrological evaluation of radioactive waste disposal site at IPEN, it is concluded that during one year (May '79 to May '80) soil moisture movement in the unsaturated zone amounted to 70 cm leading to a recharge to ground water of about 19 cm per year. Further studies are in progress to study the unsaturated zone at the disposal site.

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REFERENCES

ALLISON,G.B. and HUGHES,M.W. - 1974 - Environmental tritium in the unsaturared zone: estimation of recharge to an unconfined aquifer,Isotope Techniques in Groundwater Hydrology 1974,vol.1,IAEA,Vienna, 57-72

BEDENKAMP,D.B.,SCHUTE,J.M.,DuTOIT,G.J. - 1974 - Recharge of a dolomite aquifer as determined from tritium profiles,Isotope Techniques in Groundwater Hydrology 1974,vol.1, IAEA,Vienna,73-95

INTERNATIONA ATOMIC ENERGY AGENCY - 1968 - Guide book on nuclear techniques in hydrology,Technical Report Series NO. 91,Vienna

SMITH,D.B.,WEARN,P.L.,RICHARDS,H.J. and ROWE,P.C. - 1970 - Water movement in the unsaturated zone of high and low permeability strata by measuring natural tritium,Isotope Hydrology,IAEA,Vienna, 73-87

SUKHIJA,B.S. and RAMA,S.N.I. - 1973 - Evaluation of groundwater recharge in semi-arid region of India using environmental tritium,Proc. Indian Acad. Sciences, vol. LXXVII, Sec. A,NO. 6, 279-292

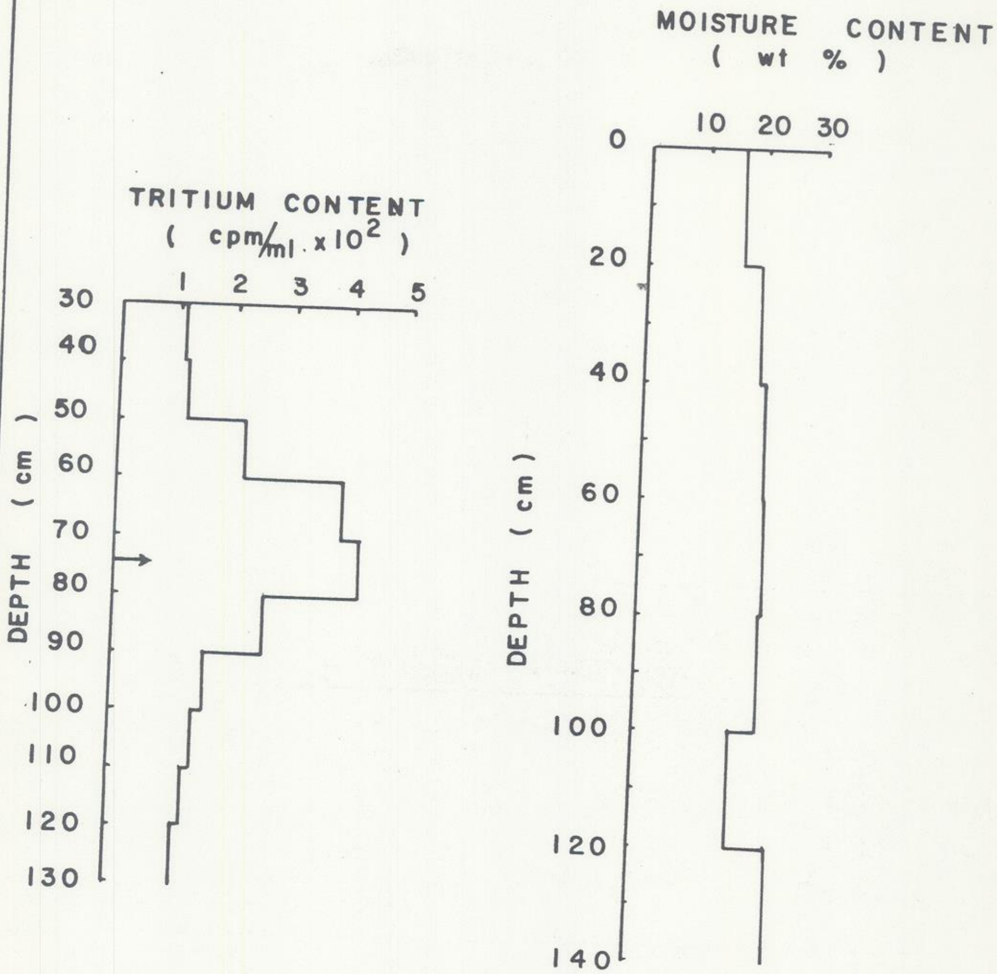
ZIMMERMAN,U.,MUNNICH,K.O.,ROETHER,W,KREUTS,W.,SCHLUBACH,K. and SIEGEL,O.- 1966 - Tracers determine movement of soil moisture and evapotranspiration, Science, vol. 152, 346-347

ZIMMERMAN,U.,MUNNICH,K.O. and ROETHER,W. - 1967 - Downward movement of soil moisture traced by means of hydrogen isotopes, Isotope Techniques in Hydrological Cycle,Geophys. Monograph NO. 11,Am. Geophys. Union,28-36

Table 1- Data of movement of soil moisture and recharge to ground water at radioactive waste disposal site at IPEN (May 879 to May '80)

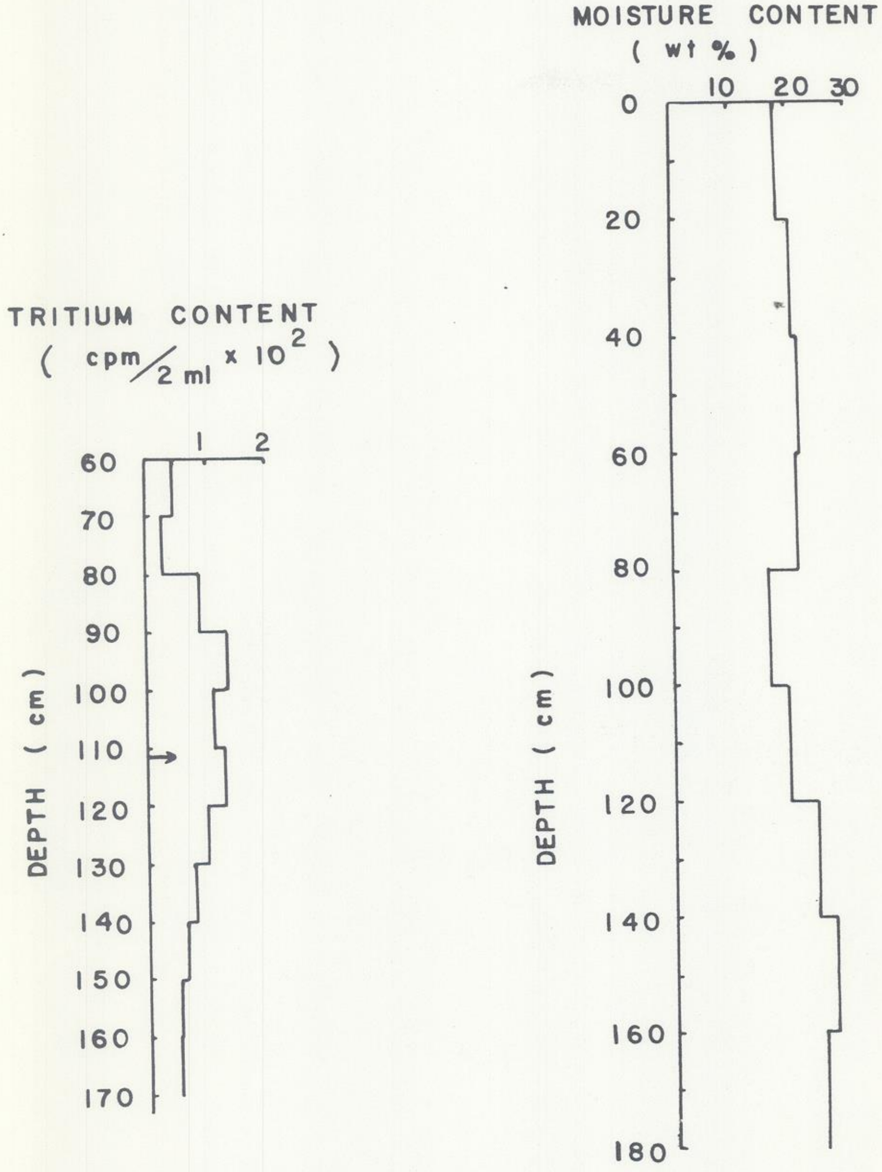
Date of injection of tritium : 24.05.79

Date of Sampling	Displacement of Tritium cm Peak	Displacement of Tritium cm Centre of Gravity (C.G.)	Soil Bulk Density g/cm^3	Moisture Content % wt (70 cm-C.G.)	Recharge cm
24 08.79	5 5	5.0	1.73	21.0	1.5
28.11.79	25 5	42.0	1.70	19.3	11.6
25.02.80	25 5	65.0	1.76	20.4	19.3
28.05.80	55 5	70.0	1.68	19.1	18.9



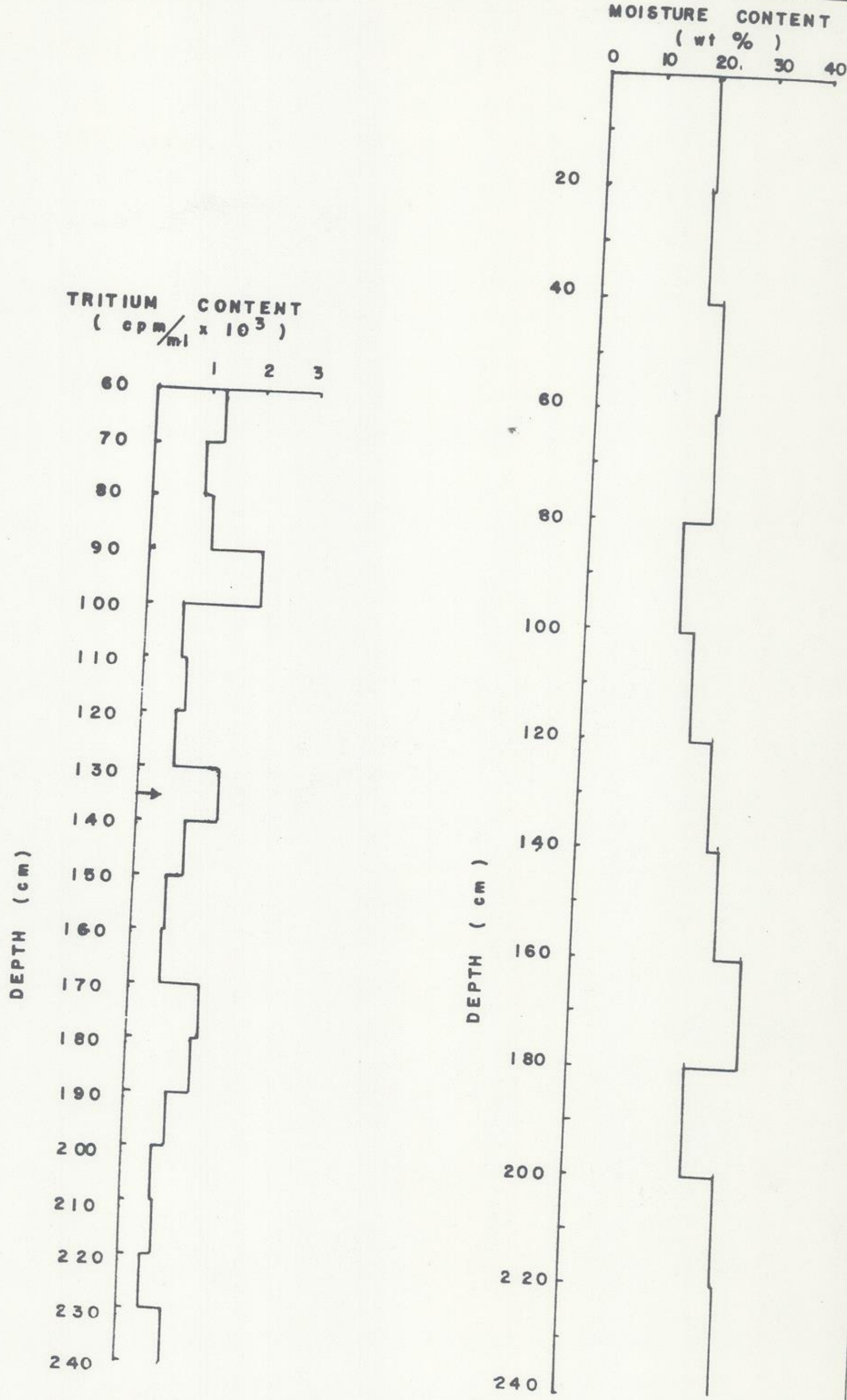
DATE OF SAMPLING : 24 AUG. 79

FIGURE 1 - TRITIUM AND MOISTURE PROFILES AFTER THREE MONTHS



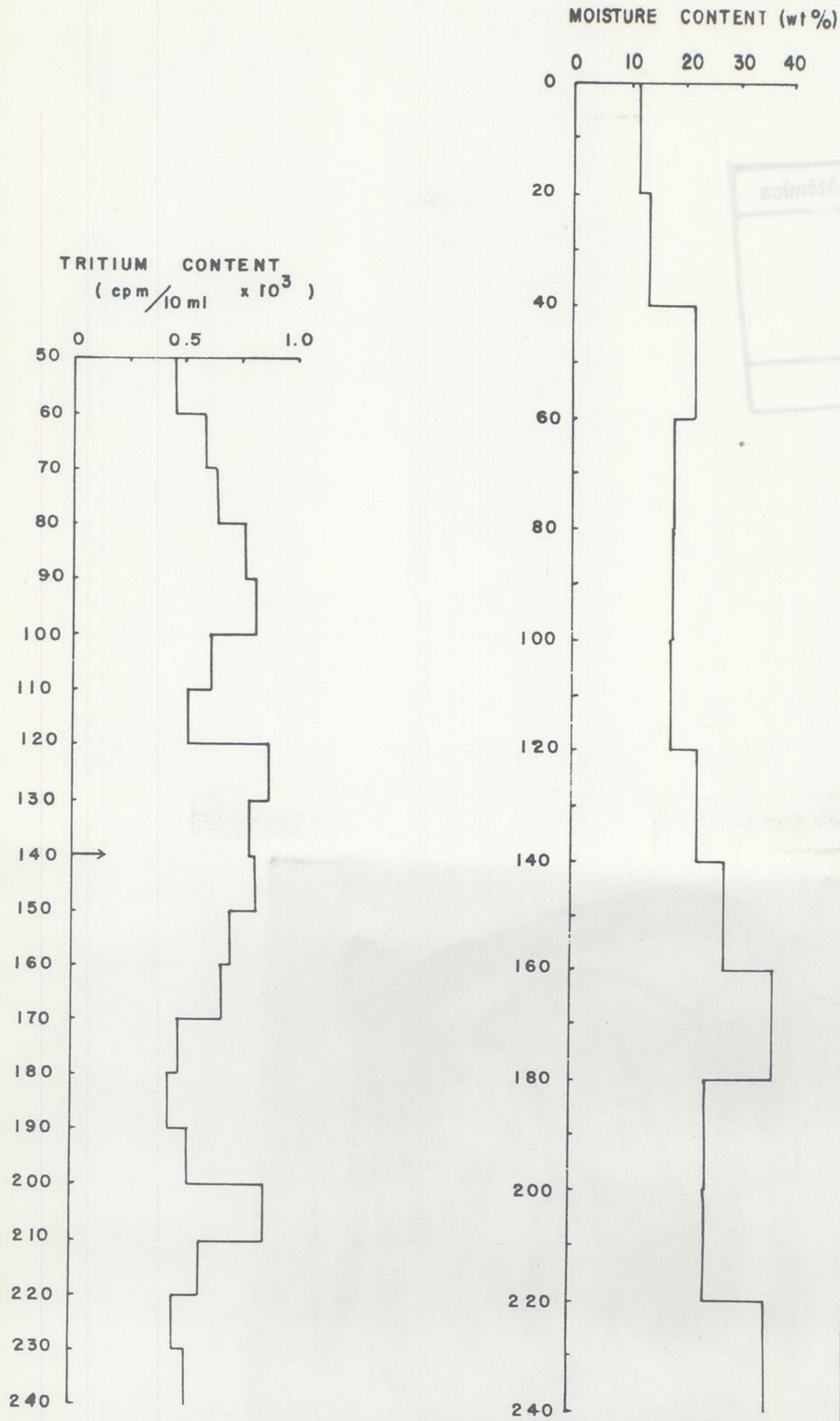
DATE OF SAMPLING : 28 NOV. 79

FIGURE 2 - TRITIUM AND MOISTURE PROFILES AFTER SIX MONTHS



DATE OF SAMPLING : 25 FEB. 80

FIGURE 3 - TRITIUM AND MOISTURE PROFILES AFTER NINE MONTHS



DATE OF SAMPLING: 28 MAY 80

FIGURE 4 - TRITIUM AND MOISTURE PROFILES AFTER TWELVE MONTHS