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Characteristics of a neutron moisture gauge with a solid state detector

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Abstract. The development of a neutron moisture gauge, using Cf^{252} as a source of fast neutrons and muscovite as a detector of thermal-neutron-induced-fission in Pu^{239} target, is reported. The laboratory and the field calibrations of the instrument reveal a linear relation between track count rate and the moisture volume fraction.

Low cost, low weight, simplicity of operation, thermal stability and elimination of electronic gadgets and power supplies are the attractive features of this instrument. The main drawback is its poor detection efficiency for thermal neutrons and the consequent unsuitability as a routine logging instrument. Its special features make it particularly suited to deep bore hole logging such as in oil exploration.

Keywords. Neutron moisture gauge; thermal neutron flux.

1. Introduction

Neutron moisture gauges, using different counting systems for detection of thermal neutrons have been in wide use for the last several years. Their advantages and limitations have been discussed by Olgaard (1965), Bell and McCulloch (1969) and Cotechia *et al* (1968) (*see* also IAEA Technical Report No. 112). Some of the constraining features of such instruments are the complexity of the equipment, its operation, thermal instability and high cost.

The neutron moisture gauge consists essentially of two parts: (i) a source of fast neutrons, and (ii) a detector of slow neutrons. The fast neutrons emitted from the source lose energy in the enclosing medium by multiple elastic scattering and are thermalised. As hydrogen is a very effective moderator, the thermal neutron flux in the neighbourhood of the source depends on the concentration of hydrogen and hence the moisture in the medium. Several variations in the nature of the source and the detector and their relative geometry are possible. A BF_3 counter or a scintillation system is generally used as a detector.

Here we report the development of a moisture gauge with a new design. It has a compact neutron source and employs a solid state detector for monitoring thermal neutron flux. Simplicity of operation, low cost and stability against large temperature variations are the features of the new instrument.

2. Design

The instrument consists of a Cf^{252} fast neutron source (Reining 1968) and a solid state fission-track detecting system. Cf^{252} (1×10^{-7} g electrodeposited as californium oxalate on the central $\frac{1}{2}''$ diameter circle of $1''$ platinum disc) forms the source of fast neutrons. The platinum disc is encased in a brass enclosure for safety in handling. The source emits $2{\cdot}3 \times 10^{5}$ neutrons/sec, with an average energy of about 2·3 MeV.

The recording system consists of two parts: (i) Pu^{239} target for capture of thermalised neutrons, and (ii) muscovite for recording the consequent fission tracks. Plutonium was deposited as a thin film of plutonium oxide on a platinum foil which was mounted on a brass disc. Two such targets were prepared. Each target was covered with a very thin mica sheet, again for ensuring safety in handling. The cover sheet was thin enough so as not to absorb the fission fragments significantly. The two plutonium targets are put face to face. In between, a thin circular sheet of muscovite of about 40 micron thickness, cut exactly to the size of brass mounts of plutonium targets with a special die is inserted. The die simultaneously marks the boundary of a circular area at the central part of the muscovite sheet, the diameter of the circle being exactly equal to that of the plutonium targets. Muscovite is chosen as the recorder of fission fragments in preference to plastics due to its comparatively high thermal stability for recording radiation damage and easy distinguishability of overetched tracks at low magnification. It has been observed that temperatures upto 200°C have no fading effect on fission damages in muscovite (Mehta and Rama 1969).

The brass discs containing plutonium targets along with the muscovite piece sandwiched between them are snuggly fitted into an aluminium mount (figure 1). This system slides into a 11 cm long brass cylinder at the base of which rests the fast neutron source. The distance between the neutron source and the detector can be changed if desired. The cylinder is closed with a watertight cap. The assembly which

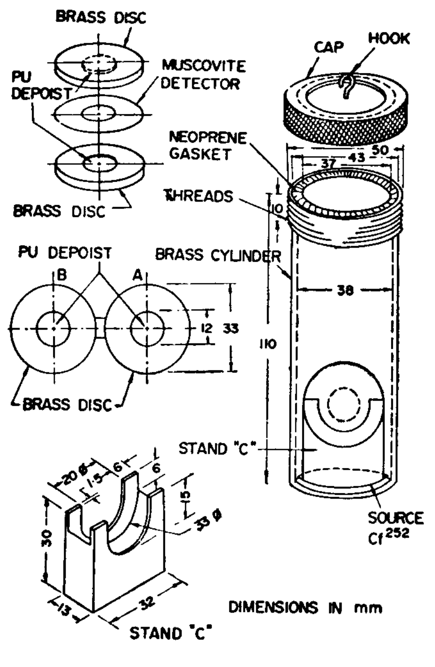

Figure 1. The neutron moisture gauge assembly

weighs only a few hundred grams can be lowered into the soil or any other medium to any desired depth, using an ordinary nylon string.

The thermal neutrons induce fission in the two Pu^{239} targets and the ensuing fission fragments are recorded on either side of the muscovite sheet. The recorded tracks in the muscovite are revealed by etching it with 48% HF at 70°C for 30 min. This treatment actually overetches the tracks. The overetched tracks can be easily counted on an optical microscope with a magnification of 300 x. Tracks on both sides of the muscovite can be counted in a single scan. The techniques of revealing the fission tracks in solid state detectors by suitable chemical etchant have been described by Price and Walker (1963) and Fleischer *et al* (1965).

The possibility of large background tracks due to fossil fission tracks in muscovite is taken care of by two fold precaution:

(i) Muscovite specimens of very low fossil track density (20-50 tracks/cm^2) are selected as detectors. Such specimens are common.

(ii) The muscovite detectors were pre-etched, i.e. before they are placed between the plutonium targets. After the experiment, the muscovite is re-etched. Thus, the fossil tracks get doubly etched and are easily distinguished from the induced tracks. The background fossil tracks are generally too few, and they become a significant fraction of the total only when moisture contents are extremely low.

All tracks in the area exposed to Pu^{239}, i.e. within the entire area marked by the die, are counted. The track count rate is plotted against the moisture volume fractions (M.V.F.), in various calibration curves.

3. Calibration

Laboratory calibration was carried out in a drum of $3' \times 3' \times 3'$. The drum was filled with sun-dried samples of sand or gravel, and observations were made by suspending the neutron probe in the centre. The observations were repeated after saturating the medium with water. In this way, two calibration points were obtained, for sand and gravel. They indicated a satisfactory slope of the curve.

The next step was to check whether there is a linear relation between the track count-rate and M.V.F. Alum was used for the medium. It is advantageous because by mixing hydrated alum ($K_2SO_4 \cdot Al_2(SO_4)_3 \cdot 24H_2O$) and anhydrous alum in different proportions, one can get desired variations in the moisture content of the medium. The results obtained are shown in figure 2, which reveals the linear behaviour of the instrument.

It was considered necessary to check the performance of the instrument in the field. But the variation of moisture content of the soil below a couple of feet from the ground was slight and the instrument could not be tested under natural conditions. The results of a semi-satisfactory experiment are however described below.

A pit of size $4' \times 4' \times 4'$ was dug in the field. The pit was filled with a homogeneous mixture of 50% soil and 50% sand, saturated with water. An access tube, 6′ long and 2·4″ diameter closed at lower end, fitted with a cap and a hook at the upper end, was inserted in the centre of the pit. The upper end of the tube was 2′ above the surface. The neutron probe was suspended at a fixed depth of 18″ from the surface. The observations were made at an interval of one week in the beginning but were later made at progressively longer intervals as M.V.F. decreased. On each day of observation, the experiment was repeated 6-10 times, each exposure lasting for 2 hr.

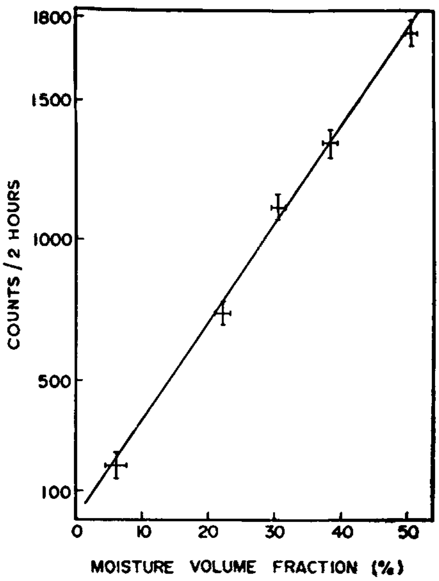

Figure 2. Laboratory calibration of the neutron moisture gauge. Medium: alum. Drum size: 15″ diam. 15″ height

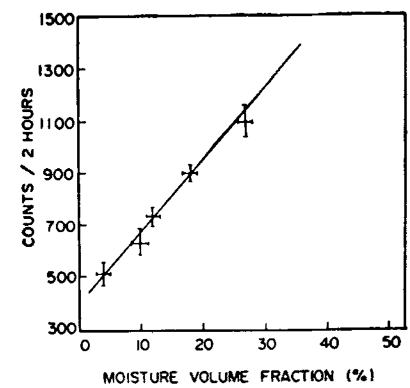

Figure 3. Field calibration of the neutron moisture gauge. Soil medium

Soil samples were taken out with a hand auger for gravimetric measurement of moisture (oven dry method). Volume of the auger hole was measured by filling it with quartzite sand. In order to get a representative value of moisture content, four auger holes were made at different points at a distance of about 1′ from the access tube. For determining the moisture content of the sample only 18″ column of the soil, 9″ above and 9″ below the neutron source, was used. It is this portion of the soil which is most effective in thermalisation of neutrons. The result of the measurements are shown in figure 3.

4. Discussion

The calibration curves show that the instrument exhibits a linear relation between the track count rate and M.V.F. as expected. The slope of the curve is satisfactory for distinguishing M.V.F. variations of about 5%, in a two hour exposure. The number of tracks recorded at moisture content of about 20% during 2 hr is about 1000, which is very much smaller than the number of counts in moisture gauges using other detectors. This puts serious limitations on the instrument, i.e. it cannot be used as a logging instrument unless a very strong neutron source with its attendant cumbersome handling, is used. In fact, an earlier attempt to make a logging camera (Rama 1966) with moving plastic film detector had to be abandoned due to this reason. Further, the instrument does not give instant results as the etching and counting has to be done in the laboratory. These disadvantages are serious enough to eliminate the use of this instrument in applications where neutron moisture gauges are generally used. But its special advantages, i.e. simple assembly, absence of need for power supply and electronic circuitry, excellent thermal stability, low cost and low weight make it especially suitable in some other problems. For example, it can be used in oil exploration, as the probe can be easily lowered in deep bore holes and the high temperature at large depths have no effect on its performance. It can also be used in moisture measurements where duration of the measurement (about 2 hr required by the instrument) is not a great handicap.

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References

Bell J P and McCulloch J S G 1969 *J. Hydrol* **7** 415

Cotechia V, Inzabhi A, Pirastru E and Richheva R 1968 *Water Resour. Res.* **4** (No. 5) 1023

Fleischer R L, Price P B, and Walker R M 1965 Solid State Track Detectors, Applications to Nuclear Science and Geophysics *Annu. Rev. Nucl. Sci.* **15**

International Atomic Energy Agency, Vienna 1970 Neutron Moisture Gauges, Technical Reports Series No. 112

Mehta P P and Rama 1969 *Earth Planet. Sci. Lett.* **7** 82

Nichols Jere P 1968 *Nucl. Appl.* **4** 382

Olgaard P L 1965 Danish Atomic Energy Commission, Riso Report 97

Price P B and Walker R M 1963 *J. Geophys. Res.* **68** 4847

Rama 1966 *Neutron moisture logging camera*, paper presented at the first meeting of the Working Group of Nuclear Techniques in Hydrology, I A E A Vienna