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FINAL REPORT

Assay of the Martian Regolith with Neutrons

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Final Report
Amparo Corporation
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In this Planetary Instrument Definition & Development Program, experimental and computational modeling are to be combined to predict and measure neutron leakage flux similar to that which would be emitted from a planetary surface. The general purpose of this study is to see how well Monte Carlo calculations can reproduce the results of experiments designed to determine the water content in a planet's regolith. The emphasis of the program in this second year was placed on analyzing of the experiments done in the first year.

In the first year experiments were done at the University of New Mexico engineering department in a large room using their PuBe neutron source and several sets of neutron counters. The set of detectors for which most of the experimental-computational comparisons have been made consisted of a pair of ^{3}He proportional counters, one of which was covered with a thin layer of cadmium. The difference in counting rates of these two detectors can be related to the water content of the soil.

The initial analyses of the experiments was done for spectra in which the soil was "dry" (near 1% by weight). The comparison of experimental and computational results was disappointing and considerable effort was made to understand why this difference existed. Figures 1 and 2 show the ratio of experimental to calculated results for several of the different arrangements as a function of theoretical counting rates. The counting rates increase either as the water content is increased or polyethylene sheets are inserted to simulate layers of water. Figure 1 is for the bare counter, and Figure 2 is for the cadmium covered counter. The points in Figure 1 for low counting rates are considerably higher than an ideal ratio of 1, indicating that there are more low energy neutrons than can be accounted for in the calculations. For the higher counting rates the agreement is better and settles to a value of about 0.8. In Figure 2, where the cadmium cover cuts out all neutrons below about 0.4 eV, the agreement is much better for the low counting rates.

With these results we searched for possible causes of the excess low energy neutrons.

SOIL COMPOSITION

We have investigated how the soil composition might effect the comparison of the experimental results with the Monte Carlo calculations in two ways: A) By using two different laboratories to analyze the soil and B) by an analytical investigation of how sensitive the epithermal amplitude is to changes in the elemental composition.

A) Soil samples were analyzed separately by LANL and Huffman Laboratory by x-ray fluorescence. In the first analysis of Huffman the sum of weight percents for the individual elements added to 110% and several discussions with them resulted in a change in their standard calibration sample. Their second analysis and that of LANL are listed as weight percent in the following table and the agreement is quite satisfactory; "lost on ignition", loi, is assumed to be water that escapes when the sample is heated.

element	Huffman	LANL
Al_2O_3	11.37	12.02
CaO	1.21	1.09
Fe_2O_3	2.80	2.42
MgO	0.41	0.40
MnO_2	0.08	0.07
P_2O_5	0.04	0.04
K_2O	3.47	3.65
SiO_2	75.3	75.1
Na_2O	3.57	3.44
TiO_2	0.25	0.25
loi	1.59	2.10

These analyses show that errors in the composition of the soil used in the experiment are probably negligible.

B) The relative sensitivity of the epithermal part of the neutron spectrum to different elements can be written analytically. We start with the epithermal amplitude of an equilibrium spectrum:

1) $$A \propto \frac{1}{\Sigma_i n_i \sigma_i \xi_i}$$

where n is the atom density, σ is the scattering cross section, ξ is a down scattering parameter, and i designates the element. Partial differentiation gives

2) $$\frac{\Delta A}{A} = - \frac{\Delta n_i}{n_i} \left(\frac{n_i \sigma_i \xi_i}{\Sigma_i n_i \sigma_i \xi_i} \right)$$

The following table shows the fractional change in the epithermal amplitude due to an error of 10% in the assay of the elements of the below table.

Element	Fractional Change
Si	0.0036
Ti	0.000013
Al	0.000045
Fe	0.00016
Mn	0.0000002
Mg	0.000044
Ca	0.00005
Na	0.0005g
V	0.0001g
P	0.000002
O	0.027
H	0.067

The point of this table is to show that the epithermal portion of the spectrum is mainly sensitive to hydrogen. A 10% change in water content is almost 3 times more effective than a 10% change in the oxygen concentration even though there are about 20 times more oxygen atoms as there are hydrogen atoms. The 0.5 weight percent difference in the two measured values of water can cause an almost 17% difference in the epithermal amplitude. This result just reinforces the power of neutron measurements in searching for water. MCNP was run for "dry" soil using the LANL and Huffman values for water content. Counting rate as a function of neutron energy is shown in Figure 3 for both calculations. It is clear that knowing the initial water content is important and that the 27% difference in the LANL and Huffman water measurements is larger than we would like.

INITIAL ENERGY SPECTRUM

We investigated the effect that a difference in the energy spectrum of the initial neutron source would have on the leakage flux of out experiment. Five calculations were made with a PuBe source, a PuBe source shifted to lower energies, a monoenergetic 3 MeV source, a monoenergetic 6 MeV source, and a 252Cf spontaneous fission source. Figure 4 shows the relative counting rates as a function of neutron energy for the 6 MeV, 3 MeV, and 252 Cf sources. Since the counting rates as a function of neutron energy have about the same shape, even though the magnitudes vary by factors of about 10, this figure shows that high energy neutrons escape our experiment.

Figure 5 shows the relative shape of two neutron source spectra that could be used in the experiment along with a LAHET calculation that shows a calculated neutron spectrum produced in a Martian type regolith. The latter curve represents neutrons, produced by cosmic-ray interactions with the soil components that have been born with or scattered to energies below 20 MeV.

ROOM RETURN

Although the experimental room at UNM is quite large, we remodeled our experiment so as to include approximate wall, ceiling, and floor composition and dimensions. These calculations showed that the source of the extra low energy neutrons could be moderation and back scattering from the room. Several other modifications to these calculations were done in order to optimize the next experiment and eliminate as much back scattering as possible. These calculations show that a ^{252}Cf neutron source is better than the PuBe source and that the addition of soil under the source improves the counting rate by about a factor of 10 for either source.

Similar calculations were made for the LANL trailer that we plan to use for the next experiment, and to the extent the model represents the trailer there is very little back scatter.

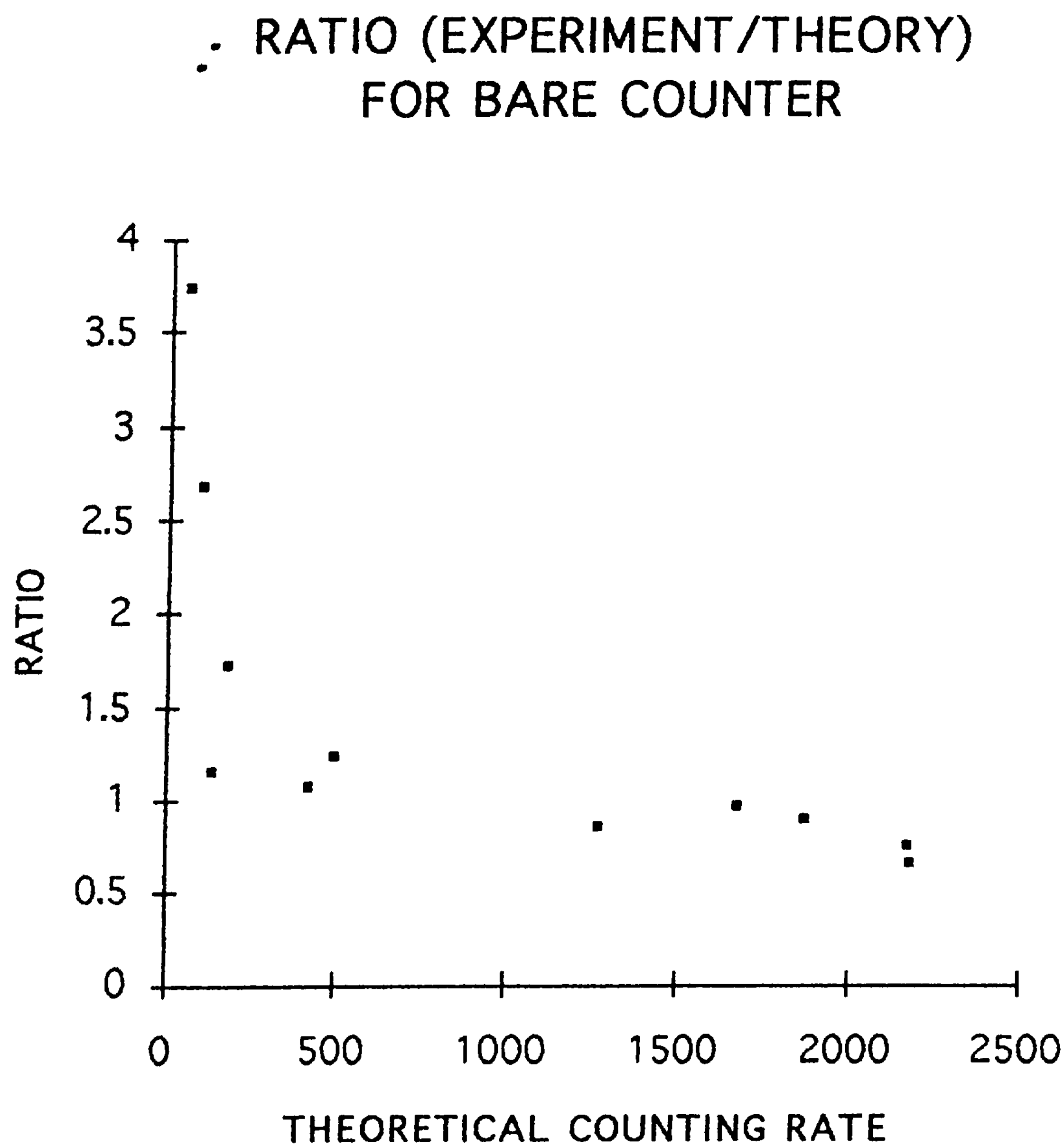
We presented a poster at the June NASA PIDDP workshop held in Pasadena and have prepared an abstract for the November In Situ Resource Utilization Technical Interchange Meeting II in Houston.

Although calculations show that use of a ^{238}U ion chamber to measure fast neutron flux for our experiment or on the martian surface would be marginal, we have acquired a 4" diameter chamber for use in the next experiment.

We have also obtained a pair of silicon counters with ^{6}LiF deposits and even though these devices are also rather inefficient, they provide much more definitive information, and we will use these also in the next experiment. This counter is the subject of the abstract for the In Situ Resource Utilization Technical Interchange meeting.

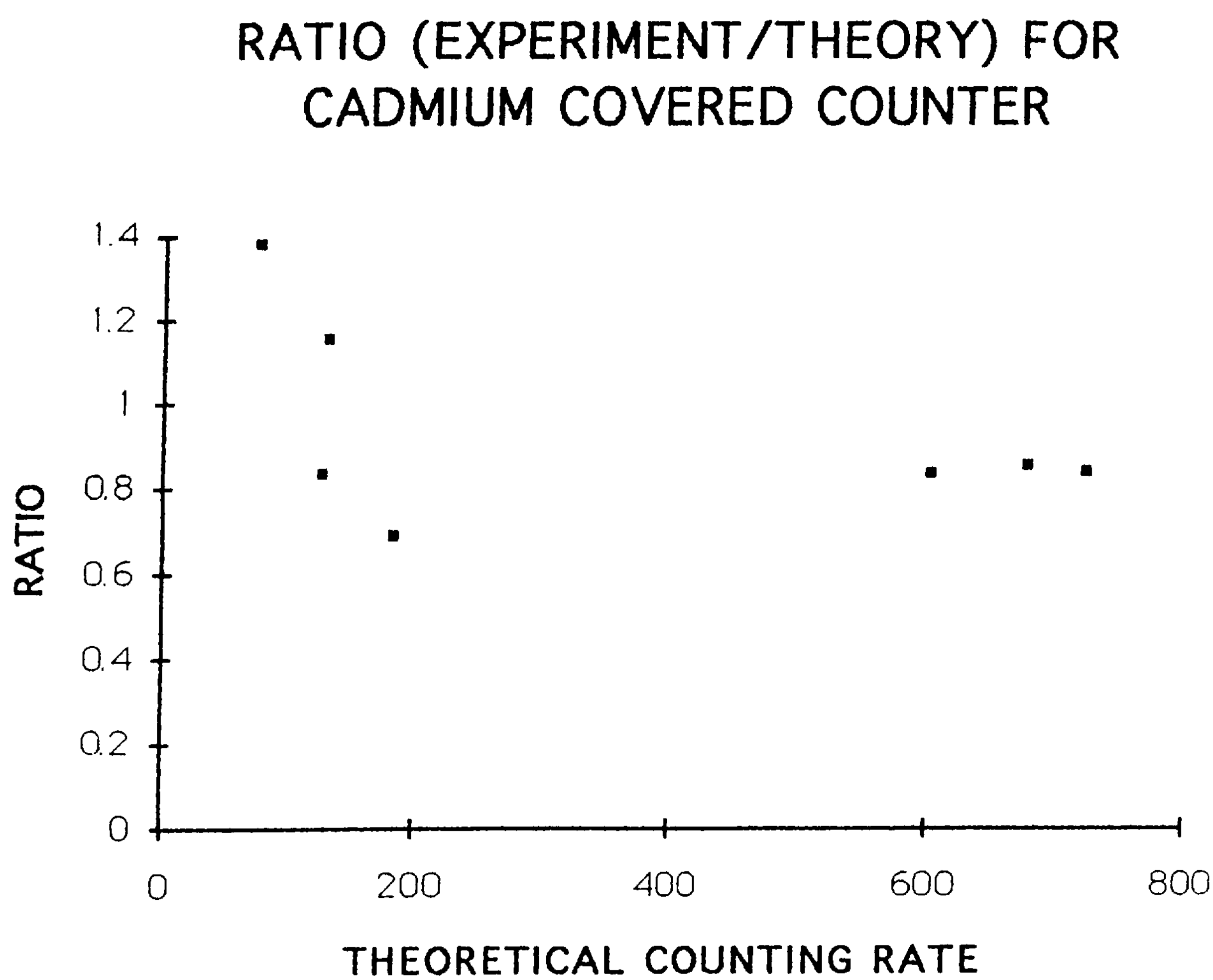
We have done the paper work necessary to use the LANL sources and trailer for the next experiment.

FIGURE 1



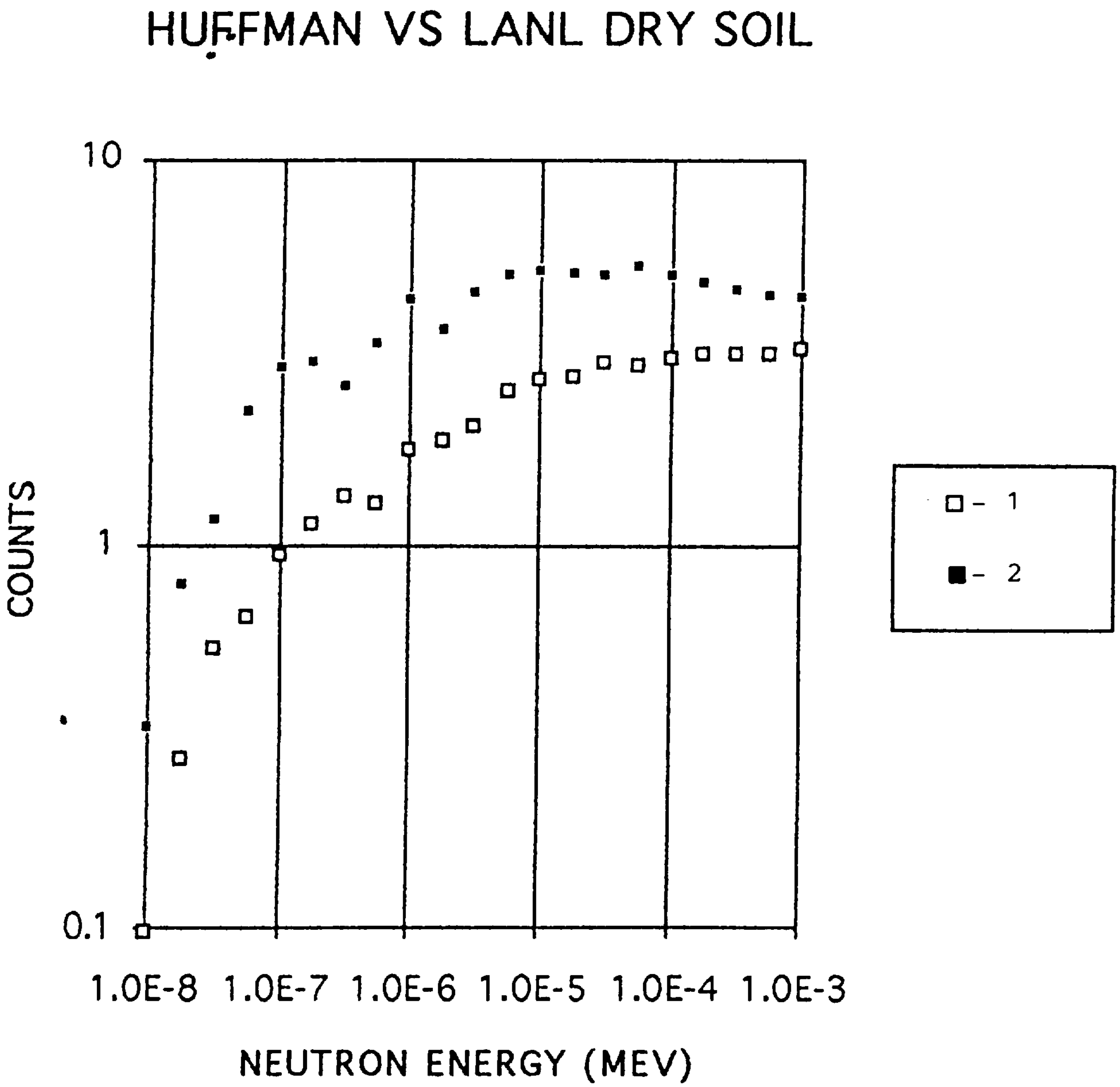
A plot of the ratio of the experimental counting rate divided by the computed counting rate for several experimental conditions ranging from dry soil to 1.27 cm of polyethylene under the counter. This plot is for the 2" diameter by 8" long ^{3}He proportional counter. The points at low counting rates are high and could be caused by either neutron room return and/or more water in the soil sample than estimated.

FIGURE 2



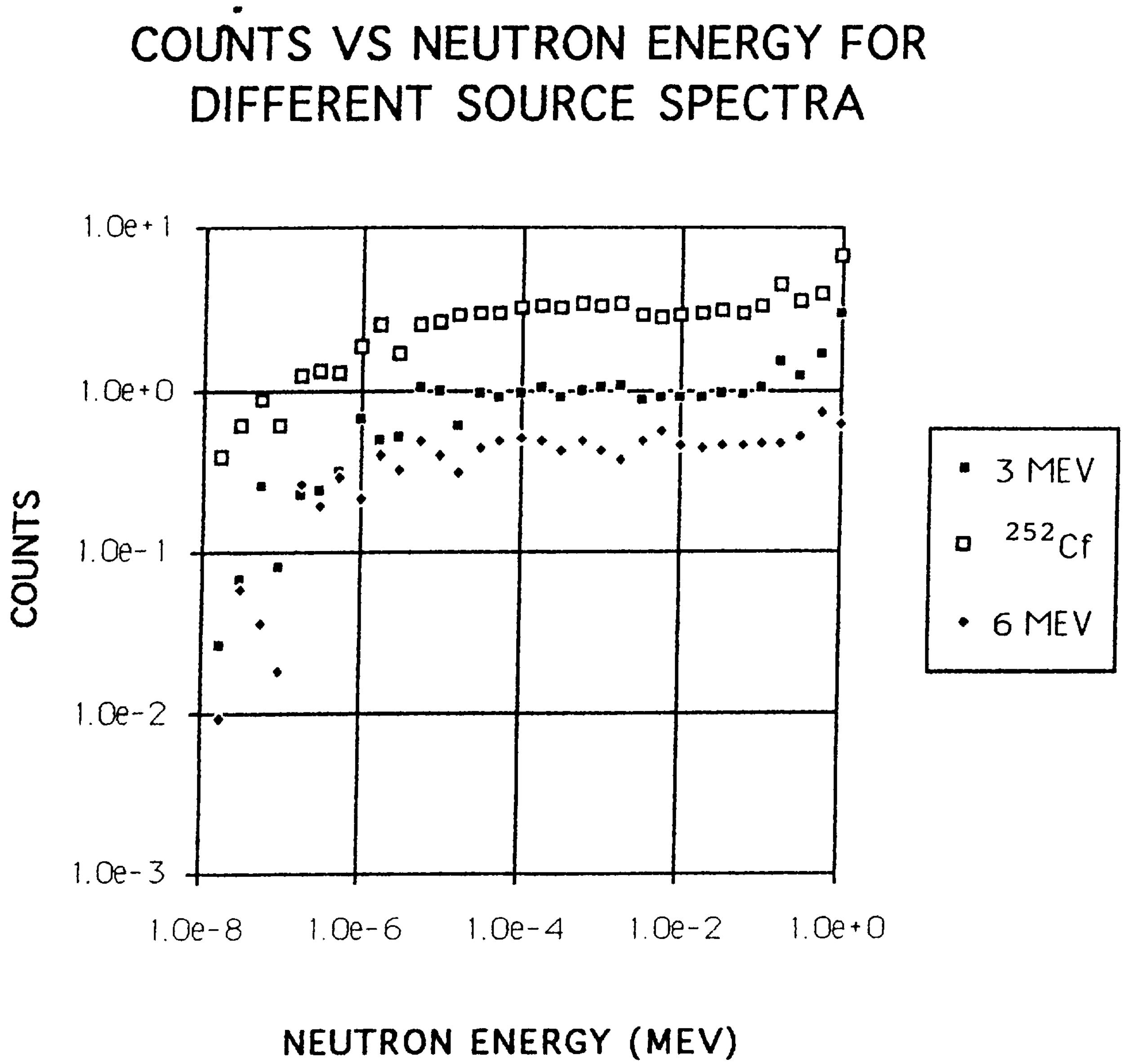
This is the sample plot as Figure 1, except the counter was covered by a thin sheet of cadmium. The low counting rate points are closer to a ratio of one than those in Figure 1 indicating that the extra neutrons are mostly below 0.4 eV.

FIGURE 3



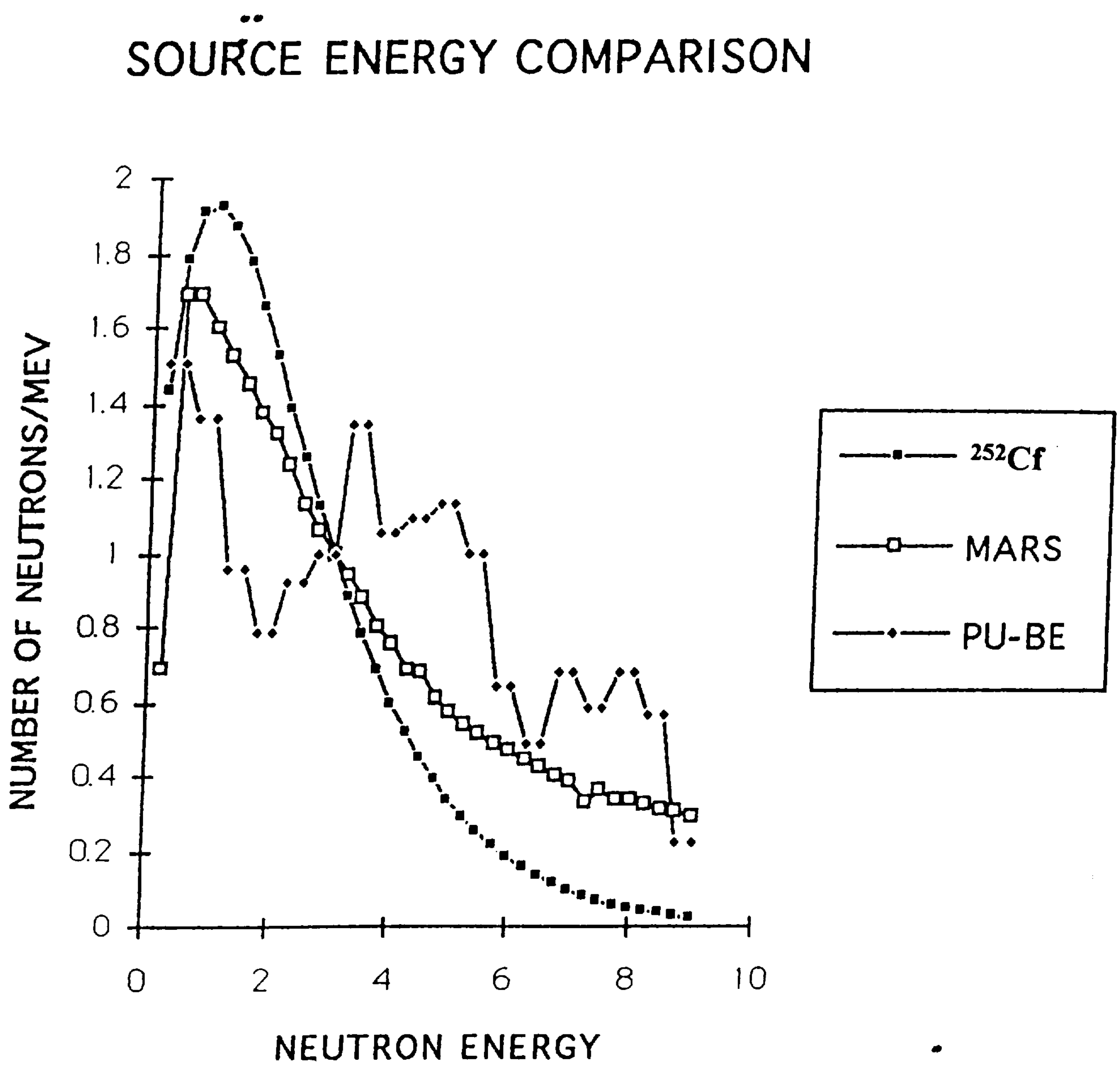
A plot of counting rates for "dry soil" versus neutron energy. The two plots correspond to: 1 - soil with the average of two measurements of water content and to: 2 - soil with an additional amount of water equal to the difference between the measurements.

FIGURE 4



A plot of relative counting rates as a function of neutron energy for three different initial neutron spectra, monoenergetic neutrons of 3 and 6 MeV and a ^{252}Cf spontaneous fission spectrum.

FIGURE 5



A plot of the energy spectrum of two possible neutron sources, PuBe and ^{252}Cf, along with a computed spectrum of neutrons produced by cosmic rays in the Martian regolith.

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13. ABSTRACT *(Maximum 200 words)*

The purpose of the research is to combine experiments and Monte Carlo transport of neutrons through volume of soil in an attempt to model neutron leakage from planetary surfaces. Emphasis is given to the change of neutron spectra as a function of water content and location. During the first stage of effort, two experiments were conducted in which leakage of neutrons from a Pu-Be source through about 30 g/cm^2 of soil were measured with several counters. A Monte Carlo code, MCNP, has been used to model many of the 100 individual runs of the experiment. Hydrogen is the element that has the most dramatic effect on the neutron spectrum and its effect on the neutron spectrum is almost the same whether it is in the form of water or polyethylene. In order to simulate various water configurations, sheets of polyethylene have been used between layers of soil as well as water in several concentrations up to 18%. Comparison of experimental results to theoretical predictions made with the MCNP code were disappointing for low concentrations of water. We have made extensive calculations to see if room return could be the cause of the discrepancies. Water concentrations of the "dry" soil were meaured by two different laboratories and differed only by 0.5%. We have made calculations to optimize the next experiment and are invstigating other methods of determining the water content of "dry" soil.

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