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Conf-770720--1

PREPRINT UCRL- 78929

Lawrence Livermore Laboratory

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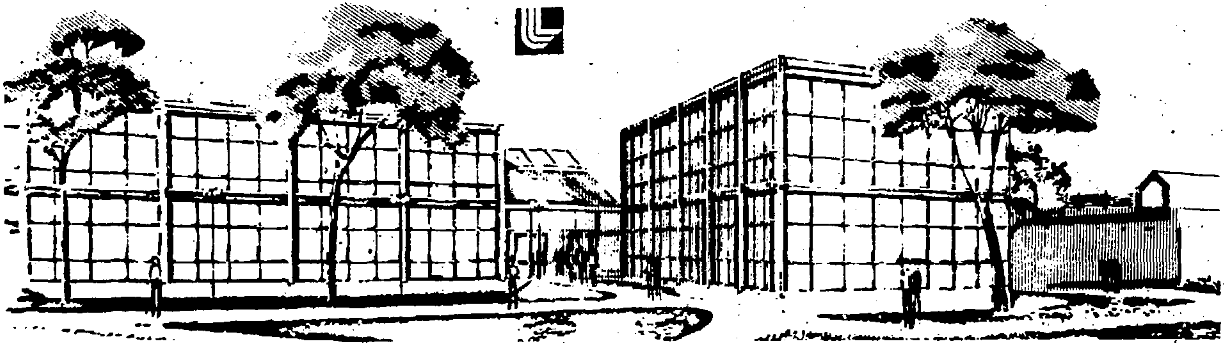
June 27, 1977

This paper was prepared for submittal to the Twenty-second Annual Meeting of the Health Physics Society in Atlanta, Georgia, July 3 to 8, 1977.



MASTER

A MODIFIED A-B REMMETER WITH IMPROVED DIRECTIONAL DEPENDENCE AND THERMAL NEUTRON SENSITIVITY.*

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Abstract

We have modified the Andersson-Braun remmeter to improve the directional dependence of the instrument to thermal and fast neutrons and increase its sensitivity to thermal neutrons. The modifications consist of partially rounding the end of the instrument, moving the BF_3 tube forward by 1/2 in., increasing the size of the holes in the boron-loaded polyethylene sleeve, replacing one of the boron-loaded end plugs with a polyethylene plug, changing the location of the other end plug, and adding a small disk of cadmium over the hole where the BF_3 tube enters the moderator.

The cost of making these modifications to the Lawrence Livermore Laboratory Andersson-Braun remmeters is ~ \$50.00 each.

These modifications to the instrument increase the thermal neutron sensitivity by a factor of ~3 when exposed at the side and a factor of ~9 at the end opposite the instrument packet. The high thermal sensitivity at the instrument packet end (a factor of ~17) is eliminated, and the directional dependence to both thermal and fast neutrons is reduced to ±10% (except at the

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*Work performed under the auspices of the U.S. Energy Research and Development Administration, under contract No. W-7405-ENG-48.

instrument packet end). The sensitivity of the instrument to fast neutrons is increased by ~15%.

The sensitivity of the modified remmeter to intermediate-neutron energy is increased, and is similar to that of the 9-in. sphere. We compare the readings of the modified instrument, the Andersson-Braun remmeter, and the 9-in.-sphere remmeter with numerous spectra encountered in field application.

Introduction

A neutron remmeter has an energy dependence similar to the dose-equivalent curve. These instruments have count rates that are essentially independent of neutron energy over a large energy region (thermal to 7.0 MeV). Three of these remmeter instruments are the Andersson-Braun (1964) remmeter (A-B), the 10-in. sphere (Hankins, 1962a,b) and the modified 9-in. sphere (Hankins, 1967, 1968).

The A-B remmeter has a cylindrical moderator which has a count rate that varies with the angle of the incident neutrons. Figure 1 shows the results obtained from an A-B type remmeter at various neutron energies (Hankins, 1974). The instrument was rotated slowly while being exposed, and the count rate as a function of angle was recorded on a multichannel analyser. The count rate of the instrument drops (except for thermal neutrons, see below) when the instrument packet is located between the moderator and the source. This is caused by absorption or scattering of neutrons by the instrument packet. The count rate also drops when the instrument is positioned with the corner of the moderator between the source and the BF_3 tube (which is located at the center of the moderator). This drop in count rate is caused by the increased thickness of the moderator between the BF_3 tube and the source.

The directional dependence of the instrument shown in Fig. 1 is saw-toothed in shape with the magnitude becoming larger at the lower neutron energies. Also, at the lower energies there is an increase in the count rate at 90° (with the instrument packet located between the source and probe) which is believed to be caused by thermal neutrons coming from the target assembly or being produced in the instrument packet.

The directional dependence of the instrument to thermal neutrons is strongly affected by the void in the moderator in which the cable and connector for the BF_3 tube are located (see Fig. 2). When the instrument is positioned with this hole oriented toward the thermal neutron beam, the count rate of the instrument jumps by a factor of 17 when compared to the count rate at the side of the instrument.

The sensitivity of the instrument to thermal neutrons impinging on the side of the instrument is low by about a factor of three (Larsen et al., 1971; Thompson et al., 1971; Hankins et al., 1974, 1975). For most survey work, where the thermal component of the dose is small, this is no problem. However, at reactors and especially at thermal columns, a low reading by as much as a factor of 3 or more could be obtained if the instrument is exposed at the end (90° in Fig. 1 is referred to as the "end" in this report).

This low thermal neutron sensitivity of the instrument probably resulted when the designers used an isotropic neutron flux to determine the thermal neutron sensitivity. Thermal neutrons reach the BF_3 tube by streaming down the cable and associated void, and would have caused a high count rate. When averaged with the low count rate obtained around the remainder of the moderator, the net count rate was probably quite accurate.

This study was made to determine what modification to the A-B remmeters would be necessary to improve the directional dependence (especially for thermal neutrons) and to increase the sensitivity of the remmeter to thermal neutrons. If possible, these modifications should be easy to perform and inexpensive.

Procedure

To improve the directional dependence to fast neutrons, the corners of the moderator at one end were cut off similar to the design of the new Studsvik remmeter. This was done by placing the moderator in a lathe and rounding the end at a radius of 4-13/16 inches. The center of the radius was located 4-1/2 inches from the end of the instrument (see Fig. 2).

It was desirable to modify the instrument without requiring that new boron-loaded polyethylene be produced. Therefore, two additional boron-loaded polyethylene sleeves and end pieces of the standard loading were obtained. The hole sizes in the sleeves and end pieces were increased to 1/2 and 5/8 in. diameter. We also made additional end pieces and one sleeve of normal polyethylene.

Later it was found that to obtain the required increase in thermal neutron sensitivity at the end of the instrument, the BF_3 tube had to be moved toward the end of the moderator. A series of discs and a modified center polyethylene plug were prepared which allowed the tube to be moved in 1/4-in. steps.

Obtaining the right combination of moving the tube forward and size of holes in the borated polyethylene proved to be difficult. Approximately 40 possible combinations were tried, with curves being drawn to evaluate trends, before we obtained the right combination.

The modifications to the moderator proved to be fairly simple, and are shown in Fig. 2. The changes are as follows:

1. Increase the size of the holes in the boron-loaded polyethylene sleeve (only) to 5/8-in. diameter.

2. Round the corners of the moderator as shown in the drawing. The feet and handle may have to be repositioned.

3. Remove boron-loaded polyethylene disk and replace with disc from other end (see step 5).

4. Drill hole in polyethylene insert 1/2 in. deeper to allow BF_3 tube to be moved forward 1/2 in.

5. Replace boron-loaded disk (see step 3) with polyethylene disk having the same dimensions.

See Note.

6. Tape a 3/4-in. diameter disc of 30-mil cadmium over the old cable hole.

7. Drill 5/8-in. diameter hole for cable at location shown in diagram.

8. Reverse position of plug to hold BF_3 tube in place, and cut groove in plug for cable.

9. Remove connector and connect cable directly to BF_3 tube. Use silastic (or equivalent material) in end cap to hold cable in place.

NOTE: Steps six through nine will depend on the design of the instrument. The polyethylene disk at the end of the instrument is used to hold the instrument packet to the moderator in the LLL-designed instruments, and may not be present in other instruments. If the disk is not present, the cable should be bent to the side and a cadmium disk (~2-in. diameter) taped over the hole to prevent thermal neutron leakage through and around the cable to the BF_3 tube. The polyethylene plug should still be reversed (step 8) to hold the BF_3 tube in place, or possibly a new plug will be required.

The cost of making these modifications to the existing A-B remmeter at current hourly charges was estimated to be $50.00 each. These modifications result in an increase in the number of neutron counts per mrem by ~15%.

Results

The directional dependence of the modified instrument is shown in Fig. 3. When exposed at angles from 180° to 360°, the directional dependence to PuBe neutrons is very flat, and for thermal neutrons is within 10%. The directional dependence to thermal neutrons could possibly be improved, but the modifications would not be as simple as those described above and would not result in a significant improvement. The drop in count rate caused by the instrument packet still exists, but the high count rate to thermal neutrons at 90° has been eliminated. The thermal neutron sensitivity of the instrument when exposed to the side has been increased by about a factor of three, and is now equal to the fast neutron sensitivity of the instrument.

Increasing the thermal neutron sensitivity of the instrument also increases its sensitivity to intermediate energy neutrons. Measurements made at the 2-, 25- and 144-keV beams at NBS indicate that the modified A-B remmeter has an energy dependence similar to that of the 9-in.-sphere remmeter. To determine what effect this would have on the readings obtained with the modified A-B remmeter, a comparison study was made at 46 field locations. Three survey instruments were used in the study, and included the A-B remmeter, the modified A-B remmeter, and the 9-in.-sphere remmeter. At each location two readings were made with the A-B and modified A-B remmeters: (1) with the side and (2) with the end oriented toward the source. Only one reading was obtained with the 9-in.-sphere remmeter since it has essentially no directional dependence.

This proved to be an interesting study of laboratory versus field results. When exposed to PuBe or ^{252}Cf sources, the directional dependence of the modified A-B remmeter (as shown in Fig. 3) is very good. In the field application we found that the side readings were sometimes lower than the end readings. This occurred when the source of neutrons was through a wall or floor and the neutrons were essentially a plane source. When the side of the instrument is exposed to the plane source, the decrease in sensitivity at the instrument pocket causes the readings to be lower than end readings. This effect is not found when the readings are obtained from a point or near point source or when the neutrons are impinging on the instrument isotropically (for example, readings made inside a source storage vault).

The A-B remmeter also gave low side readings when exposed to plane sources, but not as consistently as the modified A-B. It is believed that thermal and low-energy neutron leakage to the BF_3 tube compensates for the low readings at some exposure conditions.

The conclusion from this part of the field study is that the modified A-B remmeter should be exposed with the end toward the source, and if variations in readings are obtained when the instrument is exposed at different angles, the highest reading is the correct reading.

The readings of the instruments were essentially the same at all survey locations except those from the LPTR reactor. At the reactor, the modified A-B and 9-in.-sphere gave higher readings than the A-B remmeter, averaging 32 and 37% respectively, and the readings of the modified A-B and 9-in.-sphere were essentially the same. The exact values are difficult to determine because leakage neutrons were from a broad source, and the A-B remmeters gave different readings depending on their orientation. It is not clear whether the side or end readings should be used to compare the instrument readings.

The conclusions from this part of the study are that the three remmeters will give the same dose rate reading at all locations throughout the Lawrence Livermore Laboratory, except at the reactor where the modified A-B and 9-in.-sphere would give a reading higher than the A-B remmeter. The extent of the higher reading would depend on the orientation of the various instruments.

but would be around 35%. Since the energy dependence of the modified A-B and 9-in.-sphere is correct for thermal neutrons but is high across the entire intermediate-energy region, their readings to the reactor leakage spectrum (which is ∿1/E) are known to be high. The readings of the A-B remmeter at the reactor are probably high in spite of its low sensitivity to thermal- and near-thermal-energy neutrons. The overresponse to neutrons around 10 keV probably overcompensates for the low sensitivity to thermal neutrons.

We also obtained data with neutron sources and D_2O, H_2O and polyethylene moderators in our irradiation facility. The results with 15- and 25-cm D_2O confirm the observations made in the field with highly moderated spectra (LPTR reactor). The moderation resulting from 25-cm of H_2O or 10-cm of polyethylene is small compared to that from 25-cm of D_2O. Consequently, significant shielding of H_2O or equivalent is necessary to give a spectrum that would cause the 9-in.-sphere or modified A-B to overrespond when compared to the A-B remmeter. Our field results contained data obtained through several feet of concrete, and no differences in the three remmeter instrument readings were observed.

Conclusions

The A-B remmeter has been modified to improve the directional dependence of the instrument to thermal and fast neutrons, and to increase its sensitivity to thermal neutrons by a factor of ∿3 when exposed at the side. The high thermal sensitivity at the instrument packet end (a factor of ∿17) is eliminated, and the directional dependance to both thermal and fast neutrons is reduced to ±10% (except at the instrument packet end). The sensitivity of the instrument to fast-energy neutrons is increased by ∿15%.

The sensitivity of the modified remmeter to intermediate-energy neutrons is increased, and is similar to that of the 9-in.-sphere. We compared the readings of the modified A-B remmeter, the A-B remmeter, and the 9-in.-sphere remmeter to numerous spectra encountered in field application. All three instruments gave similar readings from greatly varying spectra except for the reactor leakage spectra where the 9-in.-sphere and modified A-B instruments were higher than the A-B remmeter by ~35%.

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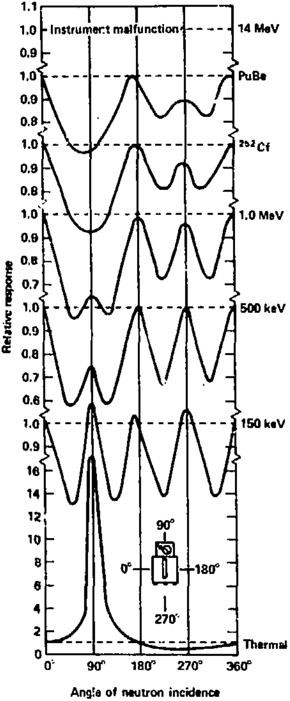
Figure Captions

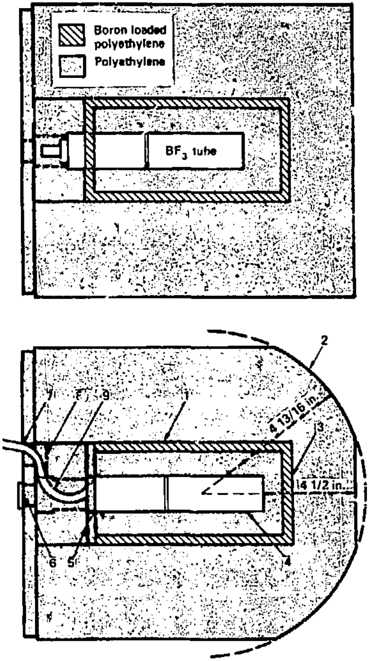
Fig. 1. Directional response curves for the A-B remmeter when rotated while in normal, hand-held position.

Fig. 2. Schematic of the moderator for the A-B remmeter and of the modifi d A-B remmeter.

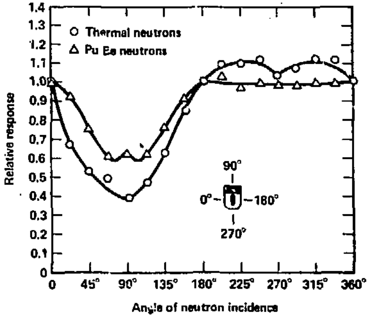
Fig. 3. Directional response curves for the modified A-B remmeter in the normal, hand-held position.



Hankins Fig. 1



Hankins Fig. 2



Hankins Fig. 3