A DISCUSSION OF THE FISSION NEUTRON SPECTRUM

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Data on the energy spectrum of fission neutrons have been published by Zinn and Szilard[1] and by von Halban Jr., Joliot, and Kowarski[2].

1. W. H. Zinn and L. Szilard, Phys. Rev. 56, 619, (1939)

2. H. von Halban, Jr., F. Joliot, and L. Kowarski, Nature 143, 939, (1939)

The results of Zinn and Szilard were of an exploratory nature and so many corrections would be required to find the true spectrum that they cannot be said to disagree with any of the later results. von Halban, Joliot, and Kowarski measured recoils in oxygen of such energy that the presence of neutrons up to 11 MV in energy was inferred. Presumably the numbers of neutrons at that energy were relatively very small. The result is suggestive, but it cannot be used directly in any final spectrum.

The spectrum has been measured directly at Rice[3] and at Liverpool[4], and these two sets of results can be compared and used to

3. W. E. Bennett and H. T. Richards, CF Report No. 325

4. Rotblat, Pickavance, Rowlands, Hall and Chadwick, B Report No. 86

estimate a spectrum for use until better measurements are obtained. Preliminary measurements have been made at Stanford[5], and these disagree

5. F. Bloch and H. Staub, CFReport No. 525

markedly with the other two sets of data. Indirect measurements include values of the mean energy of fission neutrons obtained from absorption measurements in a water tank at Liverpool and Chicago.

A criticism that applies to all of the neutron measurements is that large amounts of alloy have been used as a source. The smallest amount was a little over a kilogram (Rice). Since the average path in alloy of the emerging neutron was of the order of 2.5cm and the inelastic scattering cross-section is about $2.5 \times 10^{-24} cm^2$, the spectrum would include 26% of neutrons whose energies had been modified by inelastic scattering in the alloy. Compared with this, other sources of error in the Rice results were not serious. In measuring cloud chamber tracks, there may be a tendency on the part of the experimentor to relax the criterion that both ends of the track must be sharp when measuring a long track. This possibility was guarded against during the measurements. The number of tracks requiring any effort of judgement was probably less than 20% of the number of tracks measured so the error introduced would be less than 10%.

The Liverpool results are open to criticism because of the large amounts of material near the source of fission neutrons. There was a cubic foot of paraffin to produce thermal neutrons and 600 c.c. of Pb behind 2.9 kilograms of oxide of the alloy. Scattering with loss of energy of the neutrons would reduce the average energy of the neutrons observed. The technique of selecting and measuring tracks was not adequately described, and no correction was made for the greater probability of measuring low energy recoils. They measured recoil tracks which made an angle of less than 30° to the direction of the incident neutrons. We have attempted a correction for the greater probability of measuring low energy recoils. The factor used was $\frac{d}{2S\sin\theta_0}$ when the track range in the emulsion was $\geq \frac{d}{\sin\theta_0}$ and was $1-\frac{S\sin\theta_0}{2d}$ when range in the emulsion was $< \frac{d}{\sin\theta_0}$ d is the depth of the emulsion, S is the length of the track in the emulsion and .This correction factor is plotted on Graph I.

The corrected results are plotted on graph II along with the Rice results, the two having been normalized in the interval between one and three million volts energy. The curve has been drawn giving about equal weight to the two sets of data. The resulting spectrum is believed to be the best estimate that can be made at the present time.

The discrepancies between the two sets of results show the need of further work since there is no entirely satisfactory explanation of the differences. For further work the photographic plate method is more satisfactory for several reasons. The photographic plate can be exposed with only a few days use of bombarding equipment though the measurements may take several weeks. The photographic plate is effectively a cloud chamber of infinite width and length and the distance of the source is very large compared to track lengths so the geometrical corrections to the data are considerably smaller. The amount of scattering material in the neighborhood of the detector is much less, and it is possible to measure the whole spectrum in one experiment whereas cloud chamber technique requires a series of overlapping runs and specially constructed chambers to investigate the high energy end of the spectrum. Finally, in the photographic technique the detector, because of its small size, can be put nearer the alloy, and the gain in intensity makes it possible to use a factor of ten less alloy with resulting diminution in the effect of inelastic scattering.

The final curve drawn on graph II gives a mean neutron energy of 2.9 MV for the fission neutrons. This is nearly 50% too large if the measurements of mean neutron energy by absorption in a water tank are reliable. The prob ble errors in the latter measurements should not be such as to permit a value above 2.5 MV. It may be that the relative small

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number of high energy neutrons indicated in graph II affect the mean energy more than they would affect the effective absorption in water. The mean energy value was derived by comparison with the absorption in water of monochromatic neutrons. However, the discrepancy is large. The chief reason for giving the Liverpool spectrum the same weight as the Rice spectrum was to obtain a slightly lower mean energy.

In most techniques for measuring energy spectra of neutrons the effect of geometry and scattering is to give too many neutrons at the low energy end of the spectrum. It is often possible to make adequate corrections, but if any correction is overlooked the average neutron energy will be too slow. In general, therefore, a low result such as the Stanford results should be examined carefully to see if any further corrections are desirable. The Stanford results on the d-d spectrum are shown in graph III. It is possible to interpret this result as showing the need of a correction for scattering in addition to the correction for wall e effect (see graph). It is suggested that this d-d spectrum be repeated more carefully and higher energy neutrons ($\sim$5 MV) be used to establish what corrections are required. It would also be desirable to do the d-d spectrum with the detector inside the graphite chamber since this is the actual set up used in examining the fission spectrum. Conversely it would be feasible to do the fission spectrum outside the graphite chamber using an unmodulated source of fission neutrons. This would considerably simplify the experiment and would eliminate the uncertain "cut" corrections which are now necessary. A suitable source of sufficient intensity and small background can be made by placing about 50 c.c. of paraffin and 10 c.c. of alloy in front of a lithium target bombarded by

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2.0 MV protons. Beam currents of a couple of microamperes would probably be adequate.

A further objection to the modulation scheme as used at Stanford is that there is the possibility of including a large number of delayed neutrons in the fission spectrum. Booth, Dunning, and Slack[6] report the equilibrium number of delayed neutrons per min to be about

6. E. T. Booth, J.R. Dunning and F. G. Slack, Phys.Rev. 55, 876, (1939)

1/60 of the number of fissions per minute. Since in the modulation scheme the alloy is irradiated with an intense d-d neutron beam when the detector is not sensitive, the delayed neutrons may contribute appreciably to the Stanford spectrum.

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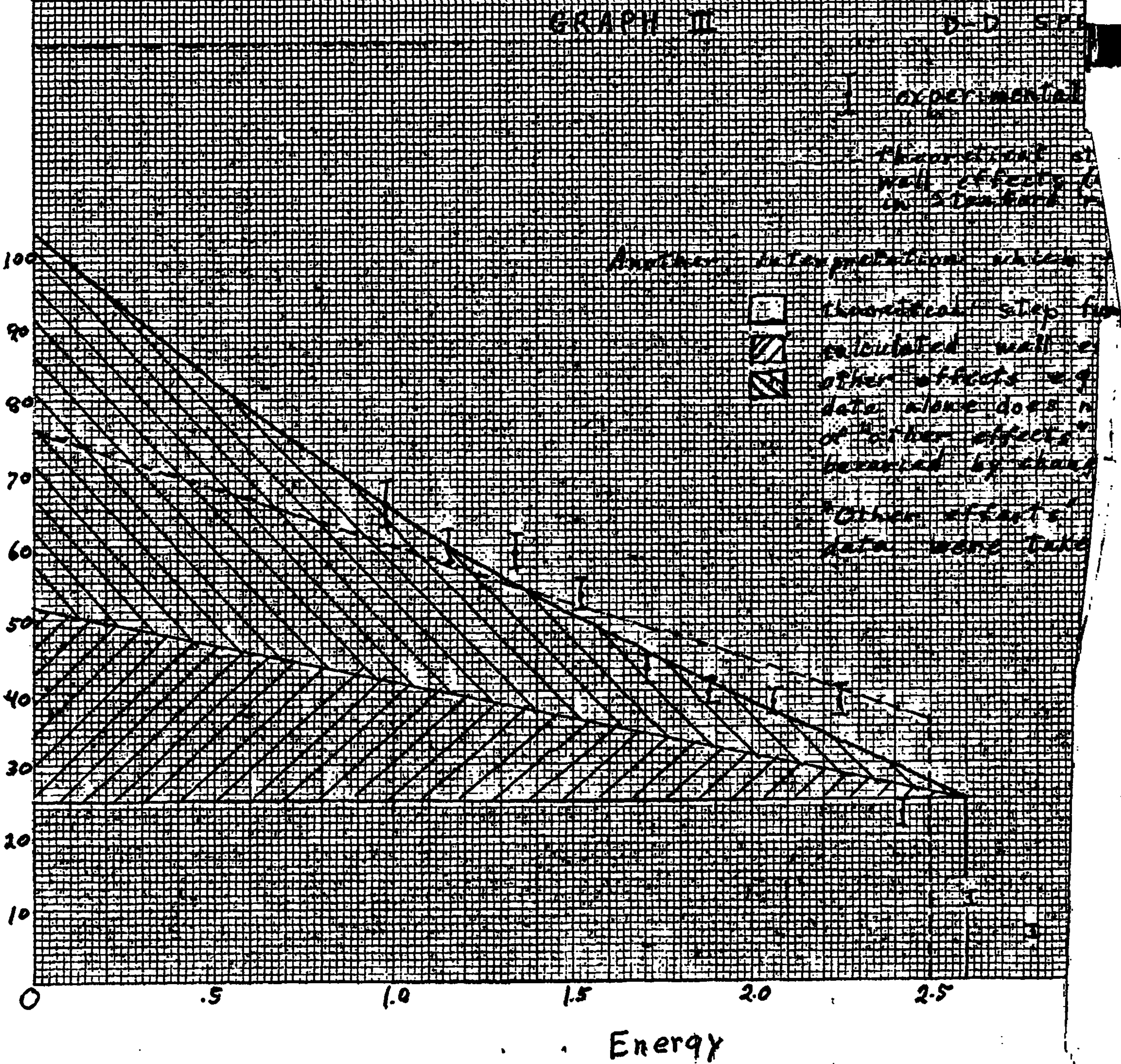

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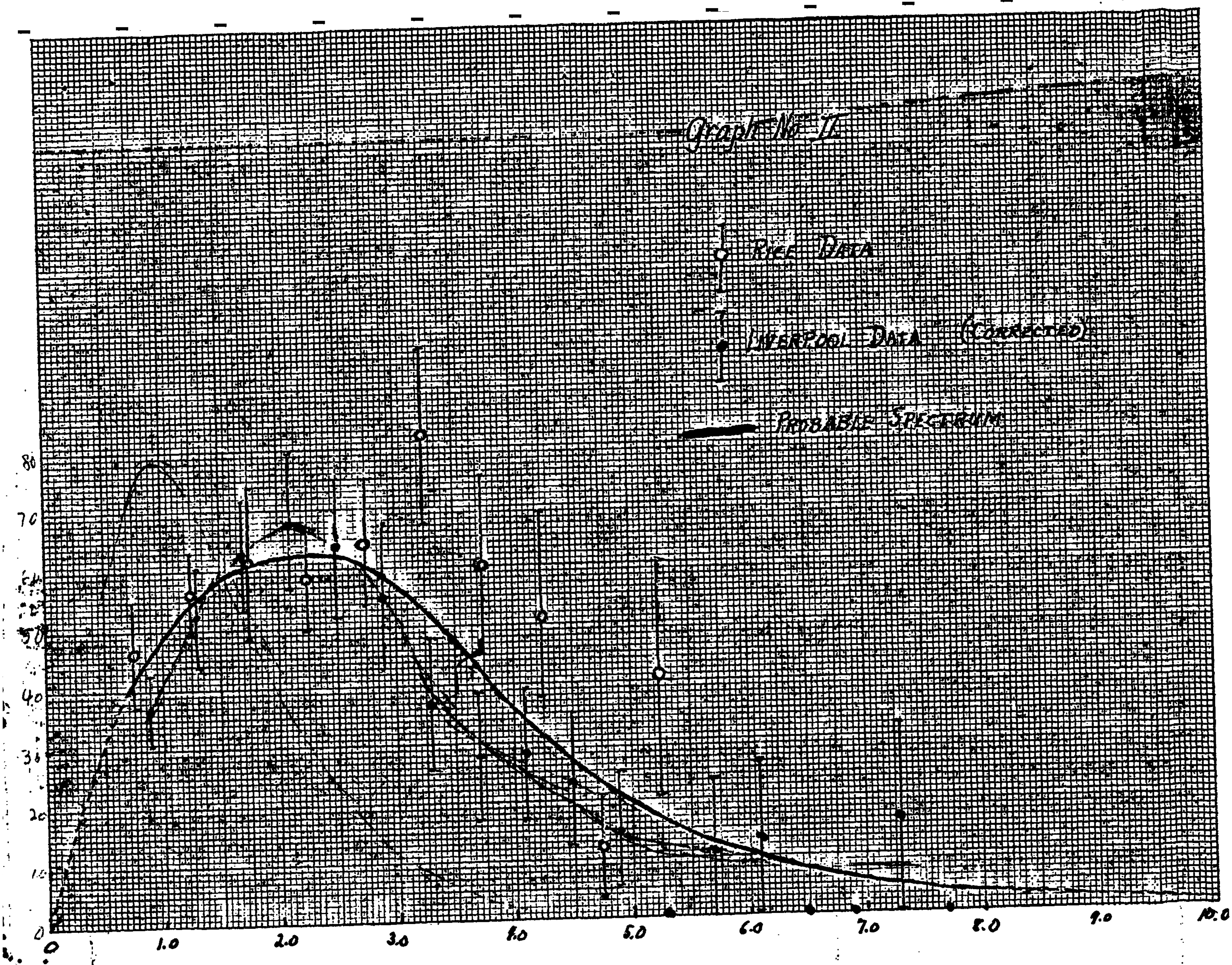

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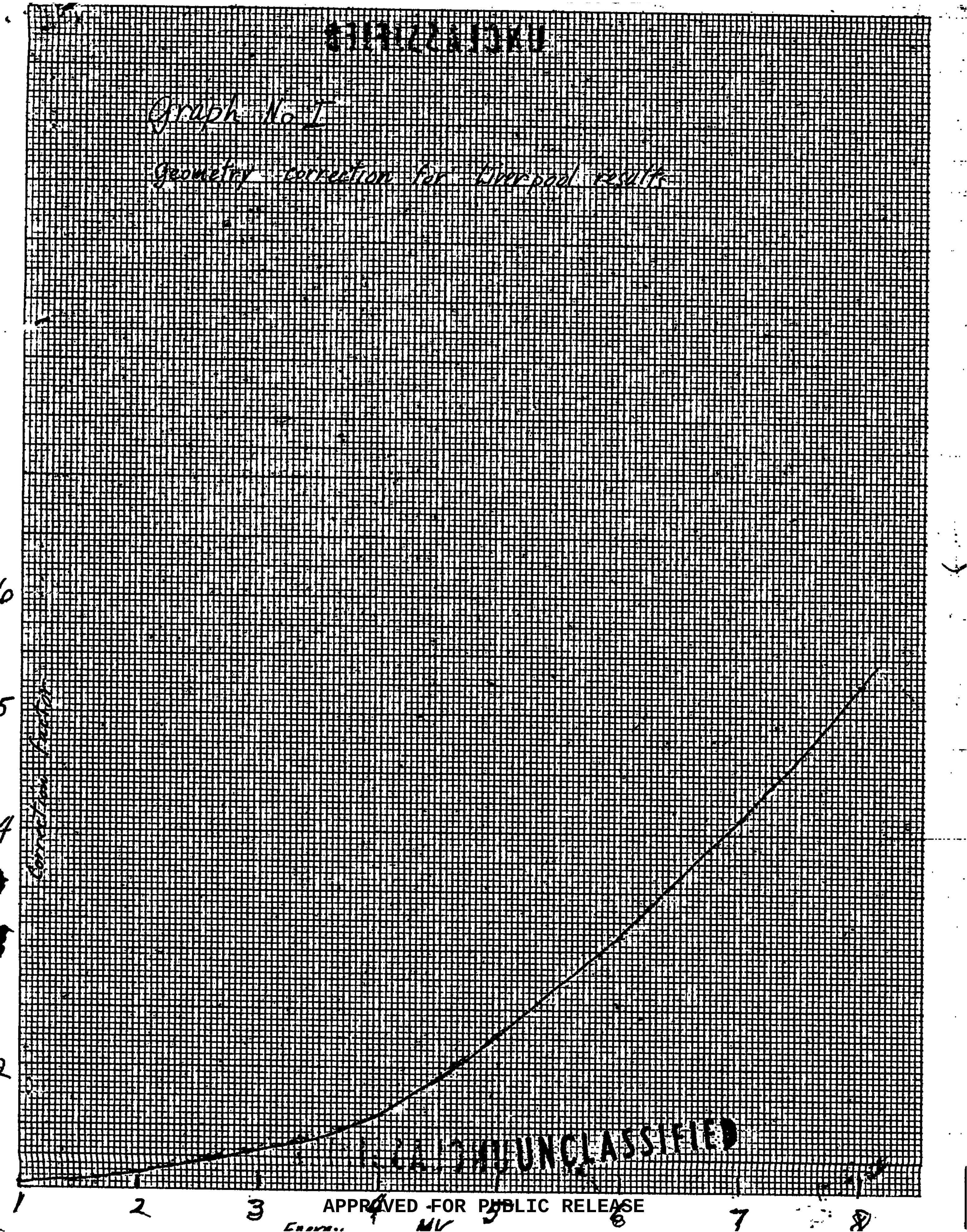
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Graph No. I
Geometry correction for Liverpool results
Correction factor
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