N O T I C E

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A NOTE ON THE REVISED GALACTIC NEUTRON SPECTRUM
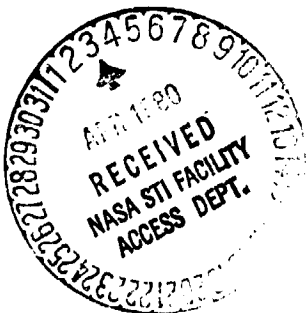# OF THE "AMES COLLABORATIVE STUDY"

by

Hermann J. Schaefer,
University of West Florida,
Pensacola, Florida.

[#] Since the contract includes several subtasks,
a major part of the final results is con-
tained in three preceding reports distributed
in April 1978, November 1978, and September
1979. For a concise summary, the Sept 1979 re-
port should be consulted.

INTRODUCTION

In a preceding report (1), hereafter referred to as the 1978
Report, the available information on the energy spectrum of
cosmic-ray produced neutrons in the Earth's atmosphere has
been reviewed and evaluated in terms of the dose equivalent
(DE). In the time since, new comprehensive measurements of
the galactic neutron spectrum have been reported in the "Ames
Collaborative Study" (2). The Ames spectrum modifies the Hess
spectrum (3) used in the 1978 Report inasmuch as it questions
the existence of the so-called evaporation peak. If corrobo-
rated, this finding would have important implications for
neutron dosimetry in space. To be sure, galactic radiation ac-
counts for only one part of the total neutron DE on a near-
Earth orbital mission. Neutrons from interactions of trapped
protons contribute a substantial additional share. Separate
measurements of the two fractions are extremely difficult, to
say the least. In fact, even the undifferentiated grand total
neutron DE in space has never been accurately determined. Re-
corded entirely outside the influence sphere of trapped pro-
tons, the Ames spectrum reflects the neutron build-up of the
unadulterated galactic radiation and therefore consitutes a
first step toward the eventual disentanglement of the com-
bined neutron spectrum from trapped and galactic protons in
space.

The cross sections for neutron production in collisions of
high-energy protons are weak and smooth functions of proton
energy and Atomic Number Z of the target material. Therefore,
the galactic neutron build-up in the atmosphere can serve,
within limits, as a model for the corresponding build-up in
the compact matter of a vehicle in orbit. The Ames group re-
ports (l.c., 2) a neutron DE rate of 220 microrems/hour mea-
sured at 48° N geomagnetic latitude and 12.5 km altitude
(41,000 feet or 180 g/cm^2 residual atmosphere). Also repor-
ted is an additional dose rate of 410 microrads/hour from all

ionizing components. These values impressively demonstrate the significance of galactic radiation in general and the role of neutrons in it in particular.

THE GALACTIC NEUTRON SPECTRUM: THE AMES VS. THE HESS MODEL.

Reflecting the energy spectrum of the primary radiation from which they originate, galactic neutrons cover an extremely wide spectrum extending from thermal to ultra-relativistic energies. However, only fast neutrons contribute significantly to the DE because of their high Quality Factors. Accordingly, only the upper part of the total spectrum beginning at about 0.1 Mev is of interest in the present context. Since the Ames group has reported data only up to 300 Mev, the comparative evaluation of the two spectral models is further reduced to the interval from 0.1 to 300 Mev.

Figure 1 shows the two energy spectra over a common logarithmic energy scale as abscissa. We recognize at once the different configurations in the region about 1 Mev where the Hess spectrum exhibits the evaporation peak whereas the Ames spectrum shows a smooth monotonic decline. The term evaporation designates the most common type of nuclear interaction at high energies in which the constituent nucleons of the target nucleus "boil off" in a quasi-thermodynamic fashion carrying off, in the case of neutrons, individual energies from zero to a few Mev.

It must be mentioned that the Hess group has presented two versions of the neutron spectrum with somewhat different evaporation peaks. The 1978 Report evaluates the model with the more pronounced peak (l.c., 3) whereas the present report follows the Ames Collaborative Study and presents, in Figures 1 and 2, the model with the less pronounced peak (4).

If the neutron flux per unit energy interval dN/dE is plotted over a log scale of energy, equal areas under the curve do not represent equal fluxes. For full equivalence of area and

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flux over the entire energy scale, we have to plot neutron flux per unit log E rather than per unit E, i.e., dN/d(log E) instead of dN/dE. Since d(log E) = (dE/E)(log e) where e is the base of natural logs, the two different flux units are connected by the relation dN/d(logE) = (dN/dE)(E/log e). Figure 2 shows the spectra of Figure 1 converted accordingly. Equal areas under the curves now represent equal neutron fluxes for any energy interval and the graphs present the two spectra in their true dimensions.

Assessment of the dosimetric implications requires conversion of flux and energy to kerma and DE. For this step, we apply, to the two spectra, the flux/DE relationship for neutrons recommended by the National Council on Radiation Protection and Measurements (5). Numerical integration over the energy interval from 0.1 to 300 Mev furnishes grand total DE rates of 380 microrems/hour for the Ames spectrum and 510 microrems/hour for the Hess spectrum. In comparing the two radiation levels, one should be aware of the above mentioned fact that the Ames study defines the spectrum only up to 300 Mev. Examining the trend of the spectra, we recognize that the Ames spectrum, quite differently from the Hess spectrum, strongly suggests a substantial additional contribution to the total DE from the undefined region above 300 Mev. In other words, the DE rate of 380 microrems/hour appears to fall short of the true value by a sizeable margin whereas the DE rate of 510 microrems/hour for the Hess spectrum should approach the true value closely. The two models, then, actually yield more closely matching DE rates than evaluation of the limited interval from 0.1 to 300 Mev indicates. To be sure, behind this equality of the DE's as such, a basic difference in the energy regions furnishing the DE's remains hidden. For the Hess spectrum, the bulk of the DE originates in a comparatively narrow energy interval centering on about 1 Mev. For the Ames spectrum, a much broader interval extending from a few to several hundred Mev furnishes the DE. Taking the total

DE rates of 380 and 510 microrems/hour for the two models
at face value and normalizing to 100 per cent, we show in
Table I their distributions in four sections of the total in-
terval from 0.1 to 300 Mev. The basic difference of the two
distributions shows up quite clearly even in this coarse
breakdown.

TABLE I

Energy Distributions of the Neutron Dose Equivalents
in the 0.1 to 300 Mev Interval for the
Ames and Hess Spectrum

Energy Interval, Mev	Per Cent of Total Dose Equivalent,	
	Ames	Hess
0.1 - 1	10	30
1 - 10	25	48
10 - 100	45	17
100 - 300	20	5

CONCLUSIONS

The particular problem of neutron dosimetry in space centers
on the limited section of the spectrum where recoil protons
of short range and very high LET produced in elastic colli-
sions account for the energy transfer. The critical energy
interval extends from a fraction of 1 to some 10 Mev. We re-
cognize in Figure 2 that the interval coincides with the evapora-
tion peak of the Hess spectrum. Beginning at about 15 Mev,
nuclear interaction overtakes elastic collision as the most
probable event hence short-ranged recoils are no longer the
predominant agents of energy dissipation. Examining Figure 2
once again we see that the Ames spectrum, showing no evapora-
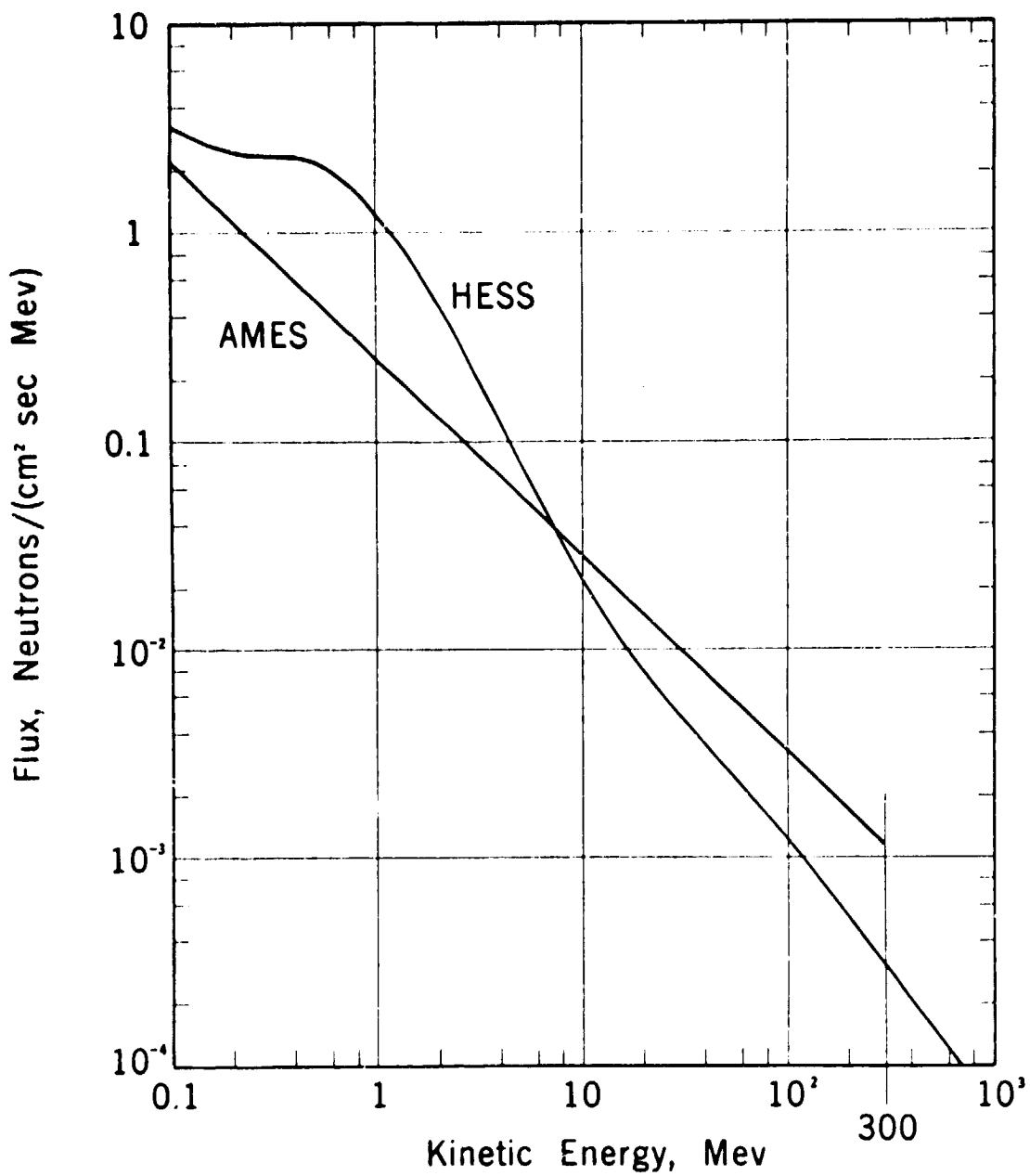tion peak, moves the bulk of the flux away from the region of

elastic collision and spreads it more evenly over higher energies. The crucial point is 'that the neutron spectrum in space does not seem to bear out the Ames model. Emulsion findings on all manned missions of the past (6) consistently indicate that evaporation events are a prolific source of neutrons in space.

The assumption is near at hand that the high frequency of evaporation events in space is due to trapped protons producing a Hess-type spectrum superimposed on an Ames-type spectrum without an evaporation peak. Since the spectrum of trapped protons centers on much lower energies than the galactic spectrum, it favors the production of evaporation over knock-on stars and the corresponding spectra of secondary neutrons should indeed differ in the indicated way. Disentangling the two spectra in the integral response of a passive dosimeter such as nuclear emulsion poses insurmountable difficulties. Recording separately, with active instrumentation, the combined spectra in the Anomaly and the pure galactic spectrum outside seems a better approach. Although such separate measurements would not be required for the exposure records of personnel, they appear indispensable for defining the sensitivity and response characteristics of a passive dosimeter. The task is formidable: In a heavy background with an LET spectrum extending far beyond the LET of recoil protons, a neutron DE is to be recorded which accrues from two sources with instantaneous DE rates strongly and independently varying over the orbital cycle.
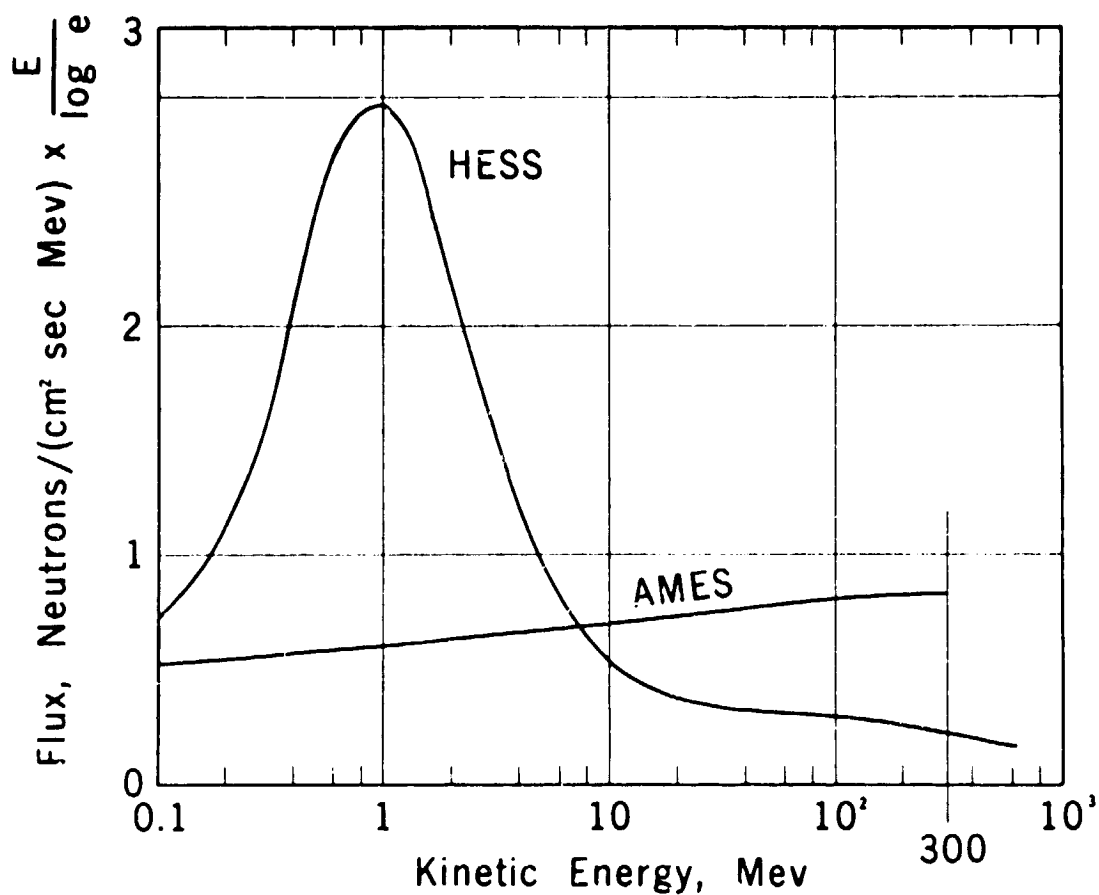
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LOG LOG PLOTS OF GALACTIC NEUTRON
SPECTRA OF AMES AND HESS

FIGURE 1.

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Y-axis: Flux, Neutrons/(cm² sec Mev) × $\frac{E}{\log e}$

X-axis: Kinetic Energy, Mev

HESS

AMES

3

2

1

0

0.1   1   10 10^2 10^3

300

ADJUSTED LIN LOG PLOTS OF GALACTIC NEUTRON SPECTRA OF AMES AND HESS

FIGURE 2.