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ESTIMATES OF RADIATION EXPOSURE FROM SOLAR COSMIC RAYS IN SST ALTITUDES

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16. Abstract

Estimates of radiation exposure to solar and galactic cosmic rays that would be experienced by crew and passengers during flights of the SST have been made. Factors influencing the exposure and some possibilities of decreasing the exposure are discussed.

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I. Limitations of Present Knowledge

So far as the radiations environment produced by solar cosmic rays in SST altitudes is concerned, until at present no experimental measurements of all biologically important components could be made during solar events. One is therefore limited to theoretical estimates. Such theoretical estimates are conducted with and without taking into account secondaries produced in the atmosphere, in the airplane, and in the body (refs. 1-9).

The result is: Most major energetic solar events which occurred in Cycle 19 with a frequency of 2 to 4 per year during especially the decreasing phase of the solar cycle produced dose rates in SST altitudes in the order of only 10 to 100 mrem/hr.

Exceptions are the very rare so-called high energy or giant events. The largest of these events observed since 1942 (ref. 6) is that of February 23, 1956. It happened during the ascending phase of the last solar cycle (Cycle 19, 1954 - 1964, which was the most solar active of the last 25 or more probably the last 80 years). During the first hours of the proton influx of this event there was seen a sea level neutron monitor increase of 3,600% (New Hampshire) to 5,000% (Leeds, England). The above mentioned other energetic events of Cycle 19 show only a neutron increase at sea level up to 225%. The above mentioned medium energy events have higher intensities in the 30 MeV range, however extend only to 600 MeV with measurable intensity (see reference 6, figure 7).

Estimates of the dose rates in SST altitudes in the first hours of the February 23, 1956 event range from 0.5 to 4 rem/hr. (0.25 to 2 rad/hr).

There are still rather large uncertainties about the magnitude of the rem dose rates, partly because idealized flux spectra are used in the above calculations, partly because the secondary production cross sections as those for neutrons, especially for protons of energy greater than 450 MeV are not well known.

In most solar cosmic ray events the primary protons or alpha particles cannot penetrate in significant intensity to cruising altitudes of the SST planes of the near future (60,000 to 65,000 feet corresponding to 18.3 - 19.8 kilometers). However, they produce in the atmosphere above the airplane secondaries in nuclear collisions especially neutrons which penetrate more freely and randomly in all directions building up a maximum of flux near SST altitudes. An accurate calculation of the secondary components which contribute most to the dose is therefore of importance.

To sharpen the estimates especially with respect to neutrons, in the following, the paper referenced 9 is used as basis. On request of NASA Langley, the Neutron Physics Division in Oak Ridge conducted specific Monte Carlo calculations for protons up to 450 MeV of rad and rem doses from solar cosmic rays in SST altitudes. Idealized fluence spectra of solar cosmic ray events (exponential rigidity spectra with P_o = 100 MV) were used which do not encompass the most important February 23, 1956 event. The elements of these calculations are, however, presented in such a way that they can easily be used to calculate rad and rem dose rates in SST altitudes for the more important flatter flux spectra in the early phases of the events which produce the bulk of biologically effective components in SST altitudes and also to estimate roughly rem dose rates which would have been obtained in the first hours of the February 23, 1956, event.

The results of such calculations using flux spectra of Cycle 19 (1954 to 1964) assembled by NASA Langley are contained in figures 1 and 2 and are the basis of the following more detailed dose estimates.

II. Crew Rem Dose Rates from Solar Cosmic Rays

Figure 1 shows the maximum rad and rem dose rates received by the crew averaged over 10 years of the solar cycle in mrem/flight hour and mram/flight hour in altitude respectively. It is called maximum dose rate because it is assumed that most major events of solar cycle 19 are encountered two to four times for one hour in altitude. The sum of this dose is divided by 4800 flight hours, the anticipated number of hours in altitude in ten years if the usual schedule of 80 hours per month flight duty (of these, 40 hours per month in altitude) is continued. The considered events are February 23, 1956; May 10, 1959; July 10, July 14, and July 16, 1959; November 12 and 15, 1960; July 12 and 18, 1961. The lowest full line is the average dose in mrem per flight hour for all events except February 23, 1956. The upper shaded strip indicates the upper and lower limit if one includes passage of the February 1956 event in its first hours. The prompt spectrum of the February 1956 event is not well known (see refs. 6 & 8), nevertheless it is clear to see that all events mentioned in this cycle except February 1956

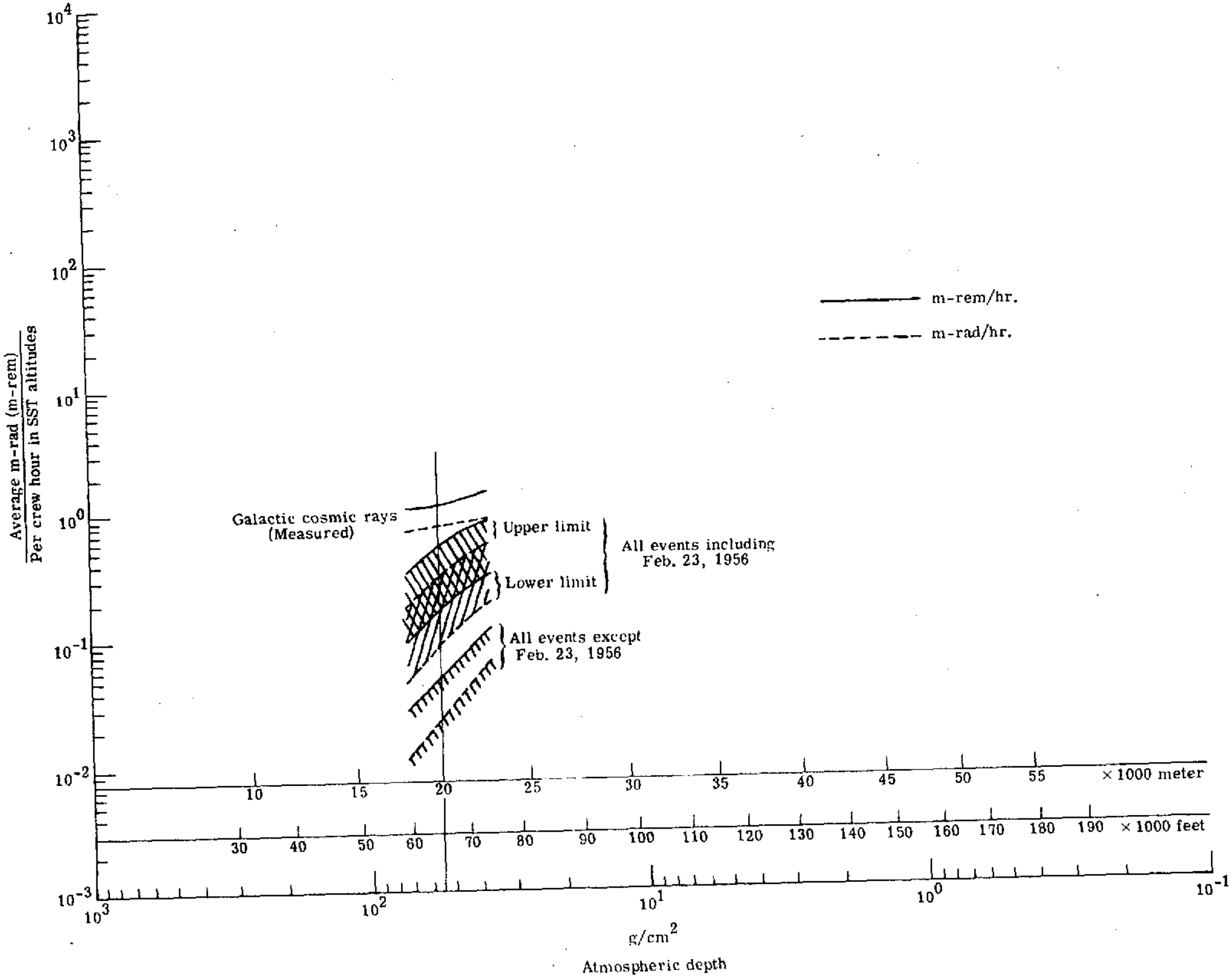

Figure 1.- Average dose rate from solar cosmic rays received by crew encountering the major events of cycle 19 (1954 - 1955).

contribute only 1/3 to 1/10 to the total average dose of 0.17 to 0.6 mrem/hr in 65,000 feet.

On top of this average solar cosmic-ray dose rate for cycle 19 is indicated in figure 1 the average dose per flight hour produced by galactic cosmic rays in these altitudes. (See section H. Schaefer)

It is seen according to these theoretical estimates that the exposure from solar cosmic rays averaged over the highly solar active cycle 19 would have been by a factor of from 3 to 2 lower depending on altitude than the exposure from galactic cosmic rays.

It may be emphasized that the above average dose rates are considered maximum values and not the most probable values in spite of neglect of gammas and underestimate of secondary neutrons in the February 1956 event. Of course, they are not considered as unduly high upper limits because the spectra were mostly measured outside of the so-called impact zones in which the radiation is especially intensive. Since the exposure from galactic cosmic rays amounts only to about 15 percent of the maximum permissible dose for radiation workers, with regard to exposure of the male crew there appear no strong reasons for evasive measures except the general philosophy to hold any radiation exposure as low as possible. If the flights are served by female and married stewardesses, this point may be reviewed because the maximum dose rate during the February 1956 event was in the order of one rem/hr and might be of significance for pregnant crew members as for pregnant passengers.

III. Passenger Rem Dose Rates from Solar Cosmic Rays

Passengers rarely encounter every major event or many events, contrary to the crew, who, on a rigid schedule, will normally encounter with about one round trip such events of a duration of 48 hours or more.

Figure 2 shows the dose rates encountered during the beginning and later phases of several prominent events. The dates and clock times written on the dose curves indicate the time when the flux spectra were measured from which the dose rate curves are derived. In higher altitudes and in February 1956 also, down to 40,000 feet, the dose rates are calculated neglecting nuclear collisions. In supersonic altitudes the Oak Ridge method is applied. One recognizes that for such soft spectra as November 13, 1960, 16:03, neglecting secondaries yields much too low dose rates. In the hard February 1956 event, however, the neglect of nuclear collisions does not substantially change the rad doses in SST altitudes.

The exposure of passengers to solar cosmic rays depends, besides their frequency of travel, mainly on the date of travel or their encounter with a high energy event similar to that of February 1956. From figure 2 it is seen that most major events are estimated to contribute not more than 10 to 80 mrem per flight hour in 65 to 75 thousand feet (20 to 23 kilometers). The maximum exposure if the passenger passes with one round trip two times each event except February 1956 in an altitude of about 65,000 feet is the order of about 300 mrem per 11 years. If one trip during the first hours of February, 1956, is included, the exposure would increase by 0.5 to 2.5 rem which is 10 to 50 percent of the allotment for 10 years for an individual of the general population (0.5 rem per year). Because of the very small number of people encountering such events, this is considered as of no genetic significance. The concern might be centered on the fact that the main part of the flare event doses would occur in a very short time; that is, in about 1 to 2 hours. A total body dose of 0.5 to 2.5 rem in one hour appears not desirable, especially for pregnant passengers and children, and might lead to

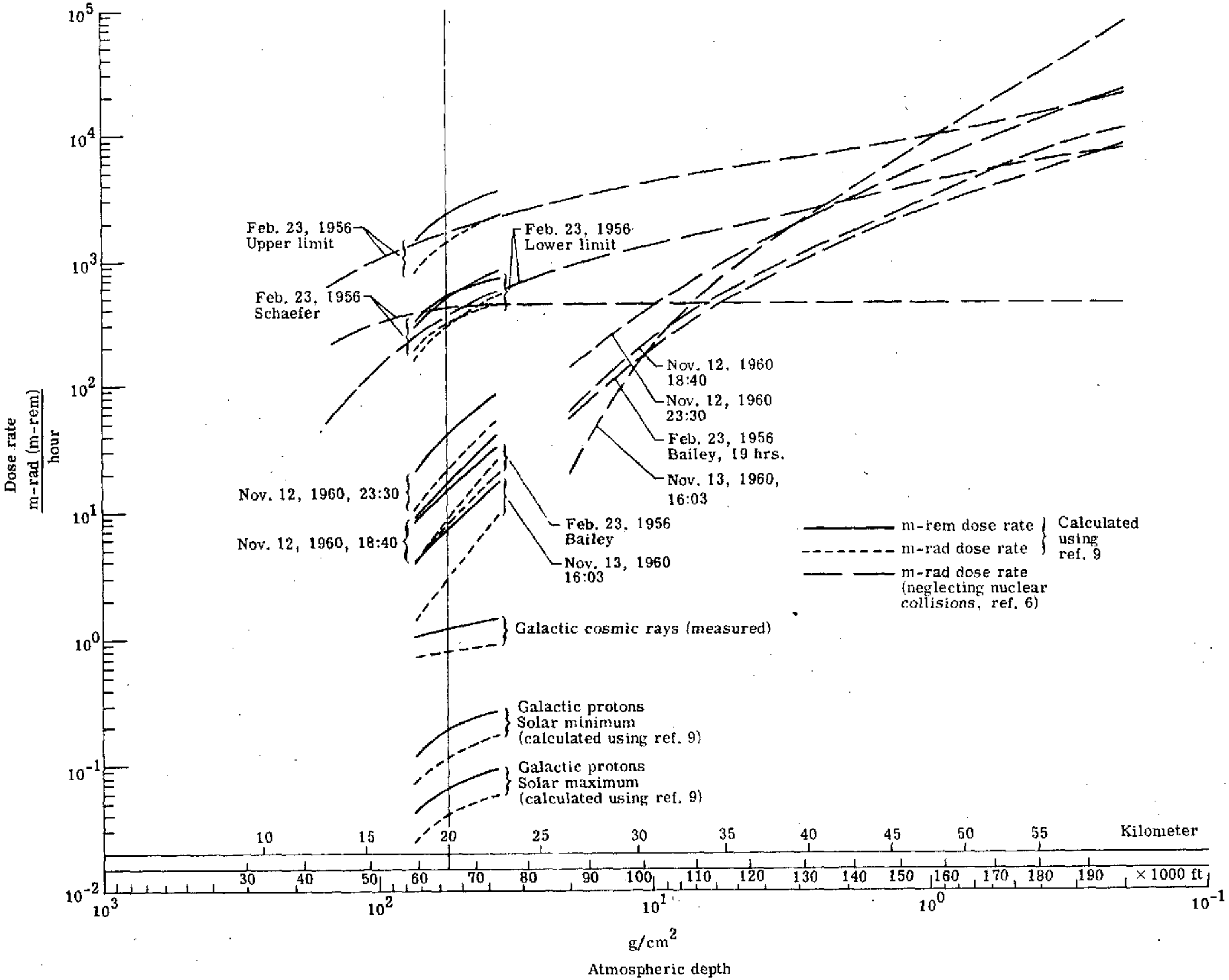

Figure 2.- Dose rates during the large solar events of February 23, 1956 and November 12, 1960.

forensic consequences if no evasion measures are taken and proof is not provided that the exposure did not surpass accepted levels.

It may be emphasized that cycle 19 was the most active cycle for at least 25 years and that cycle 20 seems lower in activity, thus an event of the size and penetration power of February 23 may not occur at all in this cycle, although they occurred in 1942, in 1946, and in 1949. On the other hand, the possibility of an energetic event of even higher intensity cannot be excluded. Of course, it appears very improbable since it did not occur since 25 to 80 years. Thus, the solar cosmic ray doses for cycle 19 may be considered as upper limits.

IV. Concluding Remarks

These theoretical calculations underestimate the contribution of protons greater than 450 MeV energy to the neutron flux produced in nuclear collisions. An upper limit of the error is obtained if one compares the galactic cosmic ray dose rates (the bulk of galactic cosmic rays have an energy greater than 1 BeV/nucleon and their spectra fall off far more slowly with energy than those of the February 23, 1956, event) confirmed by measurements, with the dose rates calculated according to Oak Ridge on the basis of the 450 MeV cross sections (see fig. 2). Besides protons, galactic cosmic rays contain about the same amount of nucleons in the form of alpha particles and heavier nuclei. If one takes into account the dose produced in SST altitudes by the heavier particles and their secondaries by a factor of 2, one obtains as upper limit of error a factor of about 5. Thus the prompt dose rates of February 23, 1956, are very uncertain; however figures 1 and 2 should contain the effective upper limits of doses because the assumed upper limit prompt spectrum is highly conservative.

In summary, if we accept the upper limit of February 23, 1956, the following doses would be obtained:

AVERAGE DOSES OVER SOLAR CYCLE (10-11 YEARS)

MAXIMUM VALUES, MAGNETIC LATITUDES >60°

CREW:		EXPOSURE
	G.C.R. (see section of H. Schaefer)	≈1.2 mrem/hr.
	S.C.R.* (without precautions)	≲0.6 mrem/hr.
		1.8 mrem/hr.

at 10 hours/week flight duty in SST altitude

18 mrem/week = 18% of MPD for radiation workers (5 rem/year)

PASSENGERS:		EXPOSURE
	G.C.R.	
	At one round trip per year	Negligible
	At 1/10 the flight time of the crew, ≈ 4 flights per month	0.6 rem/10 yrs. (12% of MPD 0.5 rem/year)
Only few individuals		
	S.C.R.*	
Without evasion measures	Max.: 0.5 - 2.5 rem in 10 yrs. (≈10 - 50% of MPD for 10 yrs. in a few hours)	0.5-2.5 rem/10 yrs. (10-50% MPD/10 yrs.)
	Min.: ≈ 0	≈ 0
		≈0-3.1 rem/10 yrs. (≈0-60% of MPD/10 yrs.)

* See note on page 10.

As mentioned before, the confirmation of the secondary and especially neutron calculations for a given particle spectrum by experiment was not expected or possible until now within the NASA-Air Force-FAA balloon and airplane program. The galactic cosmic-ray-produced levels in SST and subsonic altitudes especially of neutrons are measured since 1965 in high latitudes and will be published in the near future. In the frame of this program it is intended to confirm the rem dose estimates during solar events and from galactic cosmic rays measuring especially neutron fluxes and LET spectra in air and in body phantoms in airplanes. This includes the simultaneous measurement of the dose rate and the biologically important fluxes in lower altitudes and lower latitudes to prove the effectiveness of evasion measures and determine the exposure in today's jet altitudes.

*NOTE: Concerning the rem dose values from solar cosmic rays.

The solar cosmic ray rem doses given above are calculated from rad doses or fluxes by using the RBE factors or flux to rem dose conversion factors of Handbook 59 (1954) and 63 (1957) of the National Bureau of Standards.

As emphasized by Hermann Schaefer these RBE factors are lower by about a factor of 2 than the quality factors (Q_F) in use by the ICRP for protection and maximum permissible dose definitions since 1963.

The solar cosmic ray total rem doses cited above; e.g., in the table on page 9 and in the figures would be higher by the factor 1.5 if the new Q_F factors are used. For instance, the upper limit of rem dose rate in the first hours of the February 23, 1956, event (see Fig. 2) would be not 2.4 mrem/hr in 65,000 feet but 3.6 mrem/hr and the total average dose rate for the crew (see the table on page 9) would not be 1.8 mrem/hr but 2.7 mrem/hr.

For the galactic cosmic ray dose estimates (see Section H. Schaefer) the Q_F factors are used.

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