HEALTH PHYSICS ASPECTS OF SUPERSONIC TRANSPORT*

WALTER S. SNYDER

Health Physics Division, Oak Ridge National Laboratory, Oak Ridge, Tennessee, U.S.A.

Abstract—Passengers and crew of a supersonic transport (SST) will be exposed to more intense fields of cosmic radiation than are usually encountered in commercial flights at the present time. The assessment of the radiation hazard posed by this new development must take into account the intensity of the radiation fields in the cruising altitude of the SST (60,000–80,000 ft), the quality factors appropriate for these radiations, and the many factors which determine the frequency and duration of exposure and the age distribution of the exposed as members of the population.

Using presently available data on the relevant radiation fields, the dose rate and dose equivalent rate to occupants of the SST are estimated separately for solar cosmic radiation and for galactic cosmic radiation. These dose rates would be considerably higher in the case of planes flying a polar route than for those following a route at lower latitudes. Unusually high dose rates may occur during periods of a major solar flare, and it seems possible, in very exceptional cases, some change in flight plans might be desirable to reduce the dose from solar cosmic radiation.

The cumulative exposure of a crew member who is constantly flying on polar routes might well be in the range of the present recommended levels for occupational exposure. The dose for the vast majority of passengers would be expected to be well within the permissible limits on population exposure. Extrapolating present data on passenger miles flown per year, it appears that the total contribution to the genetic dose would be well below 1% of the recommended limit of 5 rem per generation.

INTRODUCTION

The supersonic transport aircraft, hereafter referred to as the SST, is being designed to cruise at altitudes of 60,000 to 80,000 ft. At these heights, passengers and crew will be exposed to somewhat higher levels of cosmic radiation because the overlying absorption thickness (g/cm^2) of air is less than half what it is at 30,000 or 40,000 ft, the heights used by many present commercial aircraft. Undoubtedly, the problem of solar flares, which produce radiation fields with intensity much above the average levels, has served to call attention to the general problem of radiation exposure entailed by the use of the SST. Consequently, there have been a number of studies of the problem (for example, refs. 1–5), including one by an ICRP Task Group,[6] and this paper is, in a sense, a summary of these reports and an updating with what new information has been found during the last year.

The British and French governments are cooperating to produce an SST which is termed the Concorde. Several U.S. firms are also actively at work on design, but it appears the American planes may not be ready for commercial use as soon as the Concorde which is tentatively scheduled for service in 1971. The Concorde is designed to fly from New York to Paris, for example, in 3 hr and 15 min, or from London to Sydney in 13 hr and 20 min, and will carry from 110 to 130 passengers. Nine airlines have already placed orders for 45 of these planes, and the interest in the American version is comparable. An artist's representation of the Concorde is shown in Fig. 1.

The primary spectrum of cosmic radiation is fairly well documented. There is considerable

* Research sponsored by the U.S. Atomic Energy Commission under contract with Union Carbide Corporation.

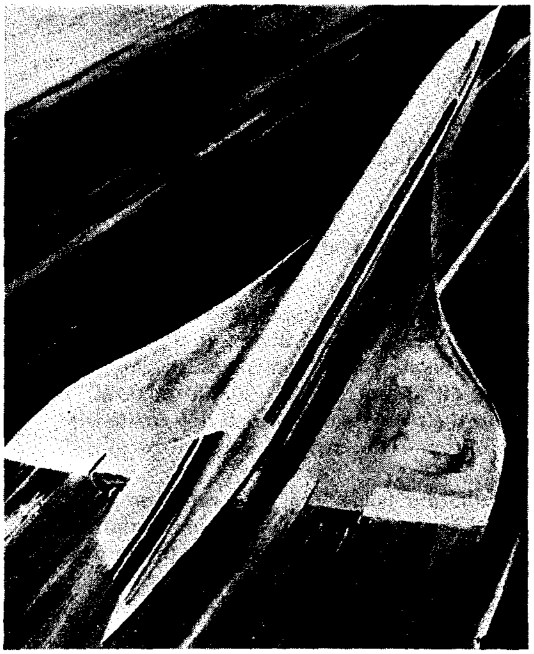

FIG. 1. The SST (Concorde).

absorption due to the 30 to 70 g/cm^2 of air above these altitudes so that this primary spectrum is considerably altered, and there have not been many direct measurements of the radiation fields within this belt. Thus the radiation fields encountered between 60,000 and 80,000 ft are not as well determined as those at lower altitudes or those at higher altitudes. It is convenient to consider these radiation fields under two separate categories: (1) galactic radiation, which originates outside the solar system, and (2) solar radiation originating with the sun, the latter including solar flares which are, in fact, only more intense and limited periods of solar radiation.

Galactic radiation consists primarily of energetic protons, alpha particles, and to a lesser extent heavier nuclei, and it is relatively constant in intensity except for effects due to magnetic fields associated with sun spot activity and solar flares. In Fig. 2, which is taken from ref. 1, the change of the composition of the cosmic ray beam with altitude is shown. The height of 60,000 ft is just beyond the region where the "transition effect" occurs and the particle fluxes begin to decrease. At lower elevations the dose will be primarily due to radiation of low LET, i.e. electrons and mesons, but at altitudes of 60,000 to 80,000 ft, the flux of nucleons increases and makes a very significant contribution to the dose and even more to the dose equivalent.

In the upper atmosphere, the total ionization increases from the earth's equator toward the poles owing to the magnetic field of the earth which deflects low-energy particles. Because of this screening effect, the number of high-energy primary particles reaching a given height above the earth increases with latitude, being minimal at the equator. This screening effect is less at lower altitudes and is hardly significant at sea level. Fowler and Perkins[3] have estimated this latitude effect for a height of 70,000 ft, and their estimate is shown in Fig. 3. It is seen

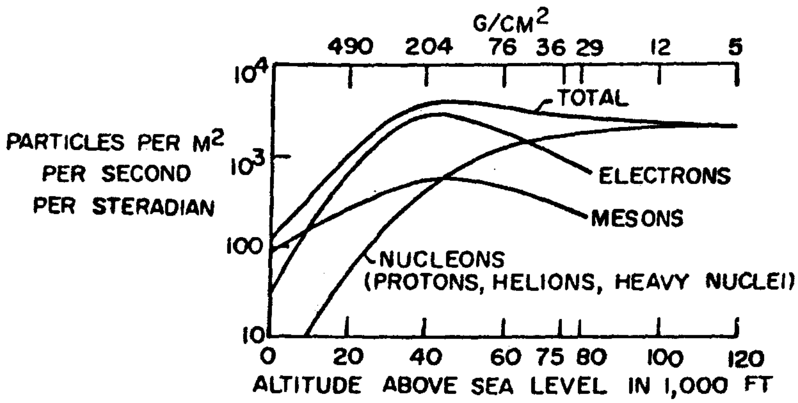

FIG. 2. Altitude profile of particle transition of cosmic ray beam in the atmosphere (from H. J. Schaefer).

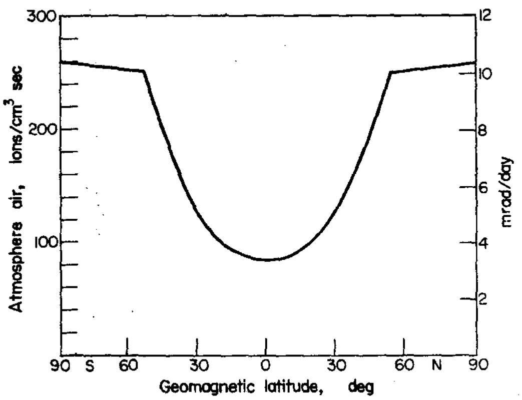

FIG. 3. Intensity of ionization at maximum of ionization depth curve (~50 g/cm²) for June–December 1965 (Neher and Anderson (1962))

that at 60° or more of north latitude the intensity of ionization is about three times greater than at the equator. Many of the most traveled routes pass through these high latitudes, and if it appears desirable to reduce dose to passengers or crew, one might achieve a substantial reduction by following routes that lie in lower latitudes so far as practicable. Crew members might be rotated so that the same individual did not fly predominantly on the routes through high latitudes. However, while these are possibilities, it is not at all clear that such practices will be required to meet current standards limiting exposure of either passengers or crew.

In years of high solar activity such as 1958–9, an interplanetary magnetic field is superimposed on the earth's magnetic field. This effect is represented in Fig. 4 which shows this effect for 1954, a year of low solar activity, and for 1937, a year of high solar activity. In the region of 60,000 to 80,000 ft, this effect is only a difference of 20–30%. The similar data for 1954 are, however, practically a factor of 3 higher than for 1958 in northern latitudes and at an elevation of ~ 90,000 ft according to Neher and Anderson.(7) Thus, this effect can account for a very substantial increase or decrease in the total dose received from galactic radiation.

Fowler and Perkins(3) have summarized and evaluated the dose and dose equivalent using the ICRP recommendations to obtain the quality factor (QF) from the linear energy transfer (LET). A significant fraction of the total ionization is produced by protons and heavier nuclei, but they have rather high energies so that the QF only averages 1.5 according to their estimate.(3) This estimate neglects the dose due to neutrons which undoubtedly increases the value of QF. The ICRP Task Group, using data of Haymes,(8) evaluated the dose from neutrons separately. Using a QF of 8 for this dose, the QF for all dose from galactic radiation averages about 2. However, it must be recognized that the measured values on which this estimate is based only include neutrons of energy above 1 MeV, and, while allowance has been

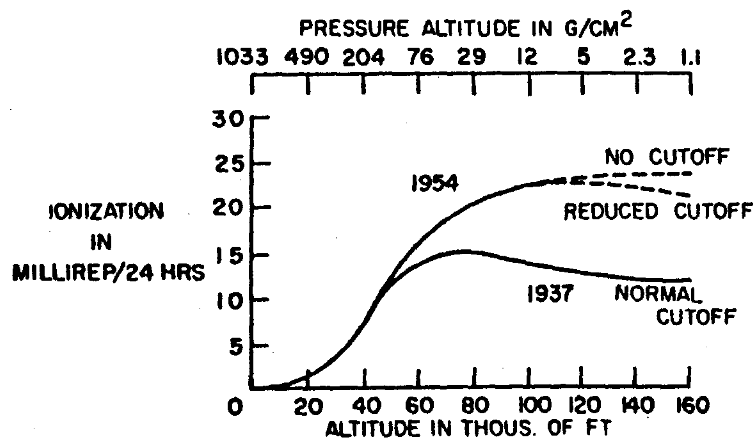

FIG. 4. Altitude profile of the total ionization in a year of high (1937) and low (1954) solar activity (from H. J. Schaefer).

made for the neutrons of lower energies, there is some uncertainty in the estimate, perhaps as much as a factor of 2. Watt *et al.*[9] give a higher dose estimate based on somewhat different assumptions concerning the neutron energy spectrum and the effect of isotropic incidence on the depth dose curve. The ICRP Task Group estimates a dose rate of 1.3 to 1.9 mrem/hr at heights of 60,000 to 80,000 ft, respectively, for polar latitudes and for years of a quiet sun. Thus these dose rates are "conservative" so far as latitude and solar effects are concerned.

Using the spectrum estimated by Fowler and Perkins,[3] one finds that about 5–10% of the dose is due to nuclei with mass greater than that of an alpha particle, and some of these have sufficient energy to produce a broad path, perhaps 10 μ in diameter, extending over many cell diameters. Schaefer has calculated the number of these "thin-down" hits per day/cm^3,[1] and they have been measured by Yagoda.[10] The variations of these hits with altitude during years of a "quiet" sun and of an "active" sun are shown in Fig. 5. The ICRP Task Group recognized the unique problems posed by this type of radiation as have other investigators. Referring to these "thin-downs", the report notes that "Such tracks of affected cells have been observed experimentally in the skin of mice exposed to cosmic radiation in the upper atmosphere and, although of little functional importance in the skin, might be of much greater importance in the embryo or in vital organs such as the brain. Attempts to study this question with microbeam irradiation suggest that the observed changes per exposed cell are smaller than for the same number of ions per cell delivered to a larger volume of tissue; however, no RBE value can be cited for an effect that is produced by high-LET radiation but not by low-LET radiation under the conditions of interest. Some other means will have to be found, therefore, if such effects are to be taken into account in calculation of the dose equivalent. Apart from this special case, the risk-limiting somatic effects from high-energy radiations are not different from those ordinarily considered in protection work."

The dose rate from solar radiation averages somewhat less than that from galactic radiation, as is indicated on Fig. 6 which is due to Fowler and Perkins. The solar radiation is composed largely of fast protons, but as these penetrate to a depth of 60,000 to 80,000 ft in the atmosphere, a spectrum of secondaries is produced so

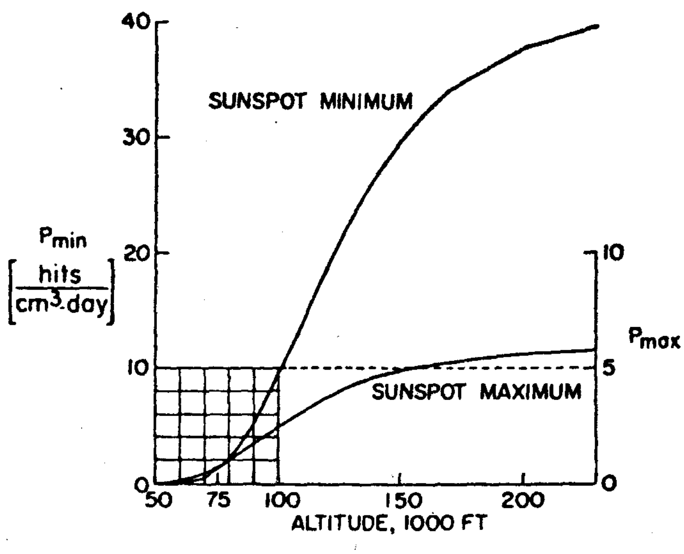

FIG. 5. Variation of thin-down intensity with altitude for seasons of maximum and minimum sunspot activity (from H. Yagoda)

that the radiation field has much of the same complexity as does galactic radiation at these depths. As will be noted from Fig. 6, the average intensity does not constitute a severe problem as compared with the galactic radiation field. However, solar radiation varies greatly in intensity, the activity being closely correlated with sun-spot activity which follows a rather regular cycle of intense and depressed activity, one cycle representing about 10–11 years and the intensity of a particular burst or "flare" may vary over as much as 6 orders of magnitude. There have been seven giant flares that have occurred during the last two solar cycles, that is, in the last 20 years, that have carried substantial fluxes of photons of 1 GeV or higher energies. These flares have produced geophysical phenomena which could be used as a basis for detection soon enough for the SST to descend to a lower altitude and have the benefit of the shielding of more of the atmosphere. The giant flare of 23 February 1956 is by far the largest observed to date and is estimated to have produced doses ranging from 2–20 rad during the first hour of the event at the 60,000- and 80,000-ft altitudes and over the polar regions. The range of values, as estimated by Fowler and Perkins, is shown in Fig. 7. The intensity at SST altitudes depends not only on the protons ejected by the sun but also is markedly influenced by the state of the magnetic fields existing between the sun and earth which may serve to deflect much of the radiation or to facilitate its passage to the earth. It must be recognized that there is considerable uncertainty in this estimate, because there was no useful balloon flight until 20 hr after the event, and the dose estimates depend upon extrapolated data on the actual intensities and spectra at SST altitudes.

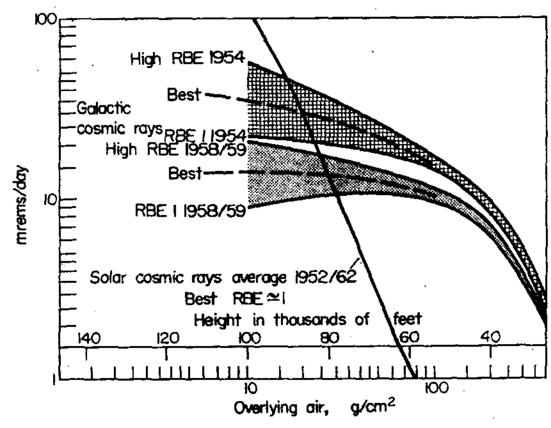

Fig. 6. Radiation intensity in rems for galactic and solar cosmic rays as computed for this report.

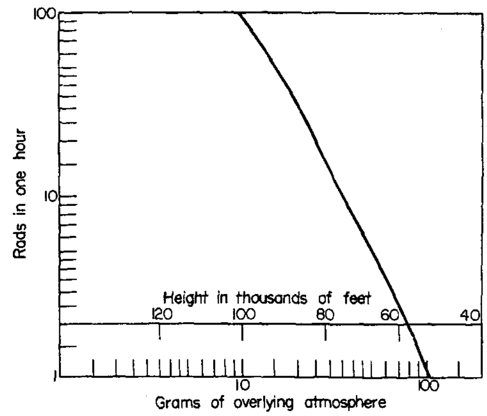

Fig. 7. Estimated dose from the most severe solo cosmic ray outburst 0345–0445 23 Feb 1956. The radiation dose for the one hour period 0345–0445 UT 23 February 1956 as a fraction of height or depth in the atmosphere for $\lambda \geq 60°$. The rest of the outburst produced a further irradiation of about 50% of that produced during the first hour.

As Fowler and Perkins[8] state, "We must now ask the question as to whether the sample over the last sunspot maximum is likely to have been representative. We estimate that the outburst of 23 February 1956 was responsible for approximately one half of all the solar particles of energy > 100 MeV that have arrived since 1950, and greater fractions of particles of higher energy. Are such outbursts to be expected more or less often than once in 10 years—or could we expect even more severe outbursts—say 10 or 100 times as great?

"We mentioned earlier that the 53 outbursts in the last solar cycle were spread over an estimated range of 10^5 in intensity, and that this huge range was due to propagation conditions between the sunspot and Earth as well as to the intrinsic intensity of the solar flare. . . . So it seems likely that the probability of experiencing another solar event comparable to that of 23 February 1956, or an even more intense one during the course of any 11 year sunspot period is rather high."

The question of taking evasive action, i.e. descending to lower altitudes or, in periods of intense activity, flying over routes which lie closer to the equator, has been proposed and often arouses quite divergent opinions. It is estimated that an SST in flight might have some 10–15 min warning before the arrival of the really intense build-up of the field which may reach peak intensity in a matter of minutes. The time course of neutron monitor readings, as observed at Deep River, Ontario, in November 1960, are shown in Fig. 8.[3] The sharp rise in intensity shown here, followed by the gradual decline in intensity extending over hours is fairly typical. In the giant flare of 23 February 1956, Fowler and Perkins estimate that the total dose during the entire day was only 50% higher than the dose during the first hour. Thus any evasive action must be rather prompt.

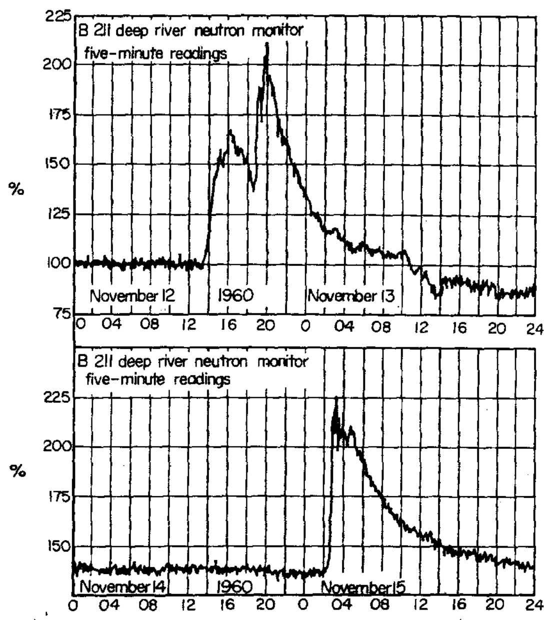

FIG. 8. Cosmic ray indices (pressure corrected hourly totals). Record of neutron monitor readings for the solar outbursts at Deep River, Ontario, for 12–15 November 1960 taken from ref. 4 or 5.

It has been questioned whether a very prompt change in course might not entail other hazards for the occupants of the SST[11] which would be more severe than the hazard posed by the radiation fields. Certainly, those who propose that such action be taken are not envisioning actions which would involve any appreciable probability of wrecking the plane or causing severe physical distress to the occupants. Those designing the SST are well aware of the problem of radiation exposure and are investigating the desirability and means of taking evasive action. Of course, this is not a definite commitment to such a policy, but some of the working reports discuss in detail the type of monitoring instruments to be carried on the plane; and, in one case, a "safe" range up to 5 mrem/hr, an "alert" or "warning" range up to 50 mrem/hr, and an "action" range above 50 mrem/hr have tentatively been selected. None of the working papers the author has seen mention or discuss any hazard that might be involved in descending to lower altitudes. Many airlines are distributing advance publicity concerning the SST in the material they offer to passengers in the seat pockets on current flights. A survey of this literature reveals that several airlines are already educating the public as to the presence of these radiation fields and reassuring them that adequate measures are being taken to meet the problem. Several of these brochures mention the possibility of evasive action, and all indicate that in the years before commercial flights begin, there will be considerable study of the problem, and during the year or more of extensive testing of the craft, there will be much more data on the problem than we now have.

In summary, the average levels of galactic and solar radiation do not pose any great problems. The ICRP Task Group report estimates, conservatively, that the average dose rate on a polar route and at 60,000 to 80,000 ft might be as much as 3 mrem/hr. For the great bulk of travelers who make only a few flights a year, this is well within the limits on exposure of individuals of the population recommended by the ICRP. For the crew, or the courrier who is continually making such trips, it is another matter, and they may have to be classed as radiation workers. For example, a schedule of 40 hr/mo of time in actual flight over high latitudes might entail about 1.5 rem/yr as an average, although it must be remembered these are generally conservative estimates. As mentioned above, some of the present plans provide for monitoring instruments on board, and these will provide better estimates as flying experience accumulates. Also, taking account of the fraction of the population likely to be involved and of time factors, the contribution to the total genetic load is small as noted by the report of the ICRP Task Group.

REFERENCES

1. H. J. SCHAEFER. Radiation and man in space. *Advances in Space Science*, Vol. 1, p. 267. Frederick I. Ordway III, ed. (Academic Press, Inc., New York, 1959).
2. T. FOELSCHE and E. H. GRAUL. Radiation exposure in supersonic transports, *Atompraxis* **8,** 365 (1962).
3. P. H. FOWLER and D. H. PERKINS. Cosmic Radiation and Solar Particles at Aircraft Altitudes —Background Note, Air Registration Board, Supersonic Aeroplane Airworthiness Committee, SAAC/20 (1962).
4. E. J. FLAMM and R. E. LINGENFELTER. *Science* **144,** 1566 (1964).
5. M. LEIMDORFER, R. G. ALSMILLER, JR. and R. T. BOUGHNER. Calculations of the radiation hazard due to exposure of supersonic aircraft to solar flare protons. In press.
6. Radiobiological aspects of the supersonic transport (a report of the ICRP Task Group on the Biological Effects of High-Energy Radiations), *Health Phys.* **12**(2), 209 (1966).
7. H. V. NEHER and H. R. ANDERSON. *J. Geophys. Res.* **67,** 1309 (1962).
8. R. C. HAYMES. *J. Geophys. Res.* **69,** 841 (1964).
9. D. E. WATT, D. M. CLARE and A. R. B. GORDON. *Tissue Dose-Equivalent Rates (i) From Cosmic Ray Neutrons. (ii) In the Low Level Environment of Chapelcross Nuclear Power Station.* PG Report 734 (CC), United Kingdom Atomic Energy Authority (1966).
10. H. YAGODA. Cosmic-ray monitoring of the manned stratolab, balloon flights, *Geophys. Research Directorate Notes*, No. 43 (1960).
11. H. W. PATTERSON. Hazards of flight in the supersonic transport, *Health Phys.* **12**(8), 1151 (1966).