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SUMMARY PAGE

THE PROBLEM

At SST altitudes the galactic radiation level is about 50 to 100 times higher than at sea level. The prospect of large-scale commercial passenger operations calls for accurate assessment of accumulated exposures of the individual crew member and passenger as well as the radiation load to the population, although the radiation level as such might not appear objectionable.

FINDINGS

In the 60- to 80,000-foot altitude region, the galactic radiation level depends strongly on geomagnetic latitude and is highest in the polar region beyond 60° where it equals about 1 millirem/hour. Spending 600 hours/year at altitude, crew members would receive a dose that exceeds by 20 per cent the Maximum Permissible Dose (MPD) for "Members of the Public" as defined by the International Commission on Radiological Protection (ICRP). If crew members are considered "Radiation Workers," the dose of 0.6 rem/year they receive would stay well below the MPD of 5 rem/year for that category.

If we assume 50 SST each flying 200 passengers for 1000 hours per year at altitude, that exposure would lead to a population dose of 10^4 rem; this would approximately equal that contributed by industrial radiation workers. Both contributions, however, rank well below the two main man-made causes of additional background exposure, medical use of x-rays and fallout.

At 65,000 feet the flux of heavy primaries is attenuated to less than 3 per cent of its free space value. Still substantially smaller is the fractional flux of nuclei of maximum ionization that accounts for the microbeam effectiveness of the heavy component. This particular hazard, which poses an essentially unknown quantity of galactic radiation exposure in free space, is selectively reduced to an insignificant level at SST altitudes.

INTRODUCTION

Cruising altitudes for the first generation of SST, the American Boeing 2707 and the Anglo-French Concorde, will be in the 60- to 65,000-foot region. At these altitudes, level and composition of environmental ionizing radiation differ substantially from those at sea level. In terms of absorbed doses in air, the radiation level in the indicated region is about 50 to 100 times higher than at sea level. Although experimental and military high-performance aircraft as well as manned spacecraft are operating routinely at altitudes where still higher environmental radiation levels prevail, the prospect of large-scale commercial passenger operations creates an entirely new situation as seen from the public health viewpoint. At a time when detailed studies of small man-made increases of the natural background radiation at sea level due to fallout or industrial or medical use of radiation are conducted, the just-quoted 50- to 100-fold increase would seem to point out the need for accurate assessment of the galactic radiation exposure at SST altitudes even though the radiation dosages involved would not appear objectionable as such.

Two basically different types of radiation exposures in the altitude region in question have to be examined: 1) short-term increases of the normal radiation level due to solar particle beams and 2) the normal radiation level due to galactic radiation. In discussions of the radiation hazard in SST, main emphasis usually rests upon the first type, the solar particle events. While it is certainly true that the pertinent radiation dosages for rarer types of solar flares can reach undesirable values, it must be emphasized that flares which would create greatly elevated radiation levels as far down in the air ocean as 65,000 feet are rare events. As a consequence, the dose contributions involved do not figure, in the record of accumulated exposure over longer time spans, as prominently as one might expect. High instantaneous dose rates from a flare prevail for a few hours at the most and will occur only a few times per year during the period of high activity in the 11-year solar cycle. Quite differently, galactic radiation is an ever present phenomenon and therefore will account for the larger part of the doses accumulated by the vast majority of crew members and passengers of SST even if no evasive action were taken to ground or divert SST to lower altitudes upon the rare occurrence of a major flare. Especially if the radiation burden to the entire population is to be assessed, the galactic radiation is a disproportionately larger contributor than the rare major flare events affecting an SST caught at altitude. It is seen, then, that an an analysis of the galactic radiation level at SST altitudes is of primary interest if the public health aspects of commercial SST operations are to be discussed.

ALTITUDE PROFILE OF GALACTIC RADIATION EXPOSURE

The primary cosmic ray particle flux at the top of the atmosphere consists of 85 per cent protons, 13.5 per cent alpha particles, and 1.5 per cent heavier nuclei. It also contains a very small flux of primary electrons which usually is not listed as a separate component since its contribution to the total ionization dosage is negligible. At an altitude of 65,000 feet corresponding to an overhead residual air mass of 58 g/cm^2, the primary proton flux is attenuated to about half its free space value, the alpha flux to about a quarter, and the heavy flux to about 3 per cent or less depending on the Atomic Numbers of the various types of heavy nuclei. Quite differently, the total ionization dosage at the altitude in question is substantially larger than that at the top of the atmosphere because of the large build-up of secondaries in nuclear interactions of high energy primaries with atomic nuclei of the atmosphere. The basic process responsible for the build-up is cascade formation since most secondaries produced in collisions of galactic primaries with air nuclei obtain enough energy to release whole sequences of secondary collision events. While the three basic types, the plain nucleonic cascade, the nucleon-meson cascade, and the photon-electron cascade, have been studied experimentally and theoretically by many investigators, their combined action and relative contributions to the local ionization dosage at different altitudes throughout the atmosphere have never been analyzed quantitatively. However, the total ionization dosage as such has been measured by many experimenters. Very elaborate are the data of Neher (1) who has carried out, over more than two solar cycles, ion chamber measurements on the altitude and latitude profiles of the total ionization with balloons.

For dosimetric purposes, a serious shortcoming of all measurements of the total ionization rests in the fact that such data do not contain information on the types of ionizing particles and their respective energy spectra. This limits the dosimetric evaluation to absorbed doses in rad units, with the corresponding dose equivalents in rem units remaining undetermined since Quality Factor (QF) and Relative Biological Effectiveness (RBE) cannot be established. This deficiency is especially serious in the case of the galactic radiation exposure at SST altitudes because a sizeable portion of the total ionization is produced by secondary neutrons and would require a QF value of 8 to 10 for conversion to dose equivalents.

Another limitation of the data on the total ionization from galactic radiation in the Earth's atmosphere rests in the fact that they allow only an inference on the exposure in free air at the altitude of observation. For a human body shielded by the airframe of an SST, that exposure is altered in a complex manner by net decreases due to attenuation of certain components of the radiation and by net increases due to additional production of secondaries in the local hardware. Evidence exists which suggests that, at SST altitudes, there will be a net attenuation of the ionizing components in the airframe material whereas the neutron component will undergo a net intensification. In regard to the neutron component, additional uncertainties exist because available experimental data from different sources do not agree as well as those for the ionizing component. This is demonstrated by the discrepancy between the assessment of the neutron dose in the report (2) of a special committee of the International Commission on Radiological Protection (ICRP) and data communicated by Watt (3) who points out that the ICRP data might be too low by a factor of 2.

Radiobiological viewpoints further emphasize the importance of the neutron component if radiation hazards to man are to be investigated. It is well established that there is little or no recovery from long-term damage from chronic exposure to low dose rates of high LET radiation as opposed to x- or gamma rays for which, at sufficiently low dose rates, a complete recovery seems to occur. A separate determination of the low and high LET fraction of the galactic exposure at SST altitudes thus seems of special importance for a complete assessment of long-term effects from accumulated exposure as, for instance, in the case of the career dose of flying personnel.

In the context of the present study where radiation safety aspects are investigated, it seems appropriate, in cases of discrepancies of experimental data, to select the higher values in order to ensure a safety margin by keeping estimates conservatively high. In doing so one arrives at the exposure levels for the ionizing and the neutron components shown in Figure 1. The neutron dose rate equivalents have been obtained by applying a QF of 8 to absorbed dose rates. As can be easily verified from Figure 1 by dividing the neutron dose equivalents by 8, the absorbed doses remain on the level of a few per cent of the contributions of the ionizing component. This demonstrates the unique importance of the neutron component for a correct assessment of the galactic radiation exposure at SST altitudes.

It has been pointed out that the maximum range of 4000 miles for the SST types presently in the design stage would preclude flying on polar routes where the galactic (as well as flare-produced) radiation exposure is at its highest and that dosages therefore should be computed for the smaller radiation levels prevailing at lower latitudes. As this argument would seem to be only of temporary validity until more advanced types of SST come into service, it is felt that the following discussion should be based on the radiation levels prevailing at high latitudes. As can be seen from Figure 1, we have to assume, then, a highest dose rate of about 1 millirem/hour (1000 microrem/hour) at a 65,000-foot altitude.

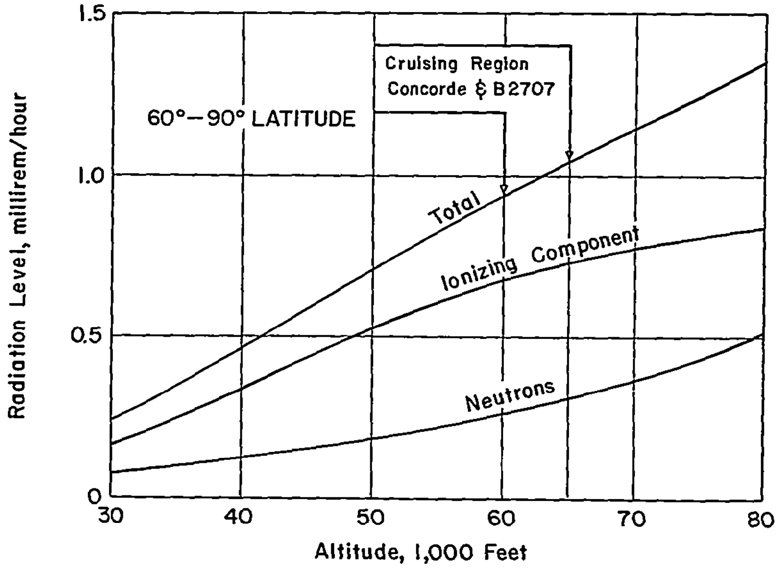

Figure 1

Galactic Radiation Level in the Lower Stratosphere at High Latitudes

COMPARISON OF RADIATION BURDENS

If the radiation exposure of crew members and passengers at SST altitudes is to be appraised correctly in its significance as an additional radiation burden for man in the technological age, it has to be aligned with the other natural and man-made sources of ionizing radiation. A compilation of typical environmental radiation levels is shown in Table I.

Table I

Typical Environmental Radiation Levels

Location or Source	Dose Rate Equivalent microrem/hour	 millirem/year
Mid-Atlantic	6	55
New York City	8-15	70-130
Guarapari, Brazil		
Average	140	1200
Hot spot	2000	17,500
Fallout from atmospheric testing		
Whole body	1-3	10-25
Bone	3-9	25-80
Color television		
Close to set	500	--
6-foot distance	10	--
30,000-foot altitude	240	--
65,000-foot altitude	1000	--

It seems reasonable to assume that SST crew members would be the most heavily exposed group of the population since they would spend an estimated maximum of 600 hours per year at altitude. The resulting exposure of 600 millirem/year is substantially higher than the fallout dose of about 25 millirem/year, as can be seen from Table I. The individual crew member or passenger would accumulate the same as the yearly fallout dose in about 25 hours at SST altitudes. For the radiation burden of the population as a whole, however, the picture is very different. If we assume 50 SST planes in operation flying their full capacity of 200 passengers each and spending 1000 hours at altitude per year, we arrive at an additional radiation load for the population of 10^4

rem as compared to 5×10^6 rem of fallout exposure for a population of 2×10^8.* In other words, the population dose from commercial SST operations would equal 0.2 per cent of the fallout exposure.

For the individual crew member or passenger the situation is, as pointed out before, very different. He was seen to accumulate the equivalent of the yearly fallout dose in 25 hours at SST altitude; thus, with 600 hours per year at altitude, a crew member would receive 600 millirem/year or 24 times the fallout dose. This same dose of 0.6 rem/year exceeds by 20 per cent the Maximum Permissible Dose (MPD) for "Members of the Public" as recommended by the ICRP (4). However, if SST crew members are considered "Radiation Workers" in terms of ICRP regulations, the exposure in question would remain well within permissible limits since, for that category, the MPD is ten times larger (5 rem/year) than for "Members of the Public" (0.5 rem/year). Considering the fact that less than 10 per cent of those employed in the atomic energy industry receive an occupational exposure in excess of 1 rem per year (5), one realizes that SST crew members receiving 0.6 rem/year would not rank low on the exposure scale of Radiation Workers at all and should indeed be classified in that category.

The addition to the population dose from the exposure of SST crew members would be, of course, very small as compared with that from industrial radiation workers because of the much smaller number of persons involved. On the other hand, if the combined additional doses from both crew members and passengers are compared with those from industrial radiation workers, the picture is again different. Assuming that the latter group constitutes 0.03 per cent of the total population or 60,000 persons (5), and considering furthermore the above-mentioned fact that less than 10 per cent of that group receives an occupational exposure in excess of 1 rem per year, one sees that industrial exposure contributes less (and in all likelihood substantially less) than 60,000 rem to the population dose. This is the same order of magnitude as the above-established contribution of 10,000 rem per year to the population dose from a fully operative SST system. It is seen, then, that the galactic SST exposure ranks, as far as the dose to the population is concerned, about equal with the corresponding dose from the industrial use of atomic energy. However, the over-all situation in regard to man-made increases of the natural background will change only very little when the SST exposure is added. As shown in Table II, both industrial and SST exposures are substantially smaller than the two other man-made contributors, fallout and medical use of x-rays.

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*In quoting the radiation load for a population, two different ways are commonly used, depending on the nature of the exposure and the available information. Either the product of the number of exposed persons and the dose is directly quoted as radiation load or the average exposure of all members of the population is determined by dividing the product by the size of the population.

Table II

Population Doses from Natural Background and Man-Made Additions

Source	Yearly Dose Equivalent, millirem
Natural background	150
Medical x-rays	100
Fallout	25
Industrial radiation workers	$\ll 0.3$
SST travellers*	0.05

*Assuming 10^7 passenger hours per year at altitude.

A further alleviation of the radiation load from SST travel derives from the fact that the dose assessment above is based on the radiation level prevailing at high latitudes, i.e., on polar routes. Since a larger fraction of SST passenger miles can be assumed to be flown at lower latitudes, a substantial reduction of the corresponding contribution to the population dose will occur. The pertinent relationship is shown in Figure 2. To be sure, for the heavily travelled transatlantic route in particular, the gain is only of moderate proportions since the galactic radiation level in the lower stratosphere in the region in question is reduced merely to about 75 per cent of the maximum in the polar region.

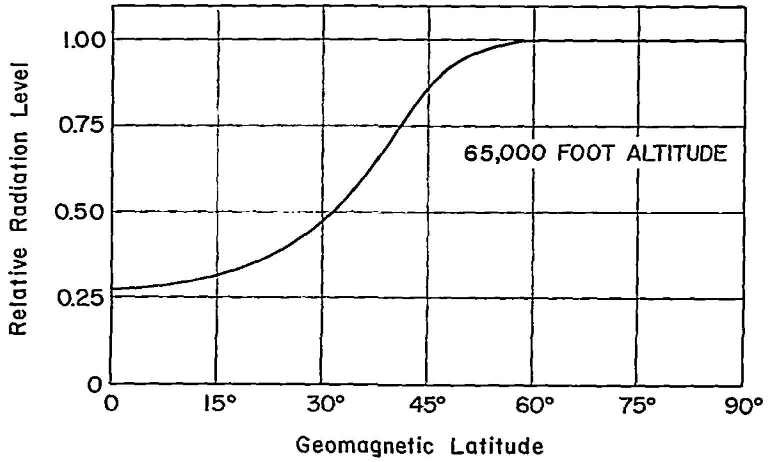

Figure 2

Latitude Dependence of Galactic Radiation Level in the Lower Stratosphere

HEAVY NUCLEI AT SST ALTITUDES

A dosimetric evaluation of the galactic radiation exposure at SST altitudes would be incomplete if analysis of the dose contribution from heavy nuclei were not included. To be sure, at a 65,000-foot altitude residual fluxes of the various Z components of the heavy spectrum are attenuated to a few per cent or less of their intensity at the top of the atmosphere. However, since a single passage of a heavy nucleus with a sufficiently large LET constitutes a local "microbeam" irradiation, for directly traversed cells, even a small flux still represents an above-threshold injury on the cellular level. The conventional concept of MPD, therefore, is not applicable to this peculiar type of irradiation, as the ICRP (4) expressly has pointed out. So far, no alternate dosimetric unit for microbeams has been proposed which would measure tissue damage in adequate quantitative terms. For galactic heavy primaries in particular, the problem is already rather complex in its pure physical aspects because the relative Z abundances and the energy spectra, which determine the microbeam fraction of the heavy flux, change in a complicated manner as the radiation penetrates more deeply into the atmosphere. The basic characteristics of this transition are reviewed briefly.

The primary galactic radiation is made up of nuclei of all chemical elements from H (Z = 1) to U (Z = 92). However, nuclei heavier than Ni (Z = 28) are so rare that Z abundances are usually listed only up to Ni. Even within these limits, it is customary to measure and quote flux values for groups comprising several Z numbers in the interest of better statistical significance and also because of the limited Z resolution of most experimental techniques.

Table III shows the Z composition of galactic radiation. Column 5 lists the relative Z abundances for the truly primary radiation outside the atmosphere. In the present context where interest centers on components with LET values greatly exceeding those of conventional high LET radiations, the transition analysis can be limited to the interval from Z = 6 to 28. Figure 3 shows the attenuation of these components in the atmosphere. The attenuation of a flux of nuclear particles with isotropic 2 pi incidence on a plane absorber layer (the atmosphere) is described mathematically by the Gross Transformation and the Gold Integral (6) which take the greater absorption length for oblique incidence into consideration. The data in Figure 3 have been established with the aid of these functions, using the collision mean free path values listed in Column 4 of Table III. Column 6 of the same table shows the flux values for 65,000 feet read from Figure 3. It is seen that the attenuation in the atmosphere (as in any other absorbing material) depends greatly on the Z number, with the heavier components attenuated to substantially smaller values. That means that the absorption in the residual air overhead at SST altitudes acts predominantly on the biologically most effective part of the heavy spectrum. This effect is further enhanced because, in the attenuation of the individual Z species, nuclei of lower energies, i.e., of higher LET, are removed faster than those of higher energies. A quantitative analysis of this transition of the energy spectrum is an involved procedure and has been described in an earlier report (7). As shown there, less than 0.1 per cent of the residual flux at 65,000 feet, i.e., less than 3/1000 of a per cent of the

Table III

Composition of Primary Galactic Radiation in Free Space and at SST Altitude

Atomic Number Z	Element	Group Representative Z	Collision Mean Free Path, g/cm^2	Relative Z Abundance in Free Space	Residual Flux at 65,000 ft % of Free Space	Dose Rate at 65,000 ft millirem/hr
1	H	1	--	10,000	--	--
2	He	2	--	1,429	--	--
3-5	Li-B	4	--	32	--	--
6-9	C-F	7	28	106	3.3	0.010
10-12	Ne-Mg	12	22	16.5	1.7	0.009
13-21	Al-Sc	20	16	6.3	0.56	0.003
22-28	Ti-Ni	26	14	5.7	0.32	0.005

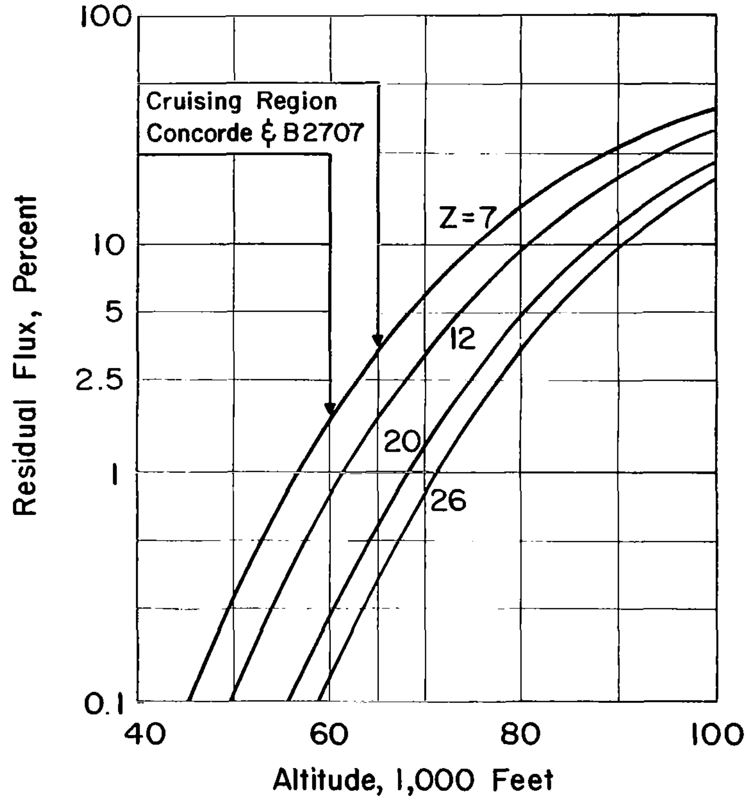

Figure 3

Depth of Penetration of Heavy Primaries into the Atmosphere

free space flux, is of the critical energy where the LET passes through a maximum. In other words, the microbeam part of the heavy flux is virtually extinguished at SST altitudes and what is left of the heavy flux can be adequately assessed in conventional dosimetric terms of dose equivalents.

CONCLUSIONS

The foregoing appraisal of radiation levels and accumulated doses for the galactic radiation exposure in SST clearly indicates that the radiation load for the individual crew member and passenger as well as the grand-total population dose does not pose special problems except for the technicality of classifying SST crew members as "Radiation Workers." On the over-all scale of man-made additions to the natural background of ionizing radiation, such contributions rank very low and would not seem to call for protective measures or record-keeping as far as travelling "Members of the Public" are concerned.

On the other hand, with the advent of the SST commercial aviation will enter a stage where high altitude radiation exposure has to be reckoned with as a new parameter of the environment. It would not seem farfetched to visualize a second generation of SST advancing to cruising altitudes of 80,000 feet. As a further step, a new type of transport using combined orbital and glide trajectory flight profiles might be developed. Such dynasoar-type vehicles would bridge global distances in a few hours non-stop, a task which seems beyond the reach of the SST with its comparatively short range. These trajectory vehicles would ascend rapidly clear through the stratosphere and stay, for a substantial fraction of their flight path, in the mesosphere. In this line of development, the radiation hazard will become an ever more important issue. From the very beginning, the radiation problem in SST should be seen in these deeper perspectives.

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13. ABSTRACT

The prospect of large-scale commercial passenger transportation at SST altitudes in the lower stratosphere calls for an accurate assessment of the galactic radiation exposure. Highest radiation levels prevail at high latitudes (polar region) and solar minimum and reach about 1 millirem/hour at 65,000 feet. The accumulated dose of 0.6 rem/year which an SST crew member spending 600 hours/year at altitude would receive exceeds the Maximum Permissible Dose (MPD) for "Members of the Public" and would classify crew members as "Radiation Workers" in terms of official recommendations. The assumption of 50 SST each exposing 200 passengers to 1000 hours/year at SST altitude would lead to a population dose about equal to the contribution from industrial radiation workers, with both exposures ranking well below the two largest man-made additions to the natural background, medical use of x-rays and fallout. The heavy flux is attenuated to 3 per cent or less at 65,000 feet, depending on the nuclear species; yet, only 0.1 per cent of this residual flux accounts for maximum ionization hits. That means the microbeam hazard of heavy nuclei is insignificant at SST altitudes.

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