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Atmospheric Ionizing Radiation (AIR) ER-2 Preflight Analysis

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Abstract

Atmospheric ionizing radiation (AIR) produces chemically active radicals in biological tissues that alter the cell function or result in cell death. The AIR ER-2 flight measurements will enable scientists to study the radiation risk associated with the high-altitude operation of a commercial supersonic transport. The ER-2 radiation measurement flights will follow predetermined, carefully chosen courses to provide an appropriate database matrix which will enable the evaluation of predictive modeling techniques. Explicit scientific results such as dose rate, dose equivalent rate, magnetic cutoff, neutron flux, and air ionization rate associated with these flights are predicted by using the AIR model. Through these flight experiments, we will further increase our knowledge and understanding of the AIR environment and our ability to assess the risk from the associated hazard.

1. Introduction

The broad aim of the atmospheric ionizing radiation (AIR) ER-2 flight measurement campaign is to improve our understanding of the ionizing radiation environment, for example, composition, spectral distribution, and corresponding intensities in the upper troposphere and lower stratosphere where people flying future supersonic transports will spend the majority of their flight time. These radiation measurements will enable radiobiologists to improve our understanding of the health risks associated with this exposure to high-altitude flight. The impetus to examine the impact of ionizing radiation stems from (1) recent reductions in recommended radiation exposure limits by the International Commission on Radiological Protection (ICRP) and the National Council on Radiation Protection and Measurements (NCRP), and (2) recent experimental results showing that an uncertainty in aircraft radiation exposure exists. The NCRP examined the state of knowledge of atmospheric radiation in high-altitude flight and made recommendations on the need for improved information to develop a protection philosophy for high-altitude commercial operations. The High-Speed Research (HSR) Environmental Impact Radiation group developed the AIR project to reduce the uncertainties of radiation measurements applicable to the high-altitude flight program of the High-Speed Civil Transport (HSCT). Once these uncertainties are reduced, an adequate protection philosophy can be developed.

Langley Research Center (LaRC) performed atmospheric radiation studies under the Supersonic Transport (SST) development program in which important ionizing radiation components were measured and extended by calculation to develop the existing AIR model. In that program, the measured neutron energy spectrum was limited to an upper value of 10 MeV by the instrumentation of the era. Extension of the neutron spectrum to higher energies was made by using theoretical models. Subsequent evaluation of solar particle events showed that high exposures will occur on important high-latitude routes, but acceptable levels of exposure can be obtained if a timely descent to subsonic altitudes is made. The principal concern was for pregnant occupants onboard the aircraft (ref. 1). As a result of these studies, the Federal Aviation Administration (FAA) Advisory Committee on the Radiobiological Aspects of the SST recommended (ref. 2) the following:

1. Crew members will have to be informed of their exposure levels.

2. Maximum exposures on any flight should be limited to 5 mSv.

3. Airborne radiation detection devices for total exposure and exposure rates will be provided.

4. A satellite monitoring system should provide SST aircraft real-time information on atmospheric radiation levels for exposure mitigation.

5. A solar forecasting system will warn flight operations of an impending solar event for flight scheduling and alert status.

These recommendations are a reasonable starting point for requirements of the HSCT with some modification reflecting new standards of protection as a result of changing risk coefficients.

One result of the SST studies was the realization that subsonic air crews are among the most highly exposed occupational groups (refs. 1 and 3). This study prompted the FAA to develop the CARI (Civil Aeronautical Research Institute) exposure estimation code based on the LUIN transport code (developed by the Department of Energy (DOE) Environmental Measurements Laboratory) to further study these air crews (ref. 4). The estimated risk of serious illness to the child of an air crew member during pregnancy is on the order of 1.3 per thousand in excess of the general population risk rate of 1.15 per thousand (ref. 5), including all types of cancer and mental retardation among children. Hence, the FAA recommended that air carriers begin to train their employees on the risks of in-flight subsonic exposure (ref. 6). The dose rates at the HSCT altitudes are a factor of 2 to 3 higher than for subsonic operations, and the HSCT crew's annual flight hours will have to be reduced by this same factor to maintain exposure levels comparable to those of the subsonic crews. One may assume that similar instruction for air crews will be required for HSCT operations and that restrictions on crew usage of the HSCT will, by necessity, be different from those on subsonic transports.

Regulations for exposure limits are based primarily on the estimated cancer risk coefficients. These coefficients have increased significantly over the last decade because solid tumor appearance is higher among the World War II nuclear weapons survivors than was initially anticipated (refs. 7 through 10). As a result, new recommendations for reducing regulatory limits have been made by national and international advisory bodies (refs. 10 and 11). Whereas subsonic crew exposures are well under the current regulatory limits, the substantial reductions (by factors of 2.5 to 5) in the recommended limits will result in the need to improve air crew exposure estimates (refs. 12 and 13). Hence, a workshop on Radiation Exposure of Civil Air Crews held in Luxembourg on June 25 to 27, 1991 was sponsored by the Commission of the European Communities Directorate General XI for Environmental Nuclear Safety and Civil Protection (ref. 12). The workshop noted the closure of the gap between subsonic air crew exposures and the newly recommended regulatory limits and, in fact, was concerned that limits may be exceeded in some cases. Therefore, uncertainty in exposure estimates becomes a critical issue, and emphases on the number and spectral content of high-energy neutrons, as well as the penetrating multiple charged ions, were identified as a critical issue for subsonic flight crews. The issues for HSCT commercial air travel are compounded by the higher operating altitudes (higher exposure levels) and the possibility of exposures to a large solar event, wherein annual exposure limits could be greatly exceeded on a single flight (refs. 1 and 14). Because of the higher expected exposures in high-altitude flight, the congressionally chartered Federal Advisory Agency on Radiation Protection (NCRP) examined the data on atmospheric radiation and made recommendations (ref. 15) on the need for future studies as follows:

1. Make additional measurements of atmospheric ionizing radiation components with special emphasis on high-energy neutrons.

2. Conduct a survey of proton and neutron biological data on stochastic effects and developmental injury for evaluation of appropriate risk factors.

3. Develop methods to avoid solar energetic particles, especially for flight above 60 000 ft.

4. Develop an appropriate radiation protection philosophy and radiation protection guidelines for commercial flight transportation, especially at high altitudes of 50 000 to 80 000 ft.

Clearly, these issues must be addressed before the HSCT goes into commercial operation to ensure the safety of the crew and passengers. In direct response to the NCRP recommendations, development of an experimental flight package to reduce the uncertainty in AIR models is being readied. The focused goal of this project is to develop an improved AIR model with uncertainties in the atmospheric radiation components of 20 percent or less to allow improved estimation of the associated health risks to passengers and crew. Special emphasis will be given to the high-energy (10 to 1000 MeV) neutrons in the altitude range of 50 000 to 70 000 ft.

The results will be expressed in terms of an environmental AIR model able to represent the ambient radiation components, including important spectral components with angular distributions, which will allow evaluation of aircraft shielding properties and the geometry of the human body. The model also must be capable of representing the atmospheric radiation levels globally, as a function of solar modulation and of evaluating radiation levels during solar particle event increases. Following the development of the AIR model, impact studies on radiation exposure limits for crew usage and passengers (especially frequent flyers) will be performed to assess the need of developing a specific philosophy to control exposures in HSCT operations. Using data from available satellite systems, new real-time software, based on the new AIR model, will allow risk mitigation and flight planning in the case of a large solar event.

These studies will result in requirements for studying the economic impact on operations costs. For example, it has been suggested that the HSCT crew be used at one third to one half the number of block hours now used by subsonic aircraft to minimize exposure. This reduction in hours will require more crews at increased cost. The other possibility is to rotate crews through less exposed routes for a portion of each year, especially during a declared pregnancy among the crew. The need for and the extent of such exposure control measures must await the improvement of the AIR model.

2. ER-2 Measurement and Instrumentation

An instrument package is being developed in accordance with the NCRP recommendations through an international guest investigator collaborative project to acquire the use of existing instruments to measure the many elements of the radiation spectra. Instrument selection criteria were established which include the following: (1) instruments must fit into the cargo bay areas of the ER-2 airplane and be able to function in that environment (some high-quality laboratory instruments were rejected because of their large size or inability to operate in the ER-2 environment), (2) instruments must be free for the project to meet budget constraints, (3) instruments must have a principal investigator with his or her own resources to conduct data analysis, and (4) the instrument array must include all significant radiation components for which the NCRP made minimal requirements. The flight package must be operational, and the first flight must occur before or near the maximum in the galactic cosmic ray intensity (circa spring-summer 1997) and extend through the next cosmic ray minimum (circa 2000 to 2003).

The flight package developed used all available space in the ER-2 cargo areas. The instrument layout is shown in figure 1. The primary instruments in the package consisted of neutron spectrometer detectors, scintillation counters, an ion chamber from the Environmental Measurements Laboratory (EML) of the Department of Energy, and charged-particle telescopes from the Institute of Aerospace Medicine of Deutsche Forschungsanstalt fur Luft- und Raumfahrt (DLR), and Johnson Space Flight Center. Ten other instruments from Germany, Italy, the United Kingdom (UK), and Canada made up most of the remainder of the flight package. These included passive track detectors from the Institute of

Aerospace Medicine, DLR, and the University of San Francisco; tissue equivalent proportional counters (TEPC's) from Boeing and the Defence Research Establishment in Ontario, Canada; and dosimeters from Boeing, the Royal Military Academy in Ontario, Canada, and the National Radiological Protection Board (NRPB) in the UK. The existing primary instruments and the data system were modified for operation on the ER-2. A data acquisition system was incorporated to control operation of the entire instrument package, and to record data from the primary instruments during flight. Data from the other instruments were recorded separately by each instrument and were recovered after a flight. The first flights were in June 1997 near solar minimum and need to be continued through solar maximum, which is expected on or before fall-winter 2003.

3. AIR Model Development

The basic quantities of the present AIR model are the air ionization rate, the 1 to 10 MeV neutron flux, and the rate of nuclear star events in nuclear emulsion. These quantities were measured over a complete set of altitudes, geomagnetic latitudes, and over the solar cycle and were scaled according to known procedures to allow a total time-dependent mapping of the global radiation field. The limitations of the model concern the high-energy neutron spectrum, the quality factor of the ionic components, and the relative contribution of the nuclear stars. The first step in improved model development is to add estimates of the proton and light ion flux by using available transport models and databases. An international agreement with the Japan Atomic Energy Research Institute is being negotiated to provide computational support for adding improved results for the radiation-induced fields from the galactic cosmic ray protons. These results will be augmented by the light and heavier galactic cosmic ion components by using the LaRC cosmic ray transport codes. Global fields, as a function of time, will be generated by using the worldwide vertical cutoff database and high-latitude neutron monitor count rates. Model validation will require a definition of the mapping of the model field quantities to the ER-2 instruments. Although all investigators are responsible for defining their own instrument response functions, the LaRC team will assist in these definitions to every extent possible within funding and manpower limitations. The first model developed for atmospheric ionizing radiation was empirically based on the global measurements program under the LaRC SST study (ref. 1). The instrumentation consisted of tissue equivalent ion chambers, fast neutron spectrometers, and nuclear emulsion. Limited flights were made with tissue equivalent proportional counters (TEPC's), Bonner spheres, and the Concorde prototype radiation monitoring instrument. The flights were made over most of solar cycle 20 with altitude surveys, latitude surveys, and measurements during the solar flare of March 1969. Unfortunately, the program was terminated in the year prior to the largest recorded solar event that was observed during solar cycle 20, the 4 August 1972 event. The data set was augmented by the decades of measurements of air ionization rates by using argon filled steel-walled ion chambers. The high-energy neutrons were estimated by using Monte Carlo calculations as an extension of the measured 1 to 10 MeV flux from the fast neutron spectrometers. These theoretical high-energy neutron flux calculations indicate that over half the neutron dose is from neutrons of energy above 10 MeV and are quite uncertain in their spectral content and intensity, as was noted in the LaRC study (ref. 1), concluded by the Luxembourg workshop (ref. 12) and by the NCRP (ref. 15). The solar particle event predictions are based on Monte Carlo calculations using the Bertini nuclear model and the United Kingdom nuclear data files (ref. 1).

The AIR model development should continue to parallel that of the flight program and should use state-of-the-art transport codes and databases to generate input data to the AIR model. The response functions of each instrument need to be modeled for validation of the AIR model by comparison with the flight data. The Bonner sphere, scintillation counters, particle telescopes, and nuclear track detectors will be used to improve the model spectral intensities.

4. Flight Trajectory

All flights originate from Moffett Field, California, the current home base of the NASA ER-2 aircraft. The ground track of the scheduled flights (flights 2, 3, 5, 6, and 7) are shown in figure 2 with radiation contours of the AIR model.

Flight 1 will be approximately a 2-hr engineering flight required by the ER-2 operations office with pilot's choice of flight path (assumed to be a racetrack around the home base). The aim is to check aircraft operational characteristics and all aircraft and experimental instrumentation to ensure that everything is operating satisfactorily prior to the acquisition of science measurements.

Flight 2 will be approximately a 6.5-hr flight on prescribed northern and easterly headings and will return to home base over the reverse flight path. The aim for this flight is to determine whether radiation measurements are being affected by the shielding characteristics of onboard aviation fuel, to determine the consistency of instrument readings, and to take science data as a function of altitude along a constant-radiation, geomagnetic latitude line. The flight plan for flight 2 is as follows:

- (37°24' N, 122°6' W) Take off and climb from Moffett Field.
- (39°19'49" N, 121°27' W) Turn easterly and continue climb.
- (38°30' N, 117° W) Begin 20-min altitude hold (assumed to be near Wine Glass at 63 000 ft); then climb back to an altitude at which climb at constant Mach number can be attained along the prescribed easterly heading.
- (37°30' N, 112° W) Correct course to maintain constant cutoff.
- (35°54' N, 105° W) Correct course to maintain constant cutoff. Begin to maintain constant altitude for 10 min before reaching point F.
- (34°39' N, 100° W) Execute 180° turn and make slow descent (500 ft/min) (Amarillo) to 52 000 ft. Maintain 52 000 ft for 10 min and then climb to normal cruise altitude along the prescribed flight path, repeating the ground track on the return to Wine Glass.
- (35°54' N, 105° W) Correct course to maintain constant cutoff.
- (37°30' N, 112° W) Correct course to maintain constant cutoff.
- Before returning to Wine Glass, descend to the same altitude as on the outbound leg over Wine Glass (assumed to be 63 000 ft) and maintain that altitude for about 20 min.
- (38°30' N, 117° W) Wine Glass, start descent in preparation of ending mission.
- (39°19'49" N, 121°27' W) Turn south and continue descent.
- (37°24' N, 122°6' W) Land at Moffett Field.

Flight 3 will be approximately an 8-hr flight on prescribed northern, western, and southern headings. The aim is to obtain radiation measurements as a function of geomagnetic latitude as far north as possible with an altitude excursion along a constant-radiation, geomagnetic latitude line at the extreme northern latitude location. The flight plan for flight 3 is as follows:

- (37°24' N, 122°6' W) Take off and climb from Moffett Field and ascend to cruise altitude. Cruise to point G.
- (59°00' N, 116°00' W) Turn west toward point H. Hold altitude fixed for 5 min (Ft. Nelson) after west turn; then execute a medium-rate descent (750 ft/min) to 52 000 ft. Maintain 52 000 ft for 5 min.
- (60°00' N, 123°40' W) Turn southerly (toward Moffett Field) and ascend to cruise altitude. Cruise to Moffett Field.
- (37°24' N, 122°6' W) Descend and land.

Flight 4 will be an engineering flight of approximately 2 hr after instrumentation additions-changes with pilot's choice of flight path (assumed to be a racetrack around home base). The aim is to check aircraft operational characteristics and all aircraft and experimental instrumentation to ensure everything is operating satisfactorily prior to the acquisition of science measurements.

Flight 5 will be approximately a 6.5-hr flight on a prescribed southerly heading over the North Pacific Ocean. At the position Latitude 17 deg N, longitude 127 deg 28 min W, execute a 180° turn and return to base. The aim of the mission is to obtain radiation measurements as a function of geomagnetic latitude to as far south as reasonably possible.

Flight 6 will be approximately a 6.5-hr flight on prescribed northern, western, and southern headings. The aim is to obtain radiation measurements as a function of geomagnetic latitude as far north as possible with altitude excursions along a constant-radiation, geomagnetic latitude line near Edmonton, Canada. The flight plan for flight 6 is as follows:

- (37°24' N, 122°6' W) Take off and climb from Moffett Field, ascend to cruise altitude, and cruise to point J.
- (54°48' N, 116°48' W). Turn west toward point K. Hold altitude fixed for 5 min after west turn; then execute a medium-rate descent (750 ft/min) to 52 000 ft and maintain 52 000 ft for 5 min.
- (56°00' N, 125° W) Turn south, ascend to cruise altitude and cruise toward Moffett Field.
- (37°24' N, 122°6' W) Descend and land.

Flight 7 is a repeat of flight 5. The aim of flight 7 is to check data measurement repeatability.

Flight 8a will be approximately a 3-hr flight; however, this flight must be combined with flight 8b with a 12-hr interval between the flights. Science requirements dictate that flight 8a should be launched about 11:00 a.m. Immediately after takeoff, climb to maximum altitude, cruise for about 30 min, and hold constant altitude for about 10 min. Initiate descent about 12:00 noon and descend at about 500 ft/min (slow rate) to 52 000 ft; then continue descent at the standard rate of descent to landing. The aim of this flight is to acquire daylight data for comparison with nighttime data to determine diurnal variation of radiation.

Flight 8b will be approximately a 3-hr flight after dark (with takeoff after about 11:00 p.m.) with a flight path similar to flight 8a (assumed to be a racetrack around the home base). Climb to maximum altitude, cruise for about 30 min, and hold a constant altitude for about 10 min. Initiate descent at 12:00 midnight and descend at about 500 ft/min (slow rate) to 52 000 ft; then continue descent at the standard rate of descent to landing. The aim of this flight is to acquire nighttime data for comparison with daylight data to determine diurnal variation of radiation.

The total flight hours for these missions is 44 hr. We currently budgeted for 46 hr; an additional 2 hr (as reserve) are recommended in case we need extra engineering flights.

5. Expectation From AIR Model

Computer simulations are made for flights 2, 3, 5, and 6. For each flight, the ground track is depicted in figure 2. The ground track is taken as great circular routes between the navigation points in the figure. The flight path, the location of the flight path, the latitude, the longitude, as well as the altitude profile as a function of time, are obtained. The flight path for flight 2 is shown in figures 3(a) to 3(c). The scientific quantities such as magnetic cutoff, dose equivalent rate $\dot{H}$, dose rate $\dot{D}$, neutron flux, and air ionization rate are predicted as a function of flight time, expressed in minutes. The results for flights 2, 3, 5, and 6 are presented in figures 3(a) to 20. For example, figures 3(a) and 3(b) show the coordinates of the flight path in which the pilot tries to maintain a constant geomagnetic cutoff. Because flight 2 has the prescribed northern and easterly heading and return to home base over the reverse flight path, the coordinates clearly show all the locations as a function of time. Figure 3(c) shows the altitude profile that the airplane is to execute, which also serves as the input data in the AIR model. Figures 3(d) to 7 are the predictions from the AIR model. Because flight 2 is designed to fly parallel to geomagnetic latitude for the major leg (easterly heading and reverse), clearly figure 3(d) shows that the magnetic cutoff value is a horizontal straight line about 4 GV. Figures 4 and 5 show the predictions for dose equivalent rate and dose rate from the AIR model. Keep in mind that those rate values are a complicated function of flight coordinates as well as the altitude and other factors. Based on the figures, clearly the altitude factor alone suggests that the rate can change from 12 to ~15 percent from 16 km to 20 km altitude. The AIR model predicts the neutron flux whose energy range is about 1 to 10 MeV in figure 6 and air ionization rate in figure 7 along the flight path for flight 2. That is, the AIR model predicts an altitude variation in the 1 to 10 MeV neutron flux of about 12 percent and in the air ionization rate of 11 percent at the 4 GV cutoff.

Figures 8(a) to 12 show similar quantities for flight 3, that is, the 8-hr flight on prescribed northern, western, and southern headings. As we mentioned earlier, the purpose for this flight is to obtain radiation measurements as a function of geomagnetic latitude to as far north as possible, with an altitude excursion along a constant-radiation, geomagnetic latitude line at the extreme northern latitude location. Figure 8(b) shows that at the extreme northern latitude, the magnetic cutoff value registers with 0.5 GV were achieved where the altitude survey was performed. Compare figures 9 to 12 with figures 3(c) through 5 for the flight 3 route; the AIR model predicts much higher radiation values than does the flight 2 route. In other words, flight 3, from a radiation safety point of view, flies in a less safe route than flight 2, as was expected. The altitude survey at 0.5 GV shows a variation on the order of 11 percent in 1 to 10 MeV neutron flux and 23 percent for the air ionization rate. Because the prime purpose of flight 3 is to perform a latitude survey, we see that the high-altitude variation in the environment during the cruise portion of the flight, along the northern path, is 32 percent in the 1 to 10 MeV neutron flux and 33 percent in the air ionization rate.

Flight 5 will examine the latitude dependence of the high-altitude environment south of the ER-2 base at Ames Research Center. The model predicted a variation of only a few percent in the radiation levels in a possible altitude survey, and such a survey was eliminated from the flight plan because it was to take place over the Atlantic Ocean and was considered an unnecessary hazard to the pilot. The cutoff reached is predicted to be over 12 GV, giving a latitude survey in conjunction with flight 3 a factor of 24 in cutoff variation. It is clear from figures 14 and 15 that a valley in exposure rates is being approached as we fly into equatorial regions.

Flight 6 is a shorter northern flight to the edge of the northern plateau of the exposures, while repeating the latitude dependence measurements up to 0.8 GV. The maximum environmental quantities are lower, but the altitude variation is a somewhat smaller excursion.

6. Concluding Remarks

The atmospheric ionizing radiation (AIR) ER-2 preflight analysis, one of the first attempts to obtain a relatively complete measurement set of the high-altitude radiation level environment, is described in this paper. The primary thrust is to charcterize the atmospheric radiation and to define dose levels at high-altitude flight. A secondary thrust is to develop and validate dosimetric techniques and monitoring devices for protecting air crews. With a few chosen routes, we can measure the experimental results and validate the AIR model predictions. Eventually, as more measurements are made, we gain more understanding about the hazardous radiation environment and acquire more confidence in the prediction models.

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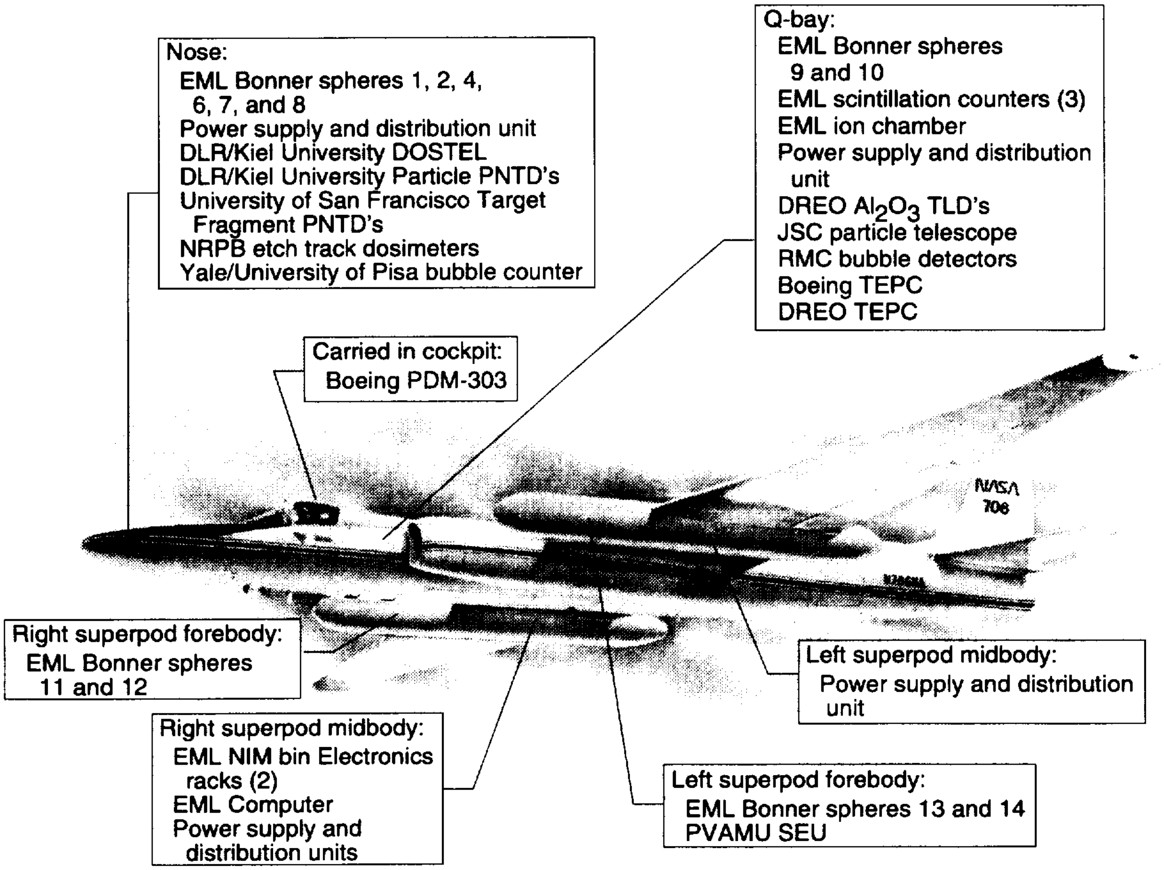
April 24, 1998

References

1. Foelsche, T.; Mendell, R. B.; Wilson, J. W.; and Adams, R. R.: *Measured and Calculated Neutron Spectra and Dose Equivalent Rates at High Altitudes: Relevance to SST Operations and Space Research.* NASA TN D-7715, 1974.
2. FAA Advisory Committee on the Radiobiological Aspects of the Supersonic Transport. Cosmic Radiation Exposure in Supersonic and Subsonic Flight. *Aviat., Space, & Environ. Med.*, vol. 46, Sept. 1975, pp. 1170–1185.
3. Schaefer, H. J.: Public Health Aspects of Galactic Radiation Exposure at Supersonic Transport Altitudes. *Aerosp. Med.*, vol. 29, 1968, pp. 1298–1303.
4. O'Brien, K.; and Friedberg, W.: Atmospheric Cosmic Rays at Aircraft Altitudes. *Environ. Int.*, vol. 20, no. 5, 1994, pp. 645–663.
5. Friedberg, W.; Snyder, L.; Faulkner, D. N.; Darden, E. B.; and O'Brien, K.: *Radiation Exposure of Air Carrier Crewmembers II.* DOT/FAA-AM-92/2, FAA, 1992.
6. White, W. J.: *Crewmember Training on In-Flight Radiation Exposure.* Advisory Circular No. 120-61, FAA, May 19, 1994.
7. Anon.: *Recommendations of the International Commission on Radiological Protection.* ICRP Publ. 26, Pergamon Press, 1977.
8. Committee on the Biological Effects of Ionizing Radiations; Board on Radiation Effects Research Commission on Life Sciences; and National Research Council: *Health Effects of Exposure to Low Levels of Ionizing Radiation—BEIR V.* National Academy Press, 1990.
9. Sources, Effects and Risks of Ionizing Radiation—United Nations Scientific Committee on the Effects of Atomic Radiation 1988 Report to the General Assembly, With Annexes. United Nations, 1988.
10. *Recommendations of the International Commission on Radiological Protection.* ICRP Publ. 60, Pergamon, 1991.
11. Anon.: *Limitation of Exposure to Ionizing Radiation.* NCRP Rep. No. 116, Mar. 1993.
12. Reitz, G.; Schnuer, K.; and Shaw, K.: Editorial—Workshop on Radiation Exposure of Civil Aircrew. *Radiat. Prot. Dosim.*, vol. 48, no. 1, 1993, p. 3.
13. Fiorino, Francis, compl.; Airline Outlook. *Aviat. Week & Space Technol.*, June 3, 1996.
14. Wilson, John W.; Nealy, John E.; Cucinotta, Francis A.; Shinn, Judy L.; Hajnal, Ferenc; Reginatto, Marcel; and Goldhagen, Paul: *Radiation Safety Aspects of Commercial High-Speed Flight Transportation.* NASA TP-3524, 1995.
15. Anon.: *Radiation Exposure and High-Altitude Flight.* NCRP Commentary No. 12, July 1995.



Nose:
EML Bonner spheres 1, 2, 4, 6, 7, and 8
Power supply and distribution unit
DLR/Kiel University DOSTEL
DLR/Kiel University Particle PNTD's
University of San Francisco Target Fragment PNTD's
NRPB etch track dosimeters
Yale/University of Pisa bubble counter

Q-bay:
EML Bonner spheres 9 and 10
EML scintillation counters (3)
EML ion chamber
Power supply and distribution unit
DREO Al_2O_3 TLD's
JSC particle telescope
RMC bubble detectors
Boeing TEPC
DREO TEPC

Carried in cockpit:
Boeing PDM-303

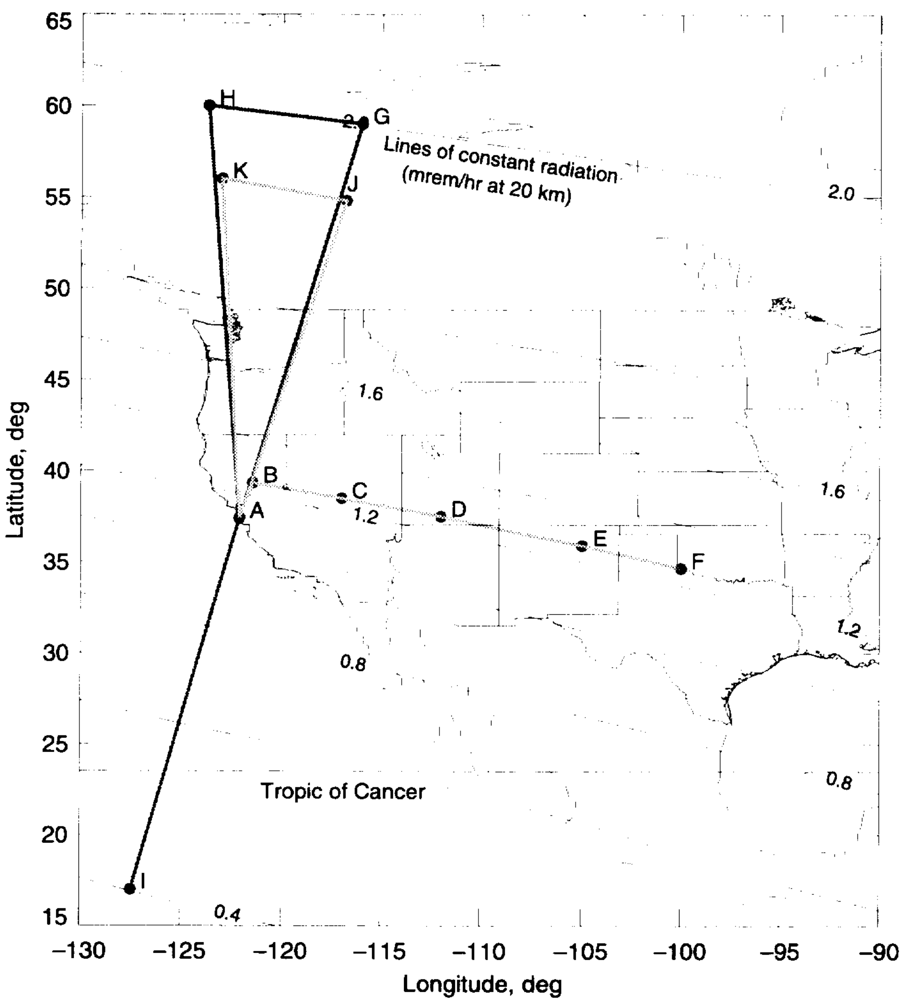
Right superpod forebody:
EML Bonner spheres 11 and 12

Left superpod midbody:
Power supply and distribution unit

Right superpod midbody:
EML NIM bin Electronics racks (2)
EML Computer
Power supply and distribution units

Left superpod forebody:
EML Bonner spheres 13 and 14
PVAMU SEU

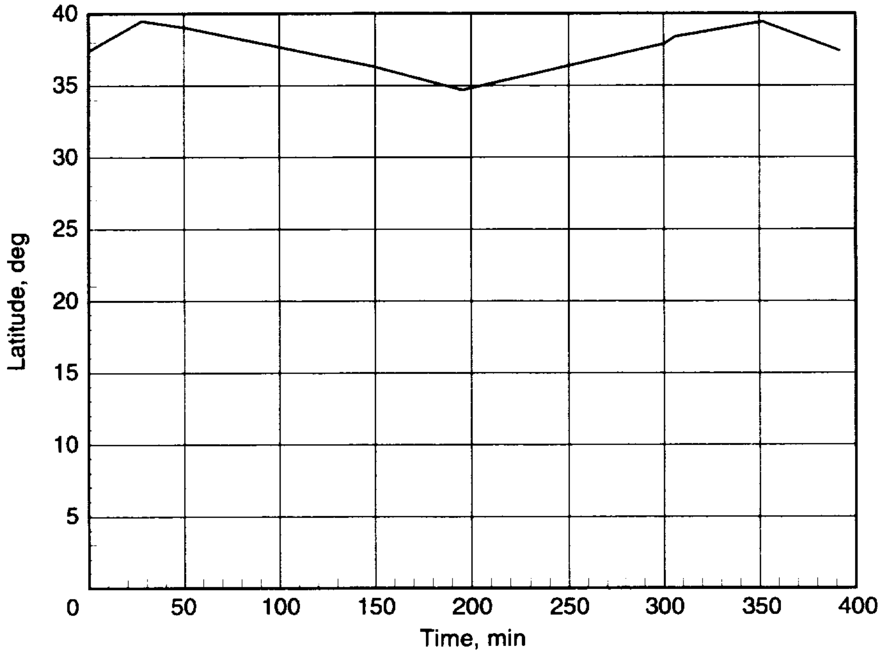
Figure 1. Instrument locations on the ER-2.



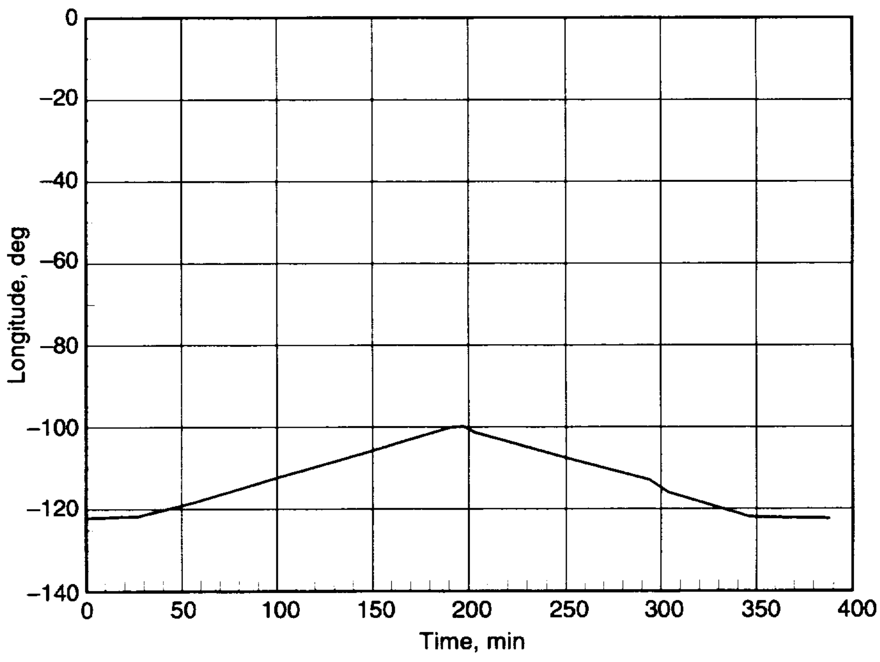
Flight path coordinates

	Latitude, deg	Longitude, deg
A	37 24	−122 06
B	39 19	−121 27
C	38 30	−117 00
D	37 30	−112 00
E	35 54	−105 00
F	34 39	−100 00
G	59 00	−116 00
H	60 00	−123 40
I	17 00	−127 28
J	54 48	−116 48
K	56 00	−123 00

Figure 2. AIR/ER-2 ground tracks.

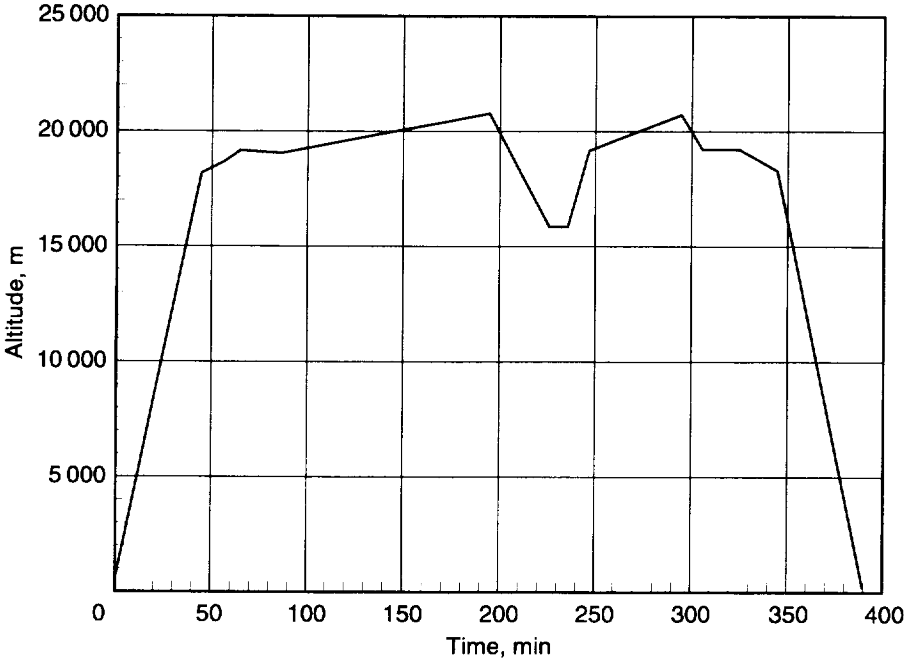


(a) Latitude.

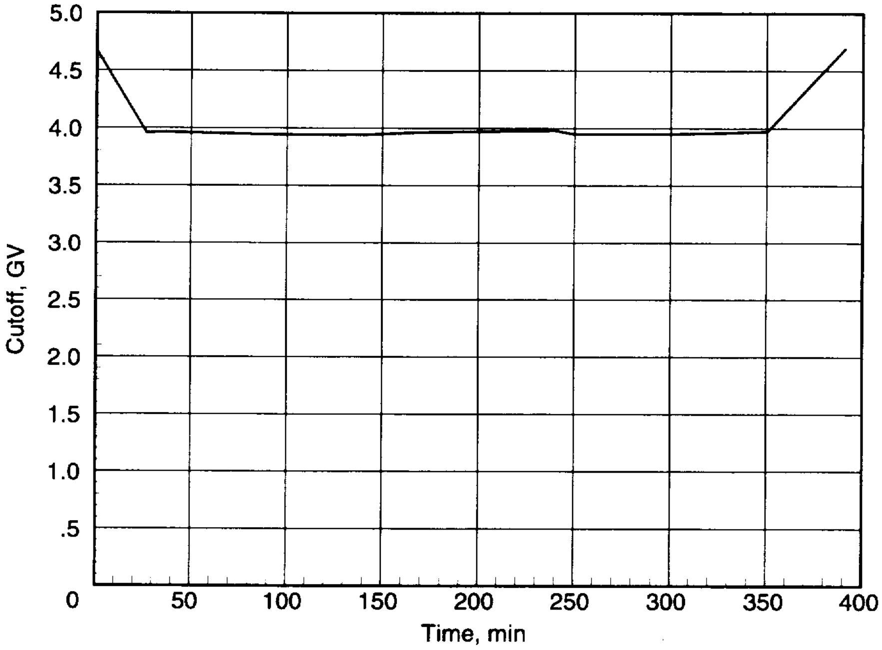


(b) Longitude.

Figure 3. Latitude and longitude of flight path as function of time for flight 2.



(c) Altitude.



(d) Magnetic cutoff.

Figure 3. Concluded.

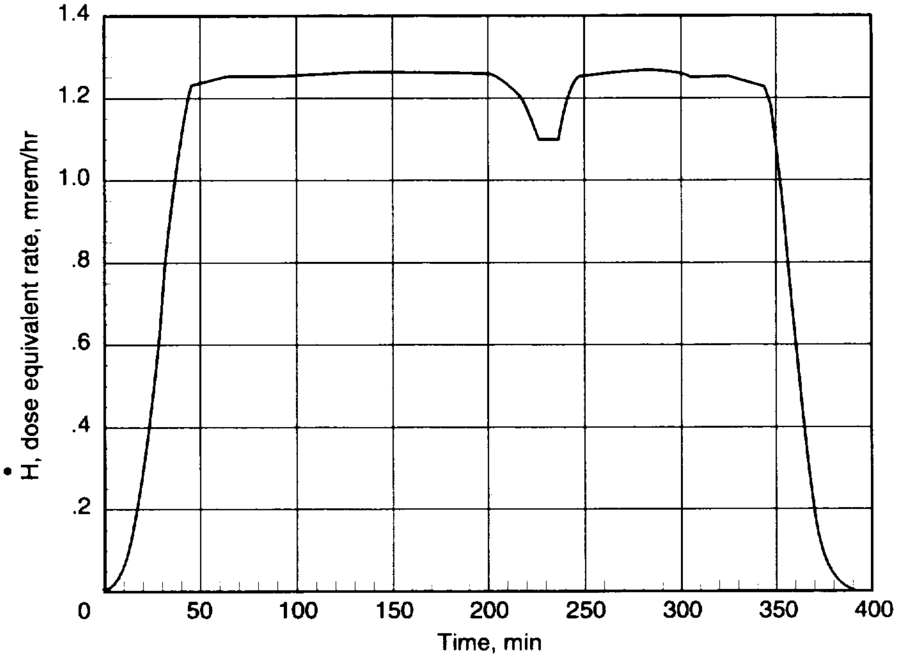


Figure 4. Dose equivalent rate as function of time for flight 2.

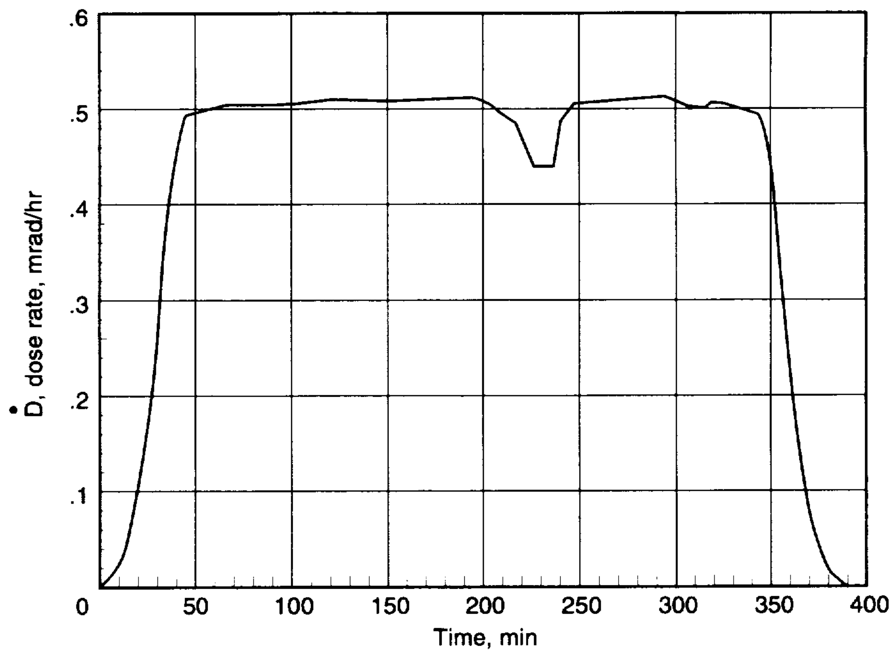


Figure 5. Dose rate as function of time for flight 2.

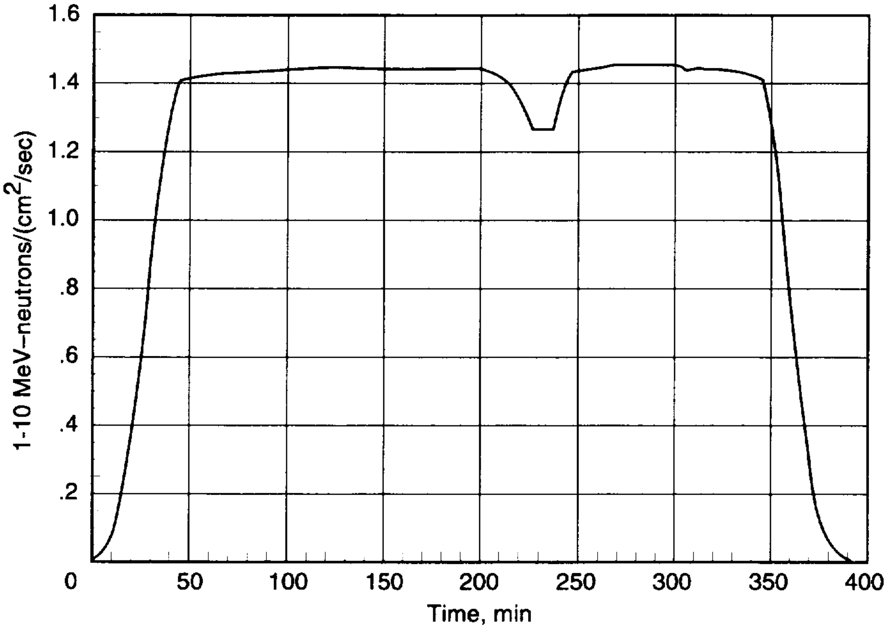


Figure 6. Neutron flux as function of time for flight 2.

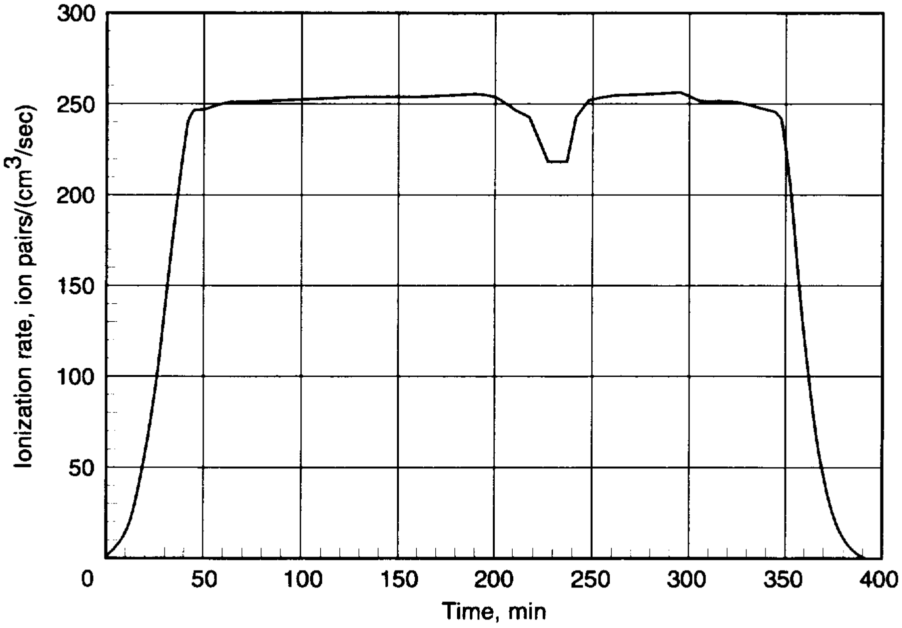
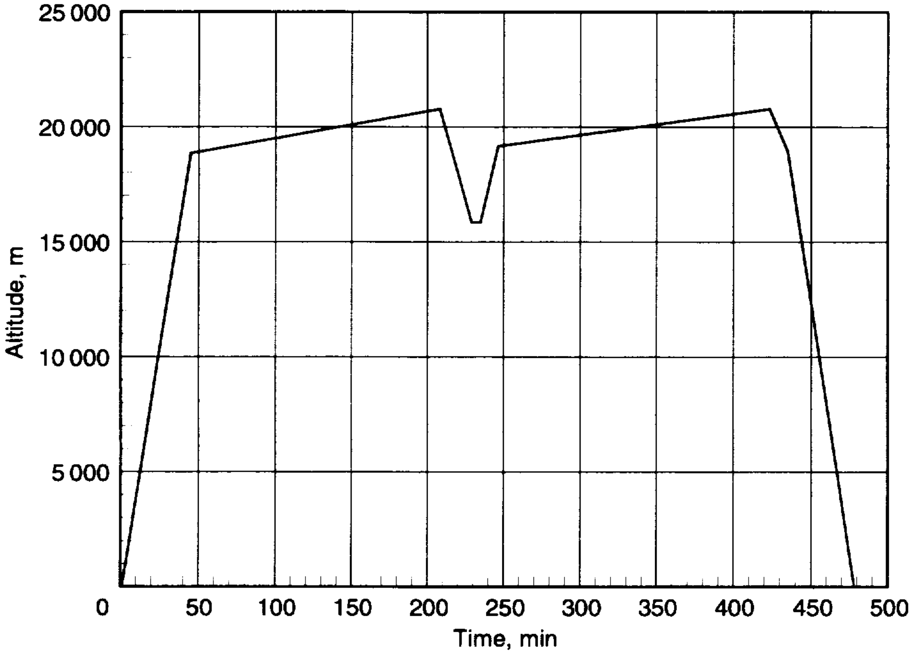
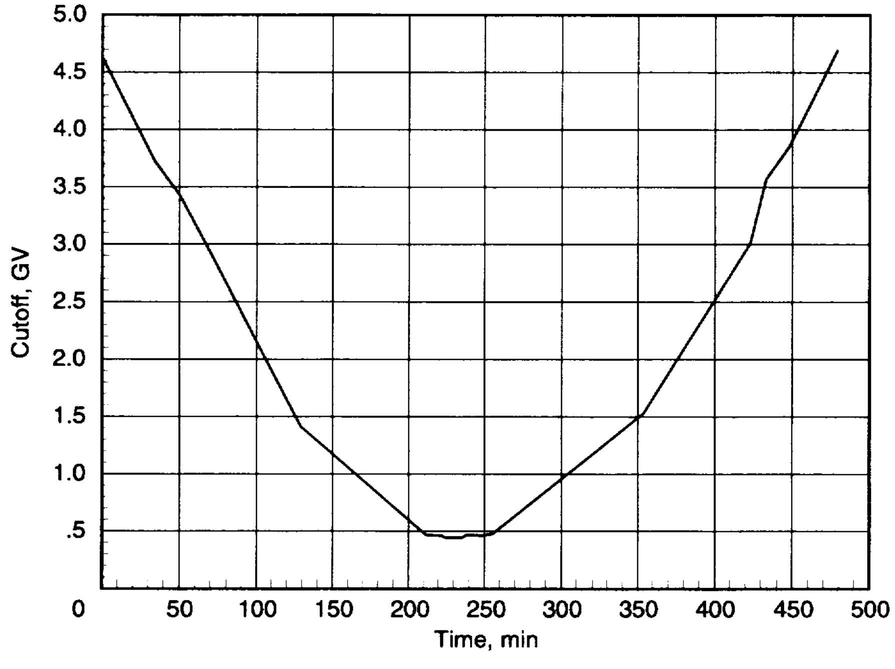


Figure 7. Air ionization rate as function of time for flight 2.



(a) Altitude.



(b) Magnetic cutoff.

Figure 8. Flight path as function of time for flight 3.

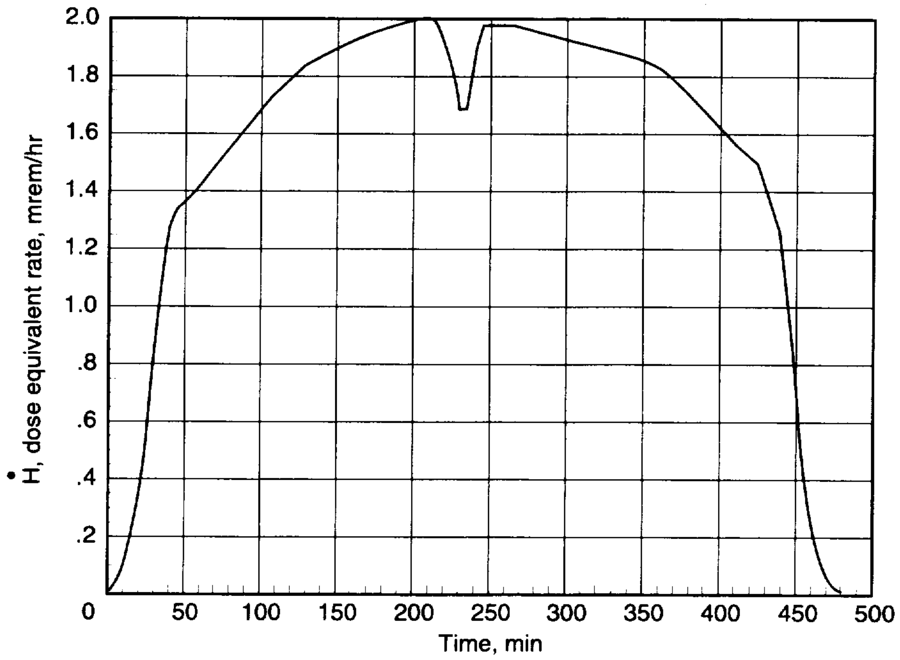


Figure 9. Dose equivalent rate as function of time for flight 3.

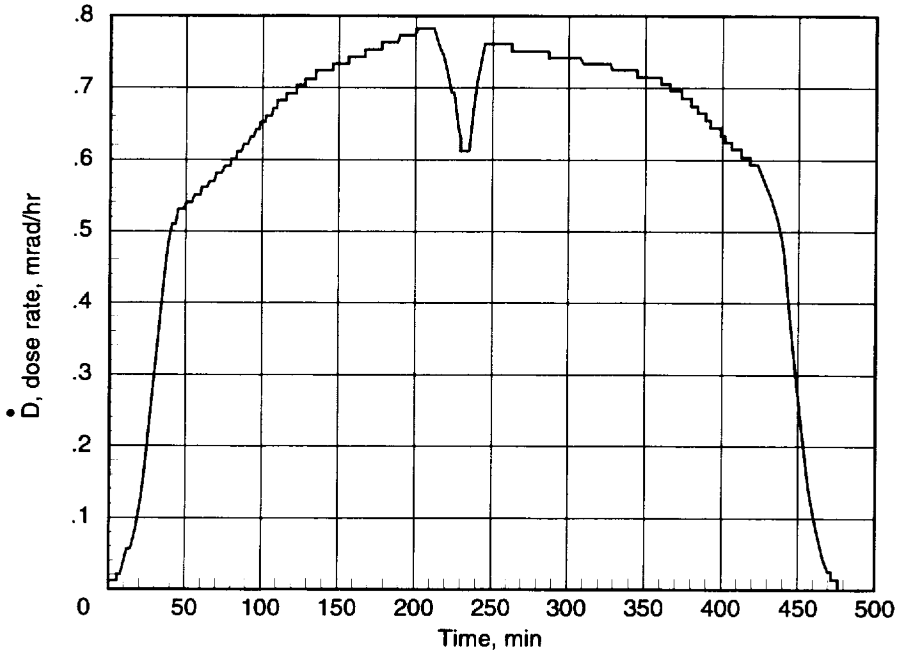


Figure 10. Dose rate as function of time for flight 3.

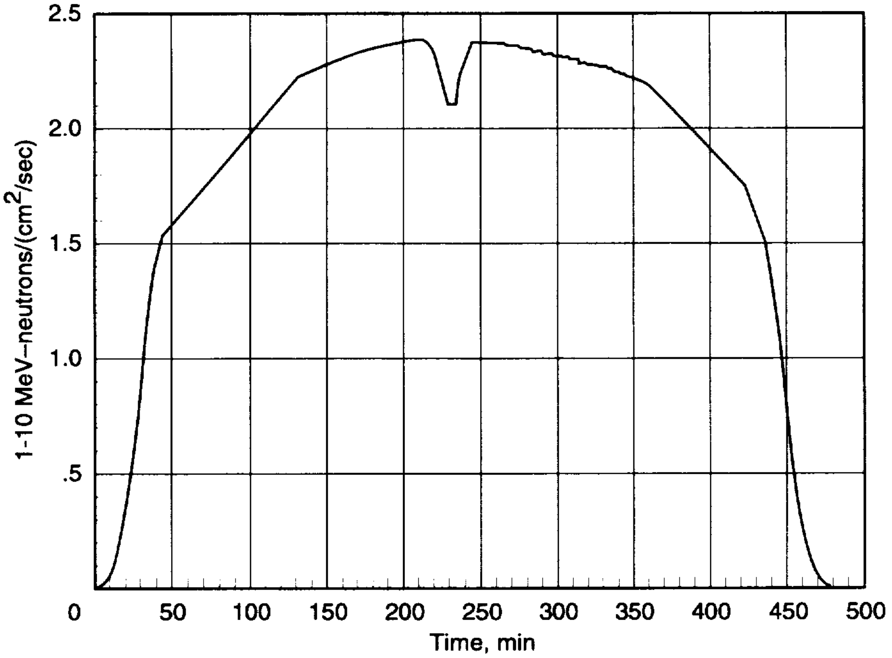


Figure 11. Neutron flux as function of time for flight 3.

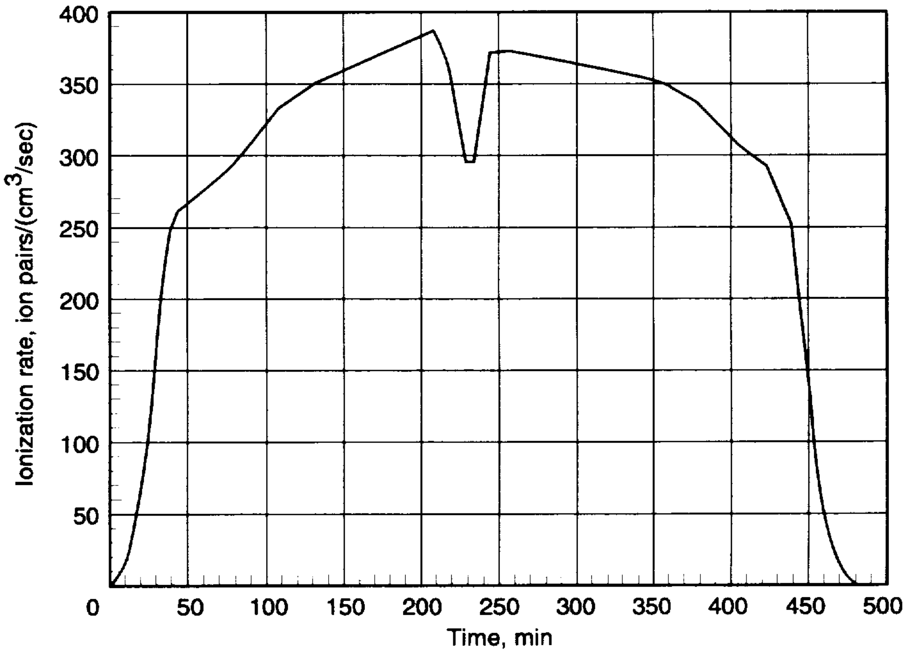
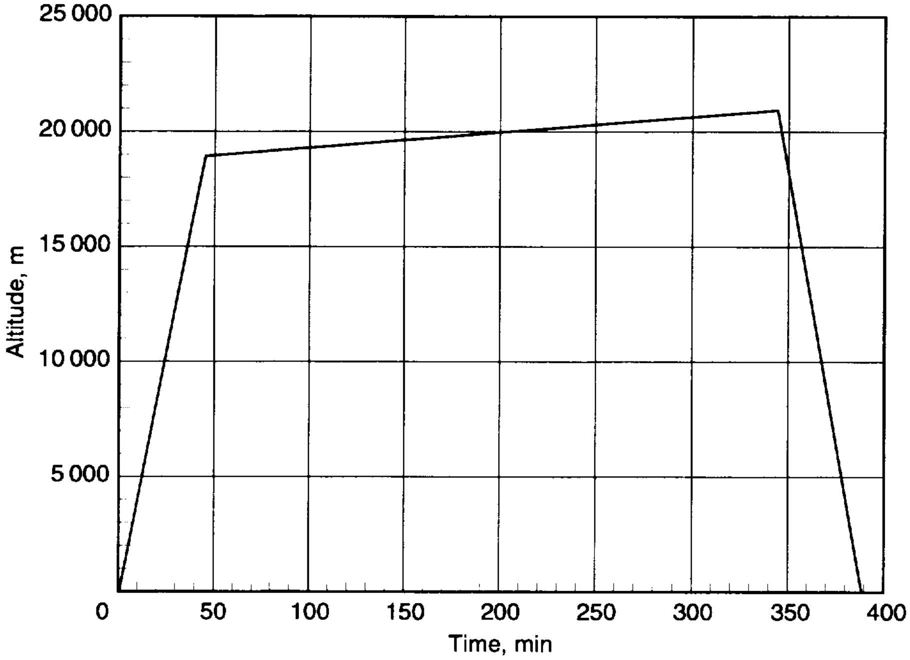
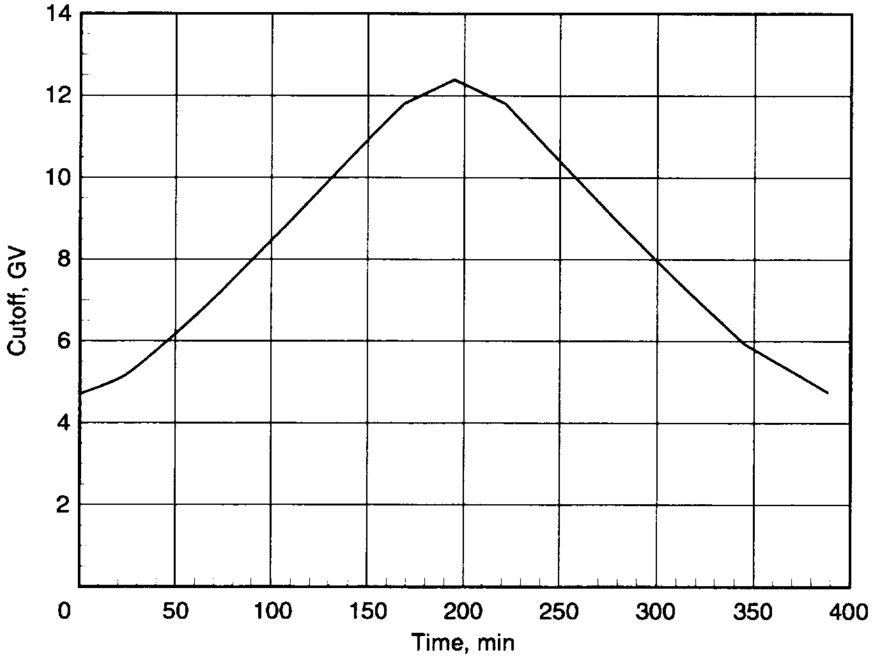


Figure 12. Air ionization rate as function of time for flight 3.



(a) Altitude.



(b) Magnetic cutoff.

Figure 13. Flight path as function of time for flight 5.

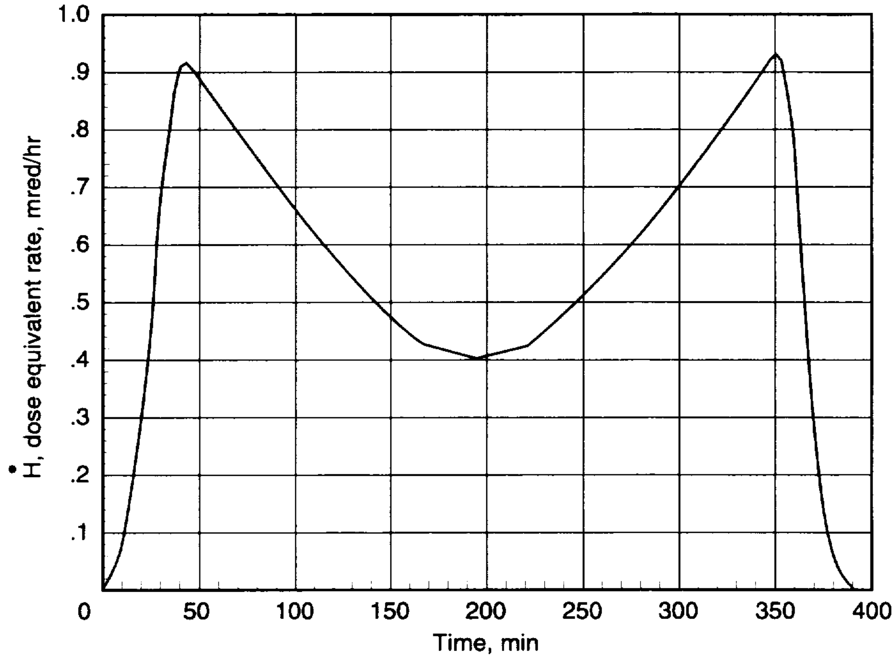


Figure 14. Dose equivalent rate as function of time for flight 5.

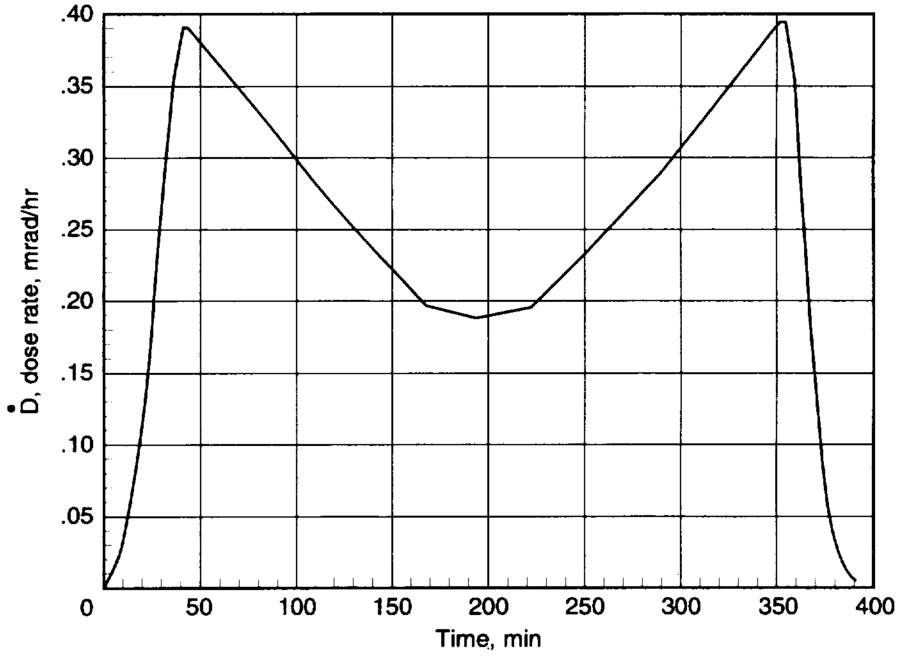


Figure 15. Dose rate as function of time for flight 5.

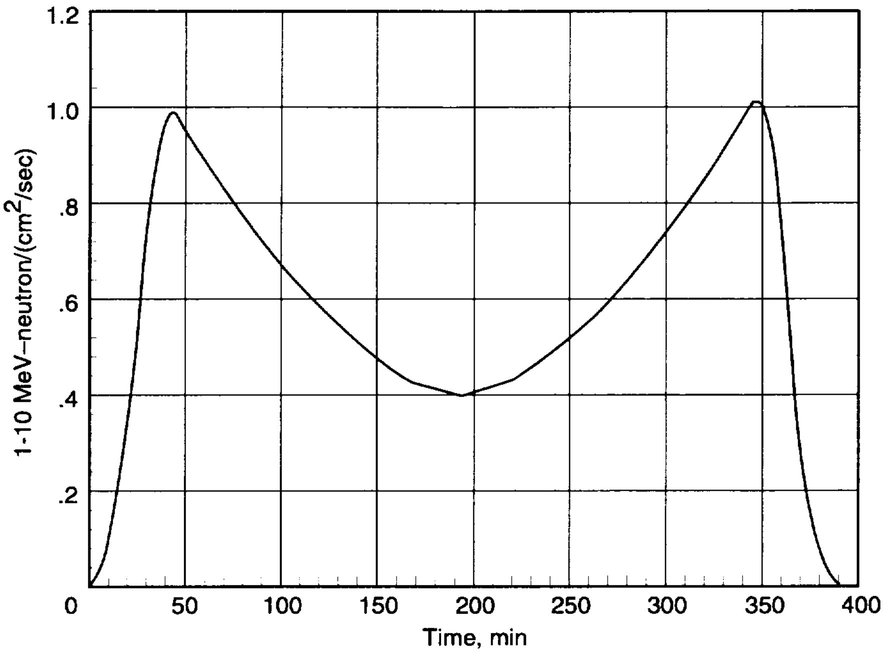


Figure 16. Neutron flux as function of time for flight 5.

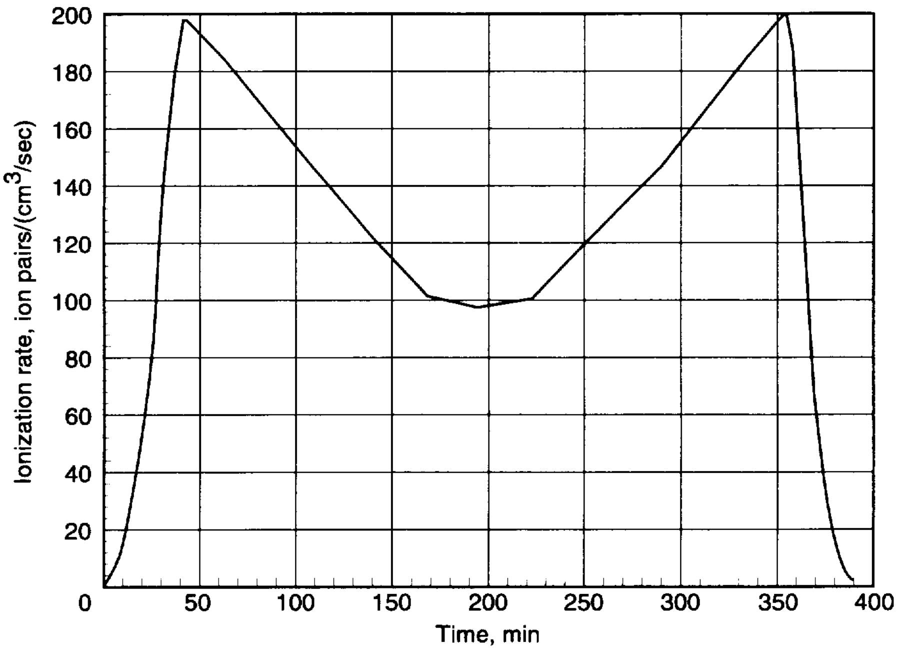
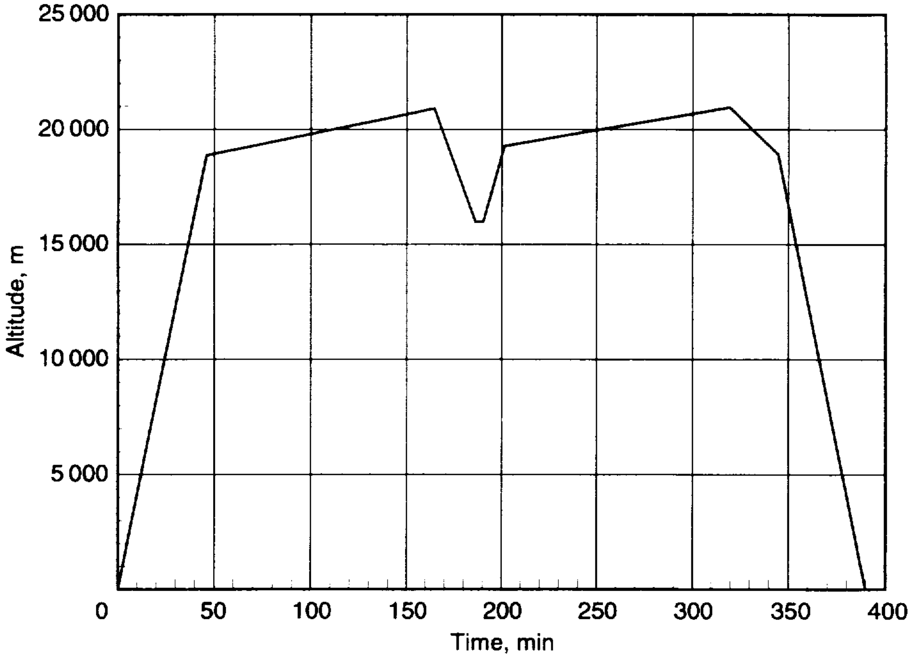
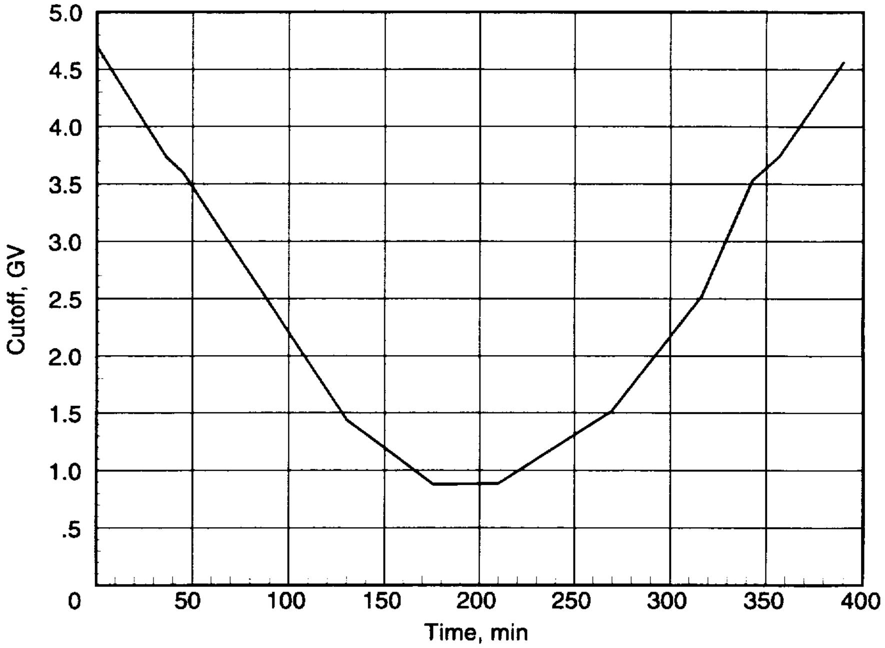


Figure 17. Air ionization rate as a function of time for flight 5.



(a) Altitude.



(b) Magnetic cutoff.

Figure 18. Flight path as function of time for flight 6.

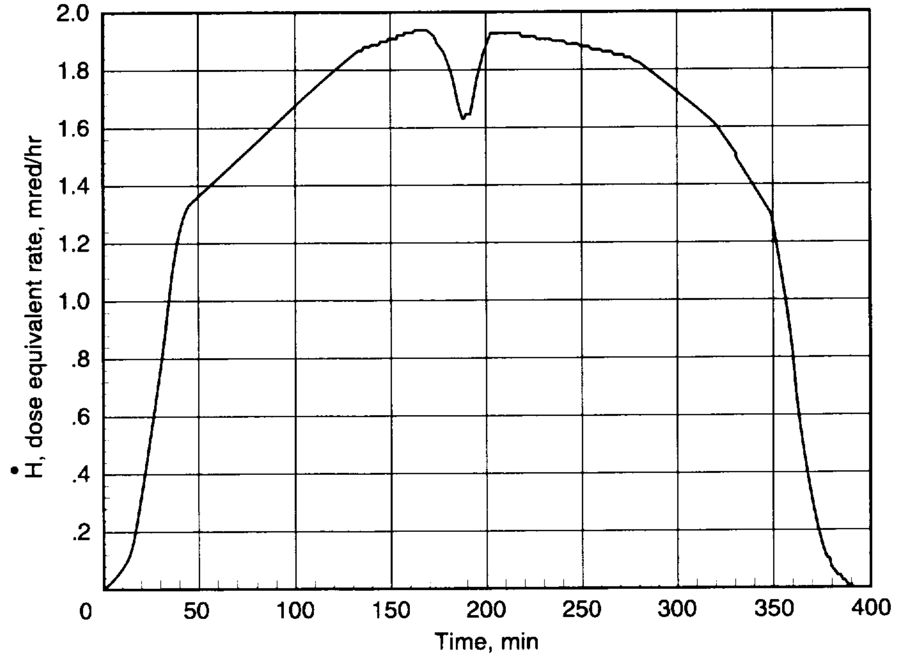


Figure 19. Dose equivalent rate as function of time for flight 6.

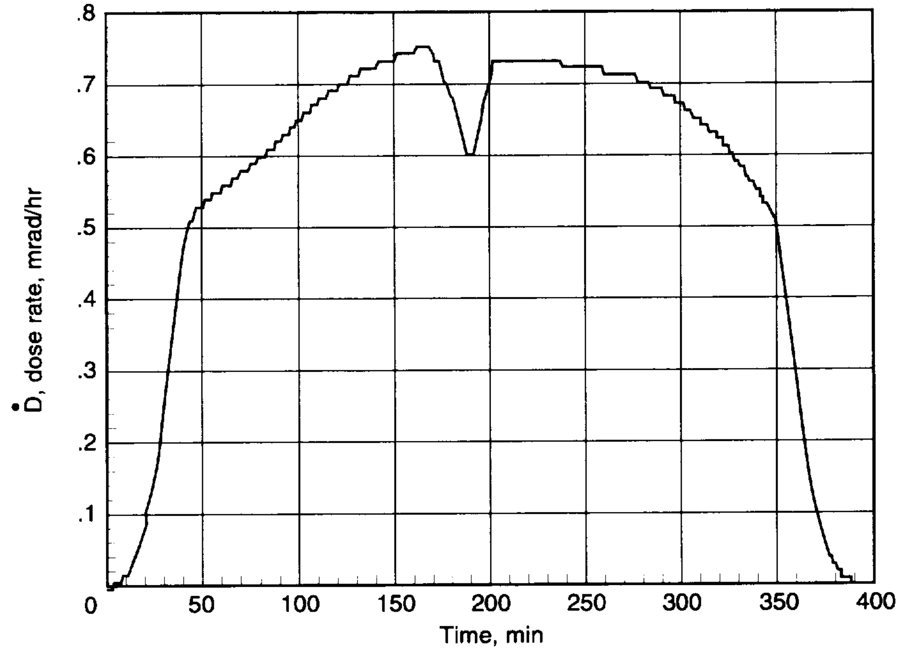


Figure 20. Dose rate as function of time for flight 6.

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13. ABSTRACT *(Maximum 200 words)*

Atmospheric ionizing radiation (AIR) produces chemically active radicals in biological tissues that alter the cell function or result in cell death. The AIR ER-2 flight measurements will enable scientists to study the radiation risk associated with the high-altitude operation of a commercial supersonic transport. The ER-2 radiation measurement flights will follow predetermined, carefully chosen courses to provide an appropriate database matrix which will enable the evaluation of predictive modeling techniques. Explicit scientific results such as dose rate, dose equivalent rate, magnetic cutoff, neutron flux, and air ionization rate associated with those flights are predicted by using the AIR model. Through these flight experiments, we will further increase our knowledge and understanding of the AIR environment and our ability to assess the risk from the associated hazard.

14. SUBJECT TERMS
Space radiation; Atmospheric ionizing radiation; Supersonic transport; Dose rate; Equivalent dose rate; AIR ionization rate

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