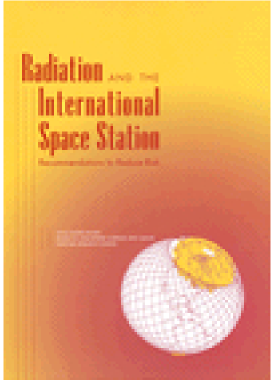
Free Executive Summary



Radiation and the International Space Station: Recommendations to Reduce Risk

Committee on Solar and Space Physics and Committee on Solar-Terrestrial Research, National Research Council

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Executive Summary

INTRODUCTION

This report originated with a request from the National Aeronautics and Space Administration (NASA) (Appendix B). To construct the International Space Station (ISS) and maintain it during construction, astronauts and cosmonauts will work in space suits outside their spacecraft in shifts, each of which is projected to last for 6 hours, for a total amount of time estimated to exceed 1,500 hours. According to the present construction schedule, these extravehicular activities (EVAs) will occur over a 4-year period that straddles the peak in activity of the current solar cycle. After the 4-year period, one or two EVAs per month will probably continue for the life of ISS. The peak in the solar cycle combines with the station's high-inclination orbit to add a new concern for managers of radiation risk.

Unlike the originally planned low-inclination orbit (28 degrees), the finally approved high-inclination orbit (51.6 degrees) cuts through high-latitude radiation environments that are sometimes quite harsh, as was noted when the redesign was contemplated in the early 1990s. These high-latitude radiation environments (energetic particles from solar storms and relativistic electrons in Earth's outer radiation belt) vary greatly over time, from benignly calm to severely stormy. At the height of their storminess, they can be intense enough to pose a radiation hazard to astronauts engaged in EVAs, although doses estimated for even worst-case scenarios fall short of life-threatening. The principal risk to astronauts that increased exposure to radiation in ISS orbit poses is the increased probability of developing cancer later in life. The principal concern for flight directors that increased exposure of astronauts to radiation raises is the potential impact on flight schedules and crew rotation if a radiation event pushes an astronaut over an allowable radiation limit. Astronauts are also concerned that crossing an allowable radiation limit will restrict flight opportunities. Storms bearing intense radiation are relatively rare, but EVAs during ISS construction flights are relatively frequent, which raises a concern that the two might by chance coincide. Information obtained during the course of this study puts at near-certainty the likelihood that on one or more occasions an ISS construction flight will be in progress when a high-latitude radiation event (described below) occurs.

This finding naturally raises the question, What is the status of radiation risk management as it pertains to ISS construction? It would seem to be a simple matter, for example, for the Space Environment Center (SEC) of the National Oceanic and Atmospheric Administration (NOAA) or for NASA's own satellites to identify solar events that could cause radiation problems and to get such information to the flight director in time to take appropriate action. But an overly restrictive flight rule and the lack of operationally calibrated models bar the path between the flight director and such sources of information. The problematic (albeit unofficial) flight rule is the "real-time, on-site data" rule, which says that changes in flight plans in response to a radiation situation must be based on real-time, on-site data only. The first recommendation of CSSP/CSTR addresses this flight rule.

> **Recommendation 1: Because it denies access to valid information and thus unnecessarily restrains flight-director options, flight directors should not adhere rigidly to the (unofficial) real-time, on-site data rule.**

As mentioned, the second obstacle in the path between the flight director and data sources is the lack of operationally calibrated models. In important cases, however, the state of radiation modeling is advanced enough, or with directed effort could quickly become advanced enough, to justify a flight rule that allows use of validated procedures to infer and, in some cases, to predict on-site radiation conditions from off-site data. The report cites such cases.

CSSP/CSTR notes that Russians performing EVAs will be directed out of the Russian mission control center in Moscow. Further, it is likely that U.S. and international crew members on ISS will also participate in EVAs directed out of mission control-Moscow. However, flight rules at mission control-Moscow pertaining to radiation may differ from those at NASA's mission control center. Although this report is directed at NASA, CSSP/CSTR believes that some of its recommendations could also be implemented by mission control-Moscow.

SOLAR PARTICLE EVENTS AND THE INTERNATIONAL SPACE STATION

Based on the assumption—the best now available—that the radiation characteristics of the current solar cycle will resemble those of the last cycle, there is nearly a 100 percent chance that at least 2 out of 43 planned ISS construction flights will overlap a significant solar particle event (SPE) and a 50 percent chance that at least 5 flights will overlap such an event. Moreover, the high-latitude zones to which solar energetic particles have access show a marked tendency to widen over the polar latitudes reached by the ISS orbit when SPEs are in progress, a tendency that becomes more pronounced as SPEs intensify. Two storms during 1989, near the maximum of the last solar cycle, illustrate the point. The areas around the poles accessible to SPE particles enlarged until they engulfed more than a quarter of the ISS orbit, and the flux of particles was high enough to have pushed an astronaut over the short-term limit for irradiation of skin and eyes during a single ill-timed 6-hour EVA. These results would seem to call for an aggressive program aimed at reducing solar radiation risk to astronauts during ISS construction. Recommendation 2 addresses means of implementing the elements of such a program.

> **Recommendation 2: For real-time SPE risk management, carry out the steps needed to make usable by SEC and the Space Radiation Analysis Group (SRAG) at Johnson Space Center (JSC) models that use real-time data to specify the intensity of SPE particles and the geographical size and shape of the zones accessible to them.**

NASA, NOAA, the U.S. Air Force (USAF), and the distributed space physics community have the capability for implementing this recommendation. The project implied in this recommendation is one of the important projects that could be implemented early enough to have an impact on SPE radiation risk management during ISS construction. It should receive high priority for early implementation. (Appendix A discusses a suite of models for this application.)

RELATIVISTIC ELECTRONS AND THE INTERNATIONAL SPACE STATION

For a portion of nearly every day, some fraction of the ISS orbit lies within the outer radiation belt, where relativistic electrons reside. At its maximum, this fraction is about 20 percent. During occasions called relativistic electron events, which happen on average about once per month and last several days, the intensity of relativistic electrons in the belt increases by up to four orders of magnitude. When the intensity of relativistic electrons is greatest, a single ill-timed EVA could deliver a radiation dose big enough to push an astronaut over the short-term limit for skin and eyes. To minimize the possibility of scheduling EVAs during such events, procedures can be implemented to specify and forecast at least approximately the intensity of relativistic electrons in the outer belt. NOAA Polar-Orbiting Operational Environmental Satellites (POES) provide measurements of relativistic electron fluxes that can be used to calculate with reasonable accuracy the relativistic electron environment at ISS. These measurements are available only about every hour and a half, however. NOAA Geostationary Operational Environmental Satellites (GOES), on the other hand, provide relativistic electron measurements continuously, but these measurements are not so directly transferable to the ISS orbit. Nonetheless, the intensity of GOES measurements tracks the intensity of POES measurements in the outer belt. Thus, in combination, POES and GOES measurements would allow radiation risk managers to quantitatively follow variations of electron intensity in the outer belt. A crucial piece of hardware that the ISS project should provide is an electron dosimeter attached outside the station. This would allow SRAG to test the quality of the specifications and forecasts that are possible from measurements taken by POES and GOES. These considerations lead to three related recommendations.

> **Recommendation 3a: NASA should implement a procedure for using POES and GOES measurements of relativistic electrons in the outer radiation belt to specify and forecast the electron radiation environment at ISS.** (Such a procedure is outlined in Section 3.3.)
>
> **Recommendation 3b: As soon as possible, JSC should install an electron dosimeter and an ion dosimeter outside the ISS that can return data in real time to SRAG at JSC.**
>
> **Recommendation 3c: A project should be initiated to develop a protocol for identifying the conditions that produce highly relativistic electron events based on the demonstrated good correlation between changes in solar wind conditions and the onset of such events. The recommended project might be a candidate for support by one of the affiliated agencies of the National Space Weather Program (NSWP).** (See Section A.5.)

SPACECRAFT SOURCES OF OPERATIONAL RADIATION DATA

Data that could contribute to reducing radiation risk are currently being acquired by a strategically placed multiagency fleet of research and operational spacecraft. This fleet can provide information on the radiation environment of ISS orbit in real time and in advance of real time. Some spacecraft monitor the Sun and its corona in multiple wavelengths and so can diagnose the X-ray potency of solar flares and warn of oncoming material spewed from the Sun by solar storms. They also monitor SPE fluxes to give direct information on the radiation intensity within zones accessible to SPE particles. Other spacecraft monitor solar wind parameters, which can be used to compute the size and shape of SPE-accessible zones. Spacecraft in relatively low-altitude, polar orbits monitor the flux of relativistic electrons in the outer radiation belt, which the ISS orbit transects. Recommendation 4 addresses a need to channel the relevant information to SRAG at JSC.

> **Recommendation 4: Promptly convene a meeting of pertinent NASA Space Science Enterprise, SRAG, and SEC managers with the principal investigators of satellite instruments. The meeting would**

(1) consider ways to extend the capabilities of the current spacecraft fleet to provide real-time radiation data for driving models and specifying the ISS radiation environment and (2) formulate an implementation plan for swiftly channeling such data to radiation risk managers at JSC.

INTERAGENCY CONNECTIONS

A major obstacle stands in the way of implementing any of the improved scientific data and modeling resources that are currently available from research programs in NASA and the National Science Foundation (NSF). Both SEC and SRAG are fully tasked in maintaining their daily program of data collection and analysis. Ongoing operations require that these be maintained. Incorporation of improvements thus becomes a secondary activity, and the lack of adequate resources and agency support in both organizations limits the rate at which improvements can be made. The next two recommendations address this condition.

Recommendation 5a: NASA, NOAA, and the USAF should cooperate to support the activities that would lead to an operational space weather forecasting capability.

Recommendation 5b: NOAA should extend the range of its SPE predictions from the present ≥10 MeV to biologically effective energy ranges. Forecasts of particle energies at several steps between 10 and 100 MeV would be a significant improvement for space radiation use as well as for other users who operate satellites and systems in space.

INTRA-NASA CONNECTIONS

There are other major programs at NASA besides the manned flight program that require an accurate knowledge of Earth's radiation environment. The kind of knowledge required varies from program to program, but the range of knowledge needed extends from the basic science, physical processes, and generation mechanisms of the radiation belts and particle events, to net integrated radiation doses averaged over a long period of time. The trend in recent years at NASA has been toward smaller and cheaper spacecraft with heavy use of microelectronics, smaller instruments, and more onboard data processing. For this and other reasons, the working knowledge of Earth's radiation environment (models, forecasts of particle events and disturbances, integrated doses, etc.) needs to be improved to address current planning and development requirements in just about every area of NASA activity.

Recommendation 6: To coordinate intra-NASA activities and concerns related to radiation, NASA should establish an agency-level radiation plan and task force. It should also establish a multidisciplinary steering committee to advise the task force.

SPACE WEATHER MODELS APPLIED TO RADIATION RISK REDUCTION

The above recommendations address means to exploit currently available resources to allow a rapid augmentation of the tools available for radiation risk management during ISS construction. Looking beyond these recommendations, there are actions of a tactical nature that can be taken to strengthen radiation risk management in the late phases of ISS construction and during ISS operations. These actions entail the selective implementation of space weather modeling efforts. Space weather modeling is the discipline responsible for developing models that take information from where instruments happen to be and use it to specify and forecast the space environment at places where the information is wanted.

Appendix A identifies research projects that address specific elements of an effort that would provide high-quality information on the parameters most crucial to assessing radiation risk. Two projects deserve particular attention, the first because its potential impact on radiation risk reduction is especially crucial, the second because the maturity of its models promises early, tangible results:

1. *Mapping latitudes at which SPE particles can penetrate under a variety of geomagnetic conditions to the altitude of ISS.* Several methods have been proposed; these should be critically evaluated and the best should be implemented. (Appendix A describes a suite of such methods.)
2. *Developing operational space weather nowcast and forecast codes.* Several of the existing advanced, data-based space weather nowcast and forecast codes (see Appendix A) could be transformed relatively quickly into operational codes to give SRAG the ability to forecast at least some radiation-risk parameters during most of the ISS construction period.

These projects could be undertaken in the near term by one or more of the affiliated agencies of the NSWP (see Section A.5 for a description of NSWP).

TIMELINE FOR IMPLEMENTING RECOMMENDATIONS

Figure ES.1 gives a timeline keyed to the ISS construction schedule (as it was known in July 1999) for the implementation of the recommendations of this report. As shown in the figure, there are recommendations that should be implemented immediately (R1, R3a, R4, R5b, and R6), recommendations that will require 1 or 2 years

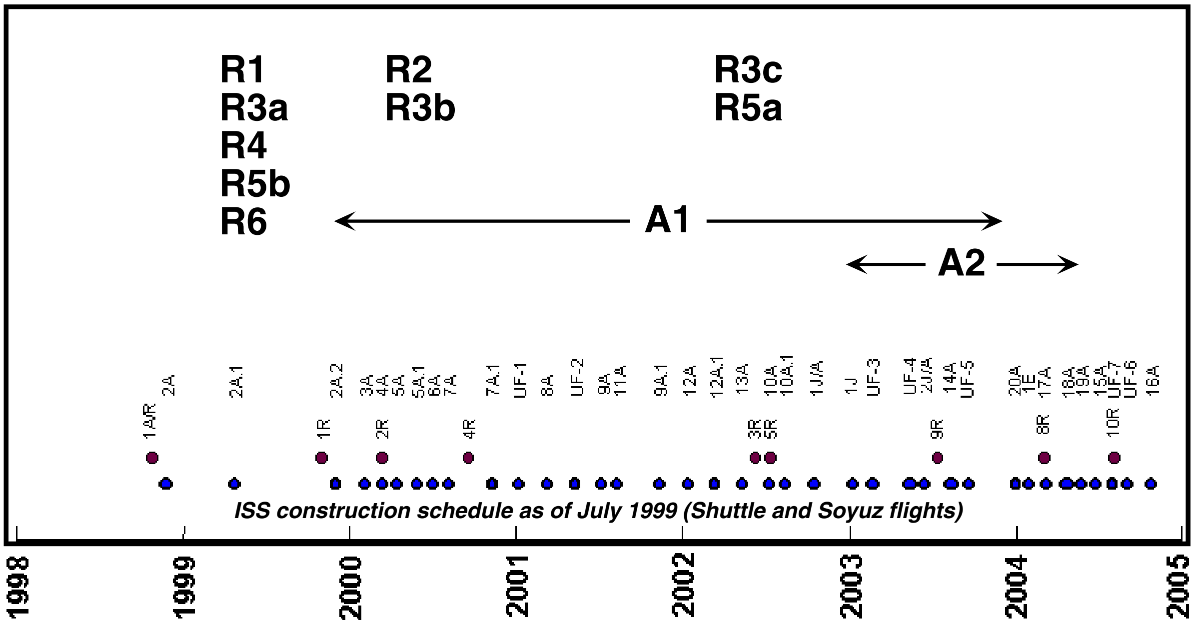

Figure ES.1 Timeline for implementing the report's recommendations, which are denoted R1 through R6. A1 and A2 refer to priority research activities (see Appendix A). The timeline is keyed to the ISS assembly sequence, which is available from NASA on the Web at <http://spaceflight.nasa.gov/station/assembly/flights/chron.html>. The first crew—a U.S. astronaut and two Russian cosmonauts—will be launched on a Russian Soyuz spacecraft in March 2000 on flight 2R (the letter "R" in the flight designation denotes a Russian mission). They will stay there 3 months. From that point on, the ISS is planned to be permanently staffed.

to implement (R2 and R3b), and recommendations that will take several years to implement (R3c and R5a). The research needed to improve space weather services in support of manned missions (described in Appendix A) is also shown in Figure ES.1. Research activities are organized into two groups: (1) those that can be implemented within 5 years (A1), with some of these activities being implemented within 1 year, and (2) those requiring more time to implement (A2).

Radiation and the International Space Station

Recommendations to Reduce Risk

Committee on Solar and Space Physics
Committee on Solar-Terrestrial Research
Space Studies Board
Board on Atmospheric Sciences and Climate
Commission on Physical Sciences, Mathematics, and Applications
Commission on Geosciences, Environment, and Resources
National Research Council

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Cover: Ground track of ISS orbits superposed on a globe along with polar cap areas (shown in yellow), where multimega-electron volt solar energetic particles penetrated to low altitudes during an SPE in November 1997. (Image courtesy of R.A. Leske, R.A. Mewaldt, E.C. Stone, and T.T. von Rosenvinge, "Geomagnetic Cutoff Variations During Solar Energetic Particle Events—Implications for the Space Station," *Proceedings of the 25th International Cosmic Ray Conference*, 2, Space Research Unit, Department of Physics, Potchefstroom University for Christian Higher Education, South Africa, 1997, p. 381.)

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Foreword

A major objective of the International Space Station is learning how to cope with the inherent risks of human spaceflight—how to live and work in space for extended periods. The construction of the station itself provides the first opportunity for doing so.

Prominent among the challenges associated with ISS construction is the large amount of time that astronauts will be spending doing extravehicular activity (EVA), or "space walks." EVAs from the space shuttle have been extraordinarily successful, most notably the on-orbit repair of the Hubble Space Telescope. But the number of hours of EVA for ISS construction exceeds that of the Hubble repair mission by orders of magnitude. Furthermore, the ISS orbit has nearly twice the inclination to Earth's equator as Hubble's orbit, so it spends part of every 90-minute circumnavigation at high latitudes, where Earth's magnetic field is less effective at shielding impinging radiation. This means that astronauts sweeping through these regions will be considerably more vulnerable to dangerous doses of energetic particles from a sudden solar eruption.

This putative radiation danger prompted the present study. It applies what we have learned from past investigations of solar emanations and their effects on Earth's magnetosphere to assess the risk and find ways to minimize it. The study estimates that the likelihood of having a potentially dangerous solar event during an EVA is indeed very high. It also recommends steps that can be taken immediately, and over the next several years, to provide adequate warning so that the astronauts can be directed to take protective cover inside the ISS or shuttle. The near-term actions include programmatic and operational ways to take advantage of the multiagency assets that currently monitor and forecast space weather, and ways to improve the in situ measurements and the predictive power of current models.

The radiation risk is real, but it is also very susceptible to management. That there have been no known overexposures to date is due partly to such good management. Now it is time to revise the protocols and practices of the past to encompass the new challenges of ISS construction and permanent habitation to ensure that this good record continues in the future.

Claude R. Canizares, *Chair*
Space Studies Board

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This report has been reviewed by individuals chosen for their diverse perspectives and technical expertise, in accordance with procedures approved by the Report Review Committee of the National Research Council (NRC). The purpose of this independent review is to provide candid and critical comments that will assist the authors and the NRC in making the published report as sound as possible and to ensure that the report meets institutional standards for objectivity, evidence, and responsiveness to the study charge. The contents of the review comments and draft manuscript remain confidential to protect the integrity of the deliberative process. CSSP/CSTR wishes to thank the following individuals for their participation in the review of this report: J. Bernard Blake, the Aerospace Corporation; Joan Feynman, Jet Propulsion Laboratory; R.J. Michael Fry, Oak Ridge National Laboratory; John Grunsfeld, NASA Johnson Space Center; Louis J. Lanzerotti, Lucent Technologies; Edward T. Lu, NASA Johnson Space Center; Frank B. McDonald, University of Maryland; and Donald J. Williams, Johns Hopkins University Applied Physics Laboratory.

Although the individuals listed above have provided many constructive comments and suggestions, responsibility for the final content of this report rests solely with CSSP/CSTR and the NRC.

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