NASA's Space Environments & Effects (SEE) Program: The Pursuit of Tomorrow's Space Technology

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ABSTRACT

A hazard to all spacecraft orbiting the earth and exploring the unknown in deep space is the existence of a harsh and ever changing environment with its subsequent effects.[1,2] Some of these environmental hazards, such as plasma, extreme thermal excursions, meteoroids, and ionizing radiation result from natural sources, whereas others, such as orbital debris and neutral contamination are induced by the presence of spacecraft themselves. The subsequent effects can provide damaging or even disabling effects on spacecraft, its materials, and its instruments. In partnership with industry, academia, and other government agencies, National Aeronautics & Space Administration's (NASA's) Space Environments & Effects (SEE) Program defines the space environments and advocates technology development to accommodate or mitigate these harmful environments on the spacecraft. This program provides a very comprehensive and focused approach to understanding the space environment, to define the best techniques for both flight and ground-based experimentation, to update the models which predict both the environments and the environmental effects on spacecraft, and finally to ensure that this information is properly maintained and inserted into spacecraft design programs. This paper will provide an overview of the Program's purpose, goals, database management and technical activities. In particular, the SEE Program has been very active in developing improved ionizing radiation models and developing related flight experiments which should aid in determining the effect of the radiation environment on modern electronics.

Keywords: space environments, ionizing radiation, technology development, environmental effects

1. SEE OVERVIEW

The Space Environments and Effects (SEE) Program was formed by the National Aeronautics and Space Administration (NASA) in 1993 to support the growing need for the development and maintenance of a preeminent program in space environments and effects technology. This initiative is intended to provide a coordinated national focus for innovative technology development to support design, development, and operation of spacecraft systems that will accommodate or mitigate effects due to the presence of the space environment. The Program is unique in that it was initiated as a customer-driven and product-oriented endeavor. Considerable effort was made to ensure that the potential industry, academia, and government agency users of the products were consulted and made a part of the Program. Today they constitute the SEE Program Users Steering Committee. Their assessment and prioritizing of future research needs for space environment definition and techniques for calculating the effects of the space environment on spacecraft systems forms the basis for the SEE Program's activities. This direct involvement of potential customers also ensures that the SEE Program sponsored research products are made available in a timely manner to those most concerned with the information, spacecraft designers and operators.

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1.1 SEE Program Philosophy

The interrelationship between the program, customers, and products is illustrated in figure 1. The philosophy of the program is customer-driven and product-oriented. The program is composed of government, industry and academic representatives and participants. The customers are current and future government and commercial space missions. General types of program products are also noted in the figure. Advocacy for national test facilities and flight opportunities are also products of the program as opposed to the facilities and flights themselves.

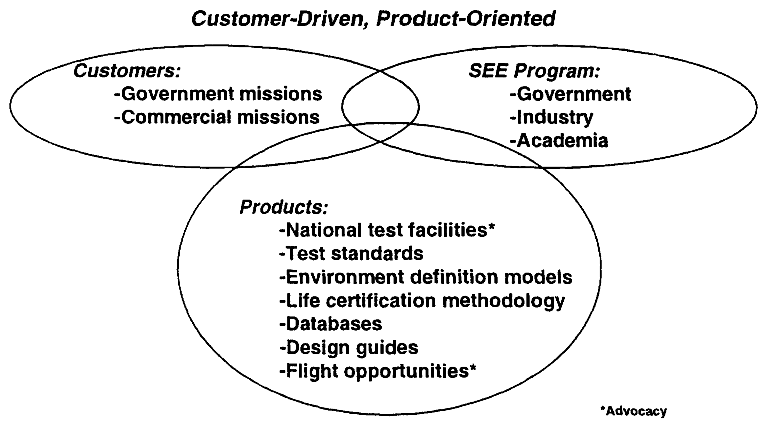

Figure 1. Space Environment and Effects Program Philosophy.

1.2 SEE Program objectives and goals

The objectives of the SEE program are to collect, develop, and disseminate the SEE-related technologies required to design, manufacture, and operate more reliable, cost-effective spacecraft for the Government and commercial sectors. In order to satisfy these objectives, the SEE Program has developed the following goals:

- Advocate technology development, flight experiments, and databases by creating and maintaining:
  - Engineering environments definitions
  - Up-to-date engineering focused models
  - Environmental and materials databases
  - Engineering Design Guidelines
  - Flight/ground simulation/technical assessments
  - Integrated assessment tools
  - Simplified access to modeling/assessment tools

- Maintain cutting edge expertise in SEE-related technologies by:
  - Coordination with other agencies, industry, and academia
  - The incorporation of technical experts and specialists
  - Sustained awareness of state-of-the-art SEE technologies

- Heighten the awareness of SEE significance and program capabilities through:
  - Internet Access
  - Quarterly Bulletin
  - Displays
  - Workshops
  - Publications [3,4,5,6]

1.3 SEE Program structure

While the SEE Program was established with NASA sponsorship, it was recognized from the start that the Program's success would depend on its ability to interact with research activities of other agencies, industry, and academia. This interaction has now become one of the principal strengths of the SEE Program. The components of the SEE Program are shown in figure 2. The SEE Program focuses on bridging the gap between the science community and the engineering community by improving environments definitions and tools for spacecraft design and operations planning.[7]

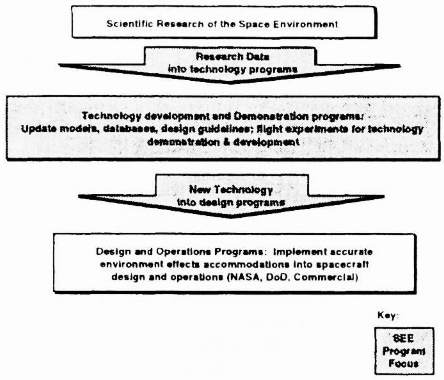

Figure 2. Components of SEE Program

The Space Environments and Effects Program is organized (Figure 3) to facilitate the implementation of the Program's mission which is directed toward research, development, verification, and transferring of SEE-related technologies to the aerospace customers.[8] While the Program functions under the direction and oversight of the NASA Space Sciences Advanced Technology and Mission Studies Division at NASA Headquarters, the key to its ability to accomplish its mission is the Technical Working Groups. These groups encompass the disciplines of electromagnetic effects, materials and processes, meteoroid and orbital debris, ionizing radiation, neutral environment contamination, and thermosphere and plasma. Their activities and responsibilities include: (1) ensuring communication with working group members, (2) coordinating development, evaluation, and maintenance of working group technical content and research areas, (3) coordinating research and development of new technologies and design issues that impact their respective space environmental areas, (4) coordinating development and use of engineering tools, models, and databases, and (5) coordinating development of spacecraft design and test techniques and methodologies for accommodating or mitigating space environment effects. The membership in the SEE Technical Working Groups is drawn from NASA, DOD, NOAA, Industry, and Academia.

The six Technical Working Groups, as shown in figure 3, are the Electromagnetic Effects, Ionizing Radiation, Materials & Processes, Meteoroid & Orbital Debris, Neutral External Contamination, Plasma & Fields, and Thermosphere, Thermal & Solar Activity Working Groups. Members of these groups direct and, in some cases, conduct studies and tests that meet a recognized need of the customer. The data from these studies are incorporated into databases, design guides and/or models and provided to the customers. The customers, through the Steering Committee, define systems requirements and needs to the Technical Working Groups and the Program.

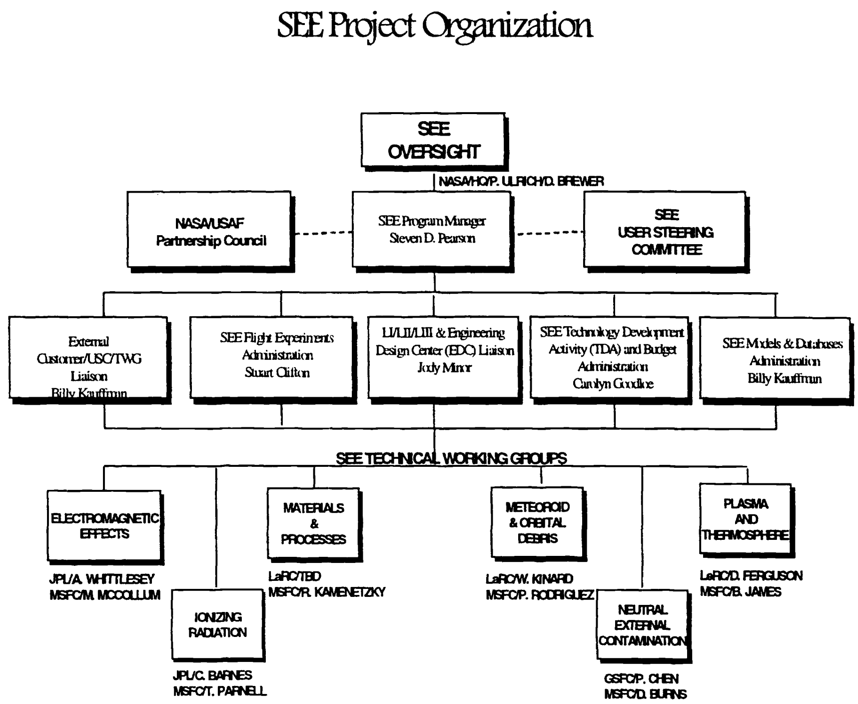

Figure 3. Space Environments and Effects Program Organization

1.4 SEE Technology Development Activities

Soon after the SEE Program was initiated in 1994, technology tasks were identified and proposals solicited through a NASA Research Announcement. Eighteen contracts were awarded, using peer review, from the 176 proposals received. The technical disciplines represented included all those encompassed by the SEE Technical Working Groups. Organizations receiving the contracts included industry, academia and government laboratories. The products of these three-year contract efforts are now being realized and as the reports are received and processed, they are being distributed to the aerospace community through the SEE Program.[8]

The future products of the Space Environments and Effects Program encompass a wide range of items. Some additional new initiatives include efforts on a satellite launch opportunities report, meteoroid and shielding by a nearby planet analysis, study of on-orbit spread receivers, materials database development, solar proton model development, and a space environments monitor package study. However, the major new future products thrust has been the release in July 1997 of the second Space Environments and Effects NASA Research Announcement. This announcement was the result of considerable coordination activities of the SEE Program Office with the SEE Program User Steering Committee, the SEE Technical Working Groups, and the SEE Workshop participants which provided "road maps" for key space environments and effects issues. Some of the key subjects identified included ionizing radiation, meteoroids and orbital debris, electromagnetic effects, neutral external contamination, materials and processes, and plasmas, solar, thermosphere and thermal environments. The technology development activities that were awarded are shown in figure 4.

TITLE	CONTRACTOR	PI	DESCRIPTION
ELECTROMAGNETIC EFFECTS:			
Electromagnetic Interference Susceptibility	Boeing	J. Sketoe	Develop an automated test system with associated processes will be developed that will demonstrate the capability of selected high priority semiconductor devices.
Transient Test Techniques Representative	EMC Compliance	K. Javor	Develop a new technique that is more representative of equipment turn-on, turn-off, and mode switching transients on space system power buses.
IONIZING RADIATION:			
Design Guidelines for Ionizing Radiation	SAIC	T. Armstrong	Develop comprehensive design guidelines for use by spacecraft designers and system engineers for both near-Earth and deep space missions.
Trapped Proton Model	Boeing	S. Huston	Develop an entirely new model of the trapped proton population based primarily on data from the TIROS/NOAA series of spacecraft and the CRRES satellite.
MATERIALS & PROCESSES:			
Testing and Optimization of Electrically Conductive Spacecraft Coating	AZ Tech	R. Mell	Focus on simulated space environments and effects testing, optimizing stability, and performance of electrically conductive coating.
Development of a Spacecraft Materials Selector Expert System	Boeing	G. Pippin	The Spacecraft Materials Selector (SMS) expect system will consist of a back-chaining inference engine and a set of knowledge bases for (1)space environments definition, (2) material properties definition, and (3) materials performance assessments.
Space Stable Polymer Thermal Control Films and MLIs	Triton	A. Shepp	Deliver a space-stable second surface mirror (SSM) and multi-layer insulation (MLI) blanket product for thermal control on space vehicles in LEO and GEO.
METEOROID & ORBITAL DEBRIS:			
New Technique for Achieving Impact Velocities Greater Than 10 km/s	Univ. Dayton	A. Piekutowsi	Develop a new technique for launch of small projectiles of known shape, size, mass, and state to a velocities of 10 km/s and higher.
NEUTRAL EXTERNAL CONTAMINATION:			
Satellite Contamination and Materials Outgassing Effects Databases		B. Green	Input the ground/flight data (accumulated from the ASTM E1559 and Space QCM flight databases as the MSX satellite mission) into separate, linked databases using a user friendly database platform.
THERMOSPHERE, THERMAL, SOLAR AND PLASMA:			
Test and Guidelines for Spacecraft Cable Charging	JPL	A. Fredrickson	Provide quantitative data and design guidelines for charging and discharging of spacecraft cables under high electron irradiation typical of Earth's and Jupiter's magnetospheres.
Interactive Spacecraft Charging Handbook	Maxwell Tech	I. Katz	CD/ROM/web interactive spacecraft charging handbook with updated spacecraft charging models and analysis tools.
Electronic Properties of Material Application to Spacecraft Charging	Utah State Univ.	J. Dennison	Establish the electrical properties for spacecraft materials and integrate them into relevant databases for use with NASA's existing computer modeling tools as well as next generation models.

Figure 4. Space Environments & Effects Program 1998 Technology Development Activities

1.5 SEE Flight Experiments

In addition to the accomplishment of non-flight technical activities, the SEE Program is involved in the advocacy of space experiments that have as their goal the understanding of the space environment and its effects on spacecraft systems and components .[9] The advocacy of SEE-related flight experiments plays an important role as an integrated aspect of the overall program in order to verify and validate the different space environments. The largest proportion of SEE flight experiments are currently associated with the International Space Station in order to validate the environment for ISS operations and attached payloads. To this end a significant effort has been undertaken at the Johnson Space Center to sponsor fourteen Risk Mitigation Experiments to characterize both the MIR and International Space Station (ISS) environments. These experiments have been flown to MIR on recent Shuttle missions, and some are currently planned for re-flights on other missions. In addition to the Risk Mitigation Experiments, a number of other satellite-borne investigations have been developed or are being planned by NASA to measure various aspects of the space environment and its effects on spacecraft systems and components. The following is a brief overview of some of the experiments being undertaken by NASA to measure the space environment and its effects.

1.5.1 MIR Photo Survey

The MIR Photo Survey employs both video and high-resolution photographic imagery of the MIR taken from the Shuttle by the astronaut crew using hand-held photographic and video equipment during the rendezvous and mated operations with the MIR. The imagery, processed and analyzed post-mission at the Johnson Space Center and at RSC-Energia in Kaliningrad, Russia, allows both qualitative and quantitative assessments of external deposition and contamination, surface degradation, unanticipated solar array motion, micrometeoroid and orbital debris strikes, and configuration verification. The ISS Risk Mitigation survey, conducted over a series of missions to MIR (STS-63, -71, -74, -76, -79, -81, -84, -86) provides a record of long-duration exposure of MIR surfaces. Photography used to provide high-resolution detail of the MIR has recorded many instances of surface damage and discoloration including effects on solar arrays, thermal protection blankets, radiator paint coatings, etc. The intensity, pattern, and location of noted discoloration is used by the technical community to determine whether its source can be attributed to outgassing, leaks, or atomic oxygen. In addition, many potential micrometeoroid/orbital debris strikes have been identified and measured, with size ranges up to 25 cm^2. Video acquired from the Orbiter payload bay cameras is primarily used to capture dynamic events such as solar array motion, free-floating debris, and thruster plume dispersion angles. MIR Photo Survey reports from each of the missions flown are available on the SEE Web site.

1.5.2 Plume Impingement Contamination (PIC) Experiment

The objective of the PIC Experiment, an ISS Risk Mitigation experiment which flew on STS-74, was to provide quartz crystal microbalance (QCM) measurements of both transient and persistent surface contamination produced by Shuttle Primary Reaction Control System (PRCS) engines, Russian 13-kg attitude control and reboost thrusters on MIR, and the Shuttle environment during nominal operations. These measurements are needed to assess the impact of hypergolic engine plume impingement contamination on the functional life of sensitive ISS surfaces, which are an important cost driver to the ISS program. Measurements were made by two essentially identical QCM's mounted on the Shuttle remote manipulator end effector. The resulting data was relayed to an on-board Shuttle computer and stored on floppy disks for post-mission analysis. The results confirmed earlier measurements for the Shuttle PRCS engines of very low values for persistent contamination and also showed no persistent contamination was detected from the Russian 13-kg thrusters. Reports concerning this investigation are available on the SEE Web site.

1.5.3 Electric Field Characterization

The radio frequency interference (RFI) environment projected for the International Space Station is of increasing concern due to new ground-based transmitters for communication and radar applications. The purpose of this experiment is to measure the electric field intensities from 400 to 18000 MHz through the Shuttle window as well as to measure the internal environment inside the Russian MIR Space Station. Post mission data analysis will be used to determine if EMI mitigation techniques are necessary due to the high field intensities. The experiment consists of an antenna mounted on the overhead window inside the flight deck. A spectrum analyzer measures the signal levels and sends the data to a Payload General Purpose Computer (PGSC) which stores the data for post flight analysis.

The Electric Field Characterization experiment, an ISS Risk Mitigation Experiment, was developed at the Johnson Space Center and was performed on the Shuttle during the docked phase of STS-76 and on both the Shuttle and MIR when the STS-79 Shuttle mission was docked.

1.5.4 MIR Environmental Effects Payload (MEEP)

The MIR Environmental Effects Payload (MEEP) provided a carrier for four SEE-related experiments: two passive optical sample arrays and two meteoroid/orbital debris experiments, all of which are described in the succeeding paragraphs. The payload was flown to MIR on STS-76 as part of the ISS Risk Mitigation program where it was deployed and exposed to the space environment for approximately eighteen months before being retrieved on STS-86 in September, 1997. The MEEP was developed by the Langley Research Center. The experiments it carried are included in sections 1.5.4.1 through 1.5.4.3.

1.5.4.1 Passive Optical Sample Assembly (POSA) - 1 and -2 Experiments

The objective of the two POSA experiments is to assess the magnitude of molecular contamination on ISS critical surfaces and to quantify the performance and degradation rate of candidate/baseline ISS exterior surface materials. The experiments consist of various passive sample trays, carousels, and plates, as well as vacuum ultraviolet diodes and atomic-oxygen pinhole cameras. The two experiments differ in the types of materials selected for space exposure, POSA-2 exposing silicon-based materials not incorporated in the POSA-1 experiment.

1.5.4.2 Orbital Debris Collector (ODC)

The objective of the Orbital Debris Collector (ODC) experiment is to capture hypervelocity orbital debris and natural micrometeoroid particles in such a fashion that the particles can be returned to Earth for compositional analysis. ODC will identify the compositional and textural makeup of captured materials and examine particles in the 10 μm to millimeter size range and (with an emphasis being placed on identifying man-made orbital debris particles) as well as determine the mass distribution and absolute flux of particles in the MIR environment. The experiment utilizes SiO_2 Aerogel, a translucent, extremely low-density (i.e., 0.02 g/cm^3) material as a capture medium to decelerate the incoming particles and reduce the heating and shock stresses such particles are normally subjected to when impacting a solid medium.

1.5.4.3 Polished Plate M/OD experiment (PPMD)

The objective of the Polished Plate Micrometeoroid and Debris (PPMD) experiment is to assess and characterize the natural micrometeoroid and the man-made debris environments in the MIR high-inclination orbit. The PPMD experiment will determine the debris impact fluxes, the mass range of debris particles encountered, sources of the debris encountered, and characterize the resulting impact damage. The PPMD experiment consists of plates made of gold, aluminum, and zinc. The plates are attached to the Experiment Container mounting plate where they will be exposed to the environment around MIR. An atomic-oxygen pinhole camera is utilized to assist in determining the viewing direction. The PPMD experiment was developed by the Langley Research Center.

1.5.5 Real-Time Radiation Monitor Detector (RRMD)

The RRMD investigation provides a series of experiments designed for the measurement of space radiation dose and the elemental composition and energy spectra of cosmic radiation in real-time. The space radiation inside the Space Shuttle was measured during the experiments using the RRMD in the same orbit as planned for the International Space Station. The detector unit contains a Linear Energy Transfer (LET) Spectrometer, which is used to measure the LET distribution of all radiation particles in the spacecraft. Another facet of the experiment is to make a comprehensive analysis of the acquired observation data and RRMD data on the sun and space environments to develop a practical system for understanding the environment affected by space radiation. Other experiments also provide information on the effect of radiation on a number of selected biological samples.

1.5.6 Optical Properties Monitor (OPM)

The OPM is an ISS Risk Mitigation Experiment designed to determine *in situ* the effects and damage mechanisms of the MIR space environment on materials. It measures the natural and induced effects of the space environment on optical, thermal control, and other materials planned for future use by ISS and other space systems. Nearly 100 peer-reviewed samples submitted by industry, academia, and government agencies were selected for flight opportunity. The samples were exposed to the space environment and measured periodically with the use of a rotating carousel. Measurements of the optical and thermal properties of the samples included spectral total hemispherical reflectance, total integrated scatter (TIS), vacuum ultraviolet (VUV) reflectance/transmittance, and total emittance. Environment measurements of solar/earth irradiance, molecular contamination, and atomic oxygen (AO) were made as well. Resulting data were stored to floppy disk and downlinked to Earth for subsequent analysis. The OPM was developed by AZ Technology and managed by the Marshall Space Flight Center. The OPM was transported to MIR in January, 1997, during the STS-81 mission and subsequently deployed. After operating autonomously for several months, exposing test materials, performing optical measurements, and monitoring environmental conditions, the OPM was retrieved on STS-89.

1.5.7 Contamination Environment Package (CEP)

The objective of the Contamination Environment Package was to characterize the generation of on-orbit contamination during the 10-day servicing period for the Hubble Space Telescope (HST) of STS-82. The package consisted of five Temperature-Controlled Quartz Crystal Microbalances (TQCM's) for measuring molecular outgassing materials and a pressure gauge to monitor the local pressure field. The TQCM's were located in two housings located on either side of the HST Flight Support System. Once the CEP instruments were activated, the measurement periods of interest included Orbiter approach to HST and other orbiter operations such as dumps, maneuvers, reboosts, and unberthing. The Goddard Space Flight Center developed the CEP with participation from the Johns Hopkins University/Applied Physics laboratory.

1.5.8 Radiation Monitoring Equipment III (RME-III)

Exposure of crew, equipment, and experiment to the ambient space radiation environment in low earth orbit poses one of the most significant health problems to long-term space habitation. The RME-III experiment provides a measurement of exposure to ionizing radiation on the Space Shuttle by displaying the dose rate and total accumulated radiation dose to the operator, while simultaneously registering the number of radiation interactions and dose accumulated at ten-second intervals. The resulting data is stored in RME-III's memory module(s) for analysis upon return to Earth. The radiation detector used in the instrument is a spatial ionization chamber called a tissue equivalent proportional counter (TEPC) which effectively simulates a target size of a few microns of tissue, the dimensions of a typical human cell. The Johnson Space Center, under the direction of the Defense Department's Space Test Program, developed RME-III. RME-III operations were carried out on the STS-84, -86, and -91 missions as part of the ISS Risk Mitigation studies. The data obtained from the RME-III are being used to update and refine models of the space radiation environment in low-Earth orbit. This will assist space mission planners to more accurately assess risk and safety factors in future long-term space missions, such as the International Space Station.

1.5.9 Space Portable Spectro-Photometer (SPSR)

The stability of materials used in the space environment continues to be a limiting technology for many space missions. The Space Portable SpectroReflectometer (SPSR) provides an *in situ* research effort to study the effects of the natural and induced space environment on optical, thermal, space power, and other materials. The SPSR provides an in-space inspection instrument for a non-destructive, quantitative engineering evaluation of spacecraft exterior surfaces. The SPSR measures the total hemispherical reflectance of external MIR surfaces to obtain their solar absorptances as an indication of the effects of the space environment on materials such as thermal coatings, viewing windows, reflectors, solar power systems, etc. The SPSR will provide valuable data for determining how materials degrade when exposed to the space environment within the Shuttle/MIR implementation framework. The experiment was developed by AZ Technology and managed by the Marshall Space Flight Center. The SPSR was carried into space on STS-86 as one of the ISS Risk Mitigation Experiments. It was deployed by Extra Vehicular Activity (EVA) where the hand-held device was placed adjacent to surfaces to be measured. The resulting data was later transferred to a laptop computer and downlinked to ground for analysis. SPSR was retrieved on STS-89 in January, 1998.

1.5.10 Evaluation of SEE on Materials (ESEM)

The ESEM investigation consisted of two passive experiments designed to monitor the effects of atomic oxygen and space debris on materials on the Shuttle STS-85 mission in August, 1997. The experiments were mounted on the Japanese Manipulator Flight Demonstration (MFD) Unit support structure. The Langley Research Center is responsible for providing the experiments with participation by Boeing Company and the College of William and

Mary. The atomic oxygen experiment exposed to the space environment advanced materials to be used in future space missions, including electric wire, solar cell, solid lubricant, thermal control film and paint. After exposure to atomic oxygen, the samples will be returned to the Earth, and analyzed for any possible changes in their material characteristics. The results of the analysis will be reflected in the future selection of parts and materials to be used for the International Space Station, and will also be used as data for developing high-performance space materials. The Cosmic Dust Collection experiment will utilize Silica aerogel, developed at the National Laboratory for High-Energy Physics, as a medium to capture meteoroids and orbital debris particles without damage and return them to earth for analysis of chemical composition, shape, size, and mass, and speed at the time of collision.

1.5.11 Cosmic Ray Effects Activation Monitor (CREAM)

The purpose of the Cosmic Ray Effects Activation Monitor is to monitor the crew dose, single event effects, and material activation radiation environments. This experiment, also an ISS Risk Mitigation Experiment, is part of a series of experiments designed to monitor those aspects of the radiation environment responsible for single event upsets in electronics and background noise in sensors across a wide range of geomagnetic coordinates and shielding conditions. CREAM is a British-built, Air Force sponsored experiment whose operations were undertaken on STS-86 and STS-91.

1.5.12 Environment Monitoring Package

The Environment Monitoring Package is a planned suite of integrated environment monitors dedicated to measuring constituents of the natural and induced environment around the International Space Station. The package will operate as an EXPRESS Pallet attached payload or positioned for measurement by the Space Station RMS Special Purpose Dexterous manipulator (SPDM). EMP is currently scheduled for flight on the UF-4 mission in the first quarter of 2002. The objectives of the package are to provide real-time monitoring of selected environment constituents for payload operations, to verify that the environment around the ISS is consistent with Space Station contamination control requirements and payload design requirements, and to provide quantitative environmental measurement data to verify ISS predicted environment models. To this end the project is currently defining a conceptual payload based on the requirements of attached ISS payload users.

1.6 SEE data archiving, database and models management

The SEE Program Office has implemented a data archiving and database management system to facilitate the implementation of the SEE goal of "advocating technology development and databases by creating and maintaining engineering focused models and databases."

The SEE Website serves as a repository for databases, flight experiments, guidelines, handbooks, models, and expert systems related to the space environment and its effects. These various elements of the repository come from products of the SEE Program's 1994 NRA contracts, other SEE directed or SEE related technology development activities, flight experiments, and the engineering and scientific community. The SEE web site (http://see.msfc.nasa.gov) currently contains results of the MIR Photo Survey and the Plume Impingement Contamination Experiments, both of which are part of the International Space Station (ISS) Risk Mitigation Experiments package. Other risk mitigation data will be archived by the SEE Program as the data becomes available.

Many space environments effects models are currently maintained on the SEE website and can be downloaded via the site or the SEE file server. Among these models is an excellent expert systems tool for contamination control, which is available now for downloading, and several interactive models that are currently being evaluated and tested. These interactive models will give users the option of running the models from within their web browser.

The SEE Program Office is currently sponsoring an activity to develop the Integrated Space Environments and Effects Engineering Tool (ISEEET) to provide a model with the capability for quick analysis of space environments and effects during the preliminary design process. Work is currently underway to coordinate with the NASA Engineering Design Centers located at several NASA centers to determine the user's requirements for the tool.

2. Ionizing Radiation Technology Development Activities (TDA's)

2.1 The Ionizing Radiation Environment and its Effects on Satellites TDA

This effort is for the development of an improved model of the ionizing radiation environment in space and its effects on satellites. Because modern electronics are becoming increasingly sensitive to ionizing radiation, a need was identified to improve the space radiation environment models and predictions of ionizing radiation effects on spacecraft. CREME96, a group of four computer codes used to model cosmic rays and flares, includes improved models of the galactic cosmic rays, anomalous cosmic rays, and solar energetic particle components of the near Earth space radiation environment. Other CREME96 modifications include improvements in the geomagnetic transmission function, nuclear transport routines, and single event upset calculation techniques. A trapped proton model and a dose model have also been added to the CREME96 suite of programs because trapped protons are the largest source of single event upsets and dose effects in low Earth orbit.

2.2 Trapped Radiation Models - Uncertainties for Spacecraft Design TDA

An understanding of the trapped radiation environment and the models predicting this environment is necessary for Earth orbit spacecraft and payload designs. These predictive models, however, are based on old flight data from two to three decades ago. More recent flight data, using improved measuring techniques and more complete altitude-inclination-time coverage, indicates that the NASA models can be very inaccurate.

This effort evaluates and documents the uncertainties associated with the trapped radiation models based on current flight data, allowing the designers to make realistic risk assessments and set definitive design margins. This will lead to more reliable and cost effective spacecraft and payloads.

A review of flight data suitable for evaluating trapped radiation model uncertainties will be made, including data from U.S., ESA, and Russian satellites. Potential US satellite measurements include SAMPEX, CRRES, DMSP, Clementine, LDEF, NOAA, DoD Molnya orbit satellites, and the Space Shuttle. Data will be assimilated over a wide spatial regime so that model uncertainties can be evaluated for a range of orbital parameters. This effort will provide support for numerous evolving Earth-orbit space missions, such as NASA's Earth observing system (EOS), Space Station, space science/astrophysics missions, and small spacecraft missions; DoD's LightSat programs; and commercial communications satellite programs.

2.3 Low-Altitude Trapped Radiation Model TDA

The Low-Altitude Trapped Radiation Model effort will develop improved models of the low-altitude trapped proton and electron environment, including a true solar cycle dependence. The objectives are to develop and validate a long-term database of trapped electron and proton fluxes at low altitudes and then compares it with data from several spacecraft in order to verify its accuracy. This database will be used to develop a general model to determine the particle flux at a given location in space and time. The model and database will apply to protons with energy between 10 and 250 MeV and electrons with energy greater than 0.3 MeV. The benefits to having more accurate dose predictions for low-altitude spacecraft will result in reduced costs for spacecraft by avoiding over-design of systems and components as well as avoiding spacecraft failures due to under-design.

2.4 Trapped Proton Model TDA

A new model of the Earth's trapped proton population is being developed, allowing more accurate predictions of the trapped proton flux. The trapped proton population is based primarily on data from the TIROS/NOAA series of spacecraft and the CRRES satellite. The model will incorporate the solar activity variations at low altitude and will extend out to $L \sim 5.5$, with an energy range coverage from 1 MeV to greater than 200 MeV. The model will be constructed to provide the user with the omnidirectional integral proton flux as a function of energy, spacecraft position, and solar activity. It will be developed so that it can be updated periodically to account for secular variations in the geomagnetic field. Benefits include reducing costs for designing spacecraft by reducing the amount of safety margin required to account for inaccuracies or uncertainties in the proton model. Additionally, spacecraft operating costs will be lower by reducing the possibility of under-designing the spacecraft for the environment in which they operate.

2.5 Design Guidelines for Ionizing Radiation TDA

With the increased use of advanced technologies to meet higher performance, lower cost, and reduced launch weight, ionizing radiation design issues are expected to become more critical in the near future. Spacecraft designers and systems engineers must consider the radiation issues at the onset of mission planning and spacecraft design to help prevent both overdesign and underdesign, as well as helping to recognize and accommodate ionizing radiation issues associated with emerging technologies. The Design Guidelines for Ionizing Radiation addresses the different phases of the mission and spacecraft design process, including the broad range of radiation effects, components, and subsystems for both current and emerging technologies. It will aid the designers in recognizing and accommodating ionizing radiation issues associated with these emerging technologies, particularly as related to emerging sub-micron, low power, low voltage electronics technologies, the increased use of advanced photonic components, and evolving new materials. The guidelines are developed for near-Earth orbits, however, much of the information would be applicable to missions independent of the orbit and mission. It will benefit both near Earth and deep space missions, multiple NASA Enterprises, and NASA, DoD, and commercial missions.

3. Ionizing Radiation Flight Opportunities

3.1 NASA's Space Radiation and Electronics Testbed (NASRET)

With the continual trend towards smaller, more compact electronic packages and the use of Commercial Off-the-Shelf (COTS) components in spacecraft systems, the effects of the radiation environment are of increasing concern. Five experiments, comprising NASRET are scheduled to fly a mission in 1999 to validate advanced microelectronics technology in a harsh space radiation environment and to improve ground test methodology. The Marshall Space Flight Center's SEE Program Office is leading this effort with major participation from the Goddard Space Flight Center, Jet Propulsion Laboratory, Langley Research Center, and Aerospace Corporation. NASRET consists of 1) a Dosimetry experiment to measure the observed radiation environment and the effectiveness of composite material and conformal coating shielding technologies, 2) an Analog COTS experiment to measure the impact of low dose rate effects and transient Single Event Effects on commercial analog devices such as operational amplifiers and voltage comparators, 3) a Digital COTS experiment to measure the impact of the radiation environment on commercial digital devices, such as stacked memories, ferroelectric memories, and Field Programmable Gate Arrays, 4) a Photonics COTS experiment to measure the enhanced proton displacement effects and transient Single Event Effects on commercial optocouplers, and 5) a Pulse Height Analysis (PHA) experiment to measure the radiation environment in terms of the stopping power of the charged particles for better Single Event Effects rate predictions.

3.2 Orbiting Technology Testbed Initiative (OTTI)

There is increasing interest for launching satellites into high radiation orbits (MEO, GTO, and Elliptical), especially within the communications industry. OTTI is an effort that is determining the need and feasibility of developing an in-flight testbed in support of future NASA, DoD, and commercial satellite programs. The concept is expected to determine whether such a mission (or series of missions), when launched into a harsh radiation environment above low earth orbit (LEO), will provide a means of enabling improved spacecraft performance and reduced spacecraft costs. Several key areas being addressed include: 1) choice of orbit, such as mid-earth orbit, which is of great interest for commercial communication satellites, 2) experiment technology issues such as in-flight technology demonstrations and choice of enabling technologies from microelectronics to photonics to system architectures (with their associated risks and benefits), 3) payload requirements driven by experiment selection, and 4) launch options and spacecraft requirements, as driven by orbit and payload requirements. In addition, the impact of space environments and the benefits and drawbacks of developing and operating a flight experiment versus ground-based testing is being addressed.

4. CONCLUSIONS

The NASA Space Environments and Effects Program, in cooperation with its participants, has made significant progress since 1993. As this paper illustrates, its participants now reflect an interagency and broad industry scope. The Program also plays an important role as advocate for space environments and effects related flight experiments. The Program's success, however, depends upon the feedback from aerospace industry and government programs on their anticipated needs and the value of the Program's products in their spacecraft systems development activities.

Those having interest in the Space Environments and Effects Program activities, whether from opportunities for participation, information on products, or to contribute inputs on future spacecraft needs relative to space environment definition or effects of the space environment on spacecraft systems, are invited to visit the Program's Website Homepage at *http://see.msfc.nasa.gov*.

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