An Environment Monitoring Package For The International Space Station

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Abstract. The first elements of the International Space Station (ISS) will soon be launched into space and over the next few years ISS will be assembled on orbit into its final configuration. Experiments will be performed on a continuous basis both inside and outside the station. External experiments will be mounted on attached payload locations specifically designed to accommodate experiments, provide data and supply power from ISS. From the beginning of the space station program it has been recognized that experiments will require knowledge of the external local environment which can affect the science being performed and may impact lifetime and operations of the experiment hardware. Recently an effort was initiated to design and develop an Environment Monitoring Package (EMP). This paper describes the derivation of the requirements for the EMP package, the type of measurements that the EMP will make and types of instruments which will be employed to make these measurements.

INTRODUCTION

Over the next few years the International Space Station (ISS) will be assembled on-orbit. Experiments will be performed on a continuous basis both inside and outside the station with external experiments mounted on attached payload locations specifically designed to accommodate them and provide a data and power interface. The ISS requirements related to the external environment are identified in space station documents. These specifications provide design guidelines to experiments so that they can be designed to operate successfully in the ISS environment. They address the external contamination environment produced by ISS, the induced neutral and plasma environment, and the voltage between the ISS structure and the local plasma. Specifications of the natural environment and definition of the perturbed environment due to both the physical presence of the space station in the ambient environment and its contribution to the environment by outgassing and venting are also given. Included are the maximum flux of contaminants to surfaces due to outgassing of hardware and venting from station elements for both quiescent and non-quiescent times. An Environment Monitoring Package (EMP) is being designed and developed for use on ISS at both fixed locations along the structure and on the end of the Space Station Remote Manipulator System (SSRMS). Actual environment data will allow more accurate evaluation of the effect of the ISS environment on science, payload operations and expected payload lifetime thus improving both science and the efficiency of payload operation.

REQUIREMENTS DEVELOPMENT

The ISS requirements are meant to provide the payload community with a definition of the environment in which they will operate. Because the EMP will provide measured data which will more specifically define this environment, it is important to assess what requirements will be levied on the EMP to provide data to the attached payload community. In order to obtain monitoring requirement input from those affected by the ISS external environment, a questionnaire was distributed to the user community through the ISS Attached Payloads Working Group. The ISS International Partners are represented in this forum and this provided an avenue for them to also provide input into these requirements. The questionnaire pointed out the ISS payload requirements which were already being addressed and requested definition of other environment data important to the payload community.

The EMP attached payloads will also support investigation of technologies as well as science. A wide range of studies are ongoing including development of new spacecraft materials, models of vented and outgassed product flow around spacecraft, models of the interaction of the local plasma with high voltage systems, and models of the synergistic interaction of the environment, contamination and materials. These and other related areas also mean that the information from the EMP will be important to such technology studies. Therefore, the questionnaire was distributed to the Technical Working Groups of the NASA Code S Space Environments and Effects (SEE) Program. The inputs from the ISS program requirements, the attached payload community and the SEE working groups provided a thorough and broad input into the monitoring requirements for EMP.

Environment Monitoring Roadmap

The development of EMP objectives and instrument parameters relied heavily on ISS requirements and the considerations of most concern to currently designated payload users. While a single suite of monitors to measure all aspects of the environment is highly desirable, budgetary and other resource constraints severely impact this option. In addition, efforts are also planned by other organizations and agencies to monitor different aspects of the ISS environment which, when taken together, will provide a comprehensive understanding of the overall space environment around ISS. These endeavors, which are international in scope, include NASA experiments already planned for the ISS, the European Space Agency's (ESA) Technology Exposure Facility, the Space Environment Data Acquisition Equipment planned by the National Space Development Agency (NASDA) of Japan, the Photovoltaic Engineering Testbed (PET) planned by the NASA/Lewis Research Center and experiments planned by the Russian Space Agency (RSA). Table 1 details preliminary information received from these agencies.

TABLE 1. Environments Monitoring Planned For ISS

ENVIRONMENT	REQ	ISS	NASDA	ESA	EMP	PET	RSA	Other
Neutral Gas Constituents	SSP41000 3.2.6.1.2				X			
Atomic Oxygen	SSP30425		X	X	X	X		
Mass Deposition	SSP30426 3.7			X	X		X	
Ambient Pressure	SSP30426 3.7			X	X	X	X	
Plasma	SSP30426 3.7		X	X	X	X		
Molecular Column Density	SSP30426 3.7				(X)			
Particulates	SSP30426 3.7/ SSUAS*							X
Electromagnetic Fields	SSUAS					X		X
Ionizing Radiation	SSUAS	X	X	X		X		
Microgravity	SSUAS	X						
Meteoroid/Debris	SSUAS		X	X				

*Space Station Utilization Advisory Subcommittee

The understanding of these initial monitoring schemes on a global basis allows better planning by the sponsoring agencies resulting not only in complementary measurements, but also in the reduction of duplicative efforts with the subsequent savings of resources and cost. Detailed data concerning the measurement plans of the ISS space environment by the different agencies listed above may be accessed from NASA's Space Environments and Effects Internet Web site at see.msfc.nasa.gov.

EMP OPERATION ON THE INTERNATIONAL SPACE STATION

The International Space Station is illustrated in Figure 1. The EMP normally operates on an EXPRESS Pallet, which accommodates up to six EXPRESS Pallet Adapters, each of which may support an experiment package. The large size of the station with line of sight obstructions due to modules, radiators and other structure makes the environment very site specific. At a fixed site the environment for that location will be characterized but it is impossible to use data from only one site to specify the environment elsewhere. That is why it is also important that the EMP be mobile and be able to be moved to various locations around ISS. It can also be operated on the Special Purpose Dexterous Manipulator (SPDM) on the Space Station Remote Manipulator System (SSRMS) in order to map the environment around the ISS to provide a more complete characterization of the environment. This mapping as a function of position will be important for comparison of the data with existing models to provide an accurate prediction of the environment at locations where the EMP may not reach.

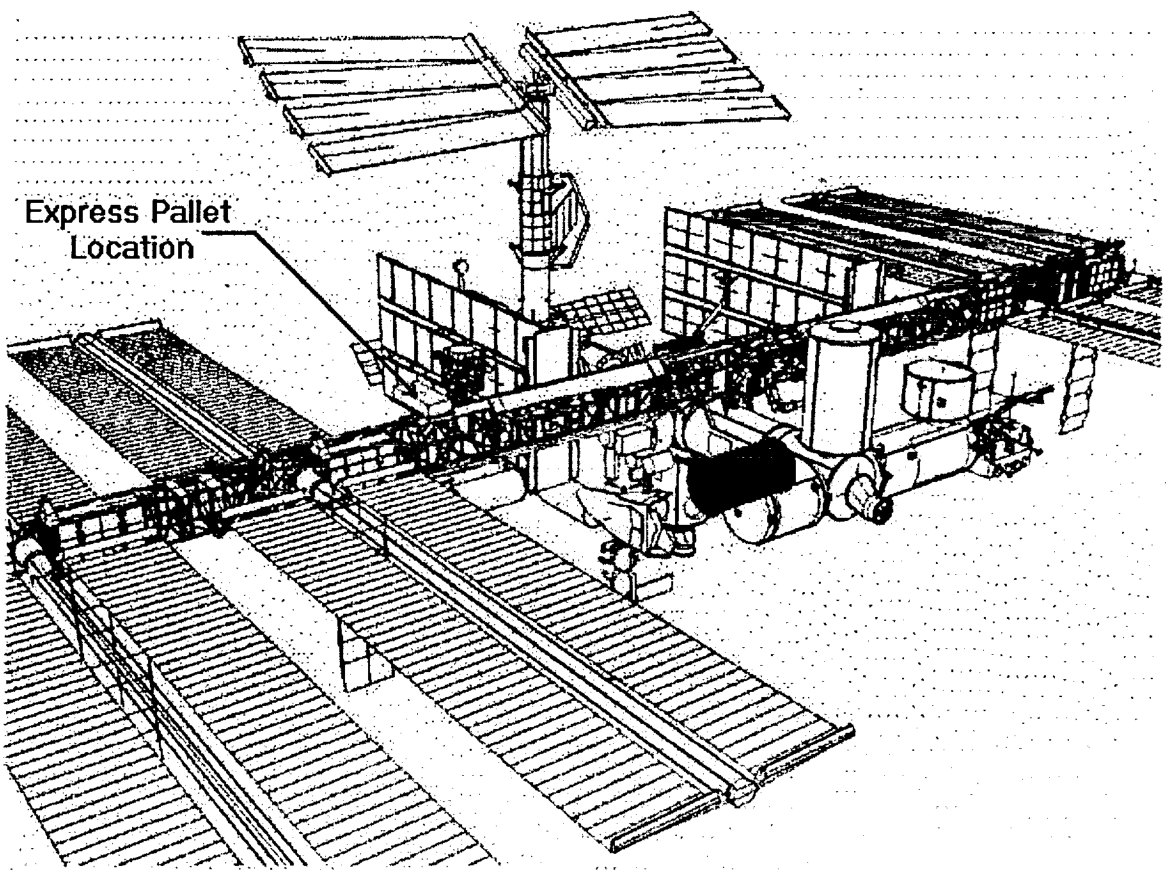

FIGURE 1. Illustration of International Space Station

The delivery of the Environment Monitoring Package to ISS is scheduled for Utilization Flight 5 (UF-5). The EMP will be transported to and from orbit via Shuttle, using the EXPRESS Pallet for launch and a standard ISS cargo carrier for subsequent return to earth. The EMP is robotically removed from the EXPRESS Pallet via the Pallet Adapter. EMP is operable on the SPDM utilizing power and data services provided through the SPDM's ORU/Tool Changeout Mechanism (OTCM) umbilical. Figure 2 illustrates it looking in the direction of vents, labeled as RSA, on the Russian hardware. The knowledge of the position and orientation of the EMP will be governed by the capability of the SPDM to determine spatial location. The envelope within which the EMP can be operated will be defined by SPDM and SSRMS reach and orientation capabilities which provide access to a large volume around ISS.

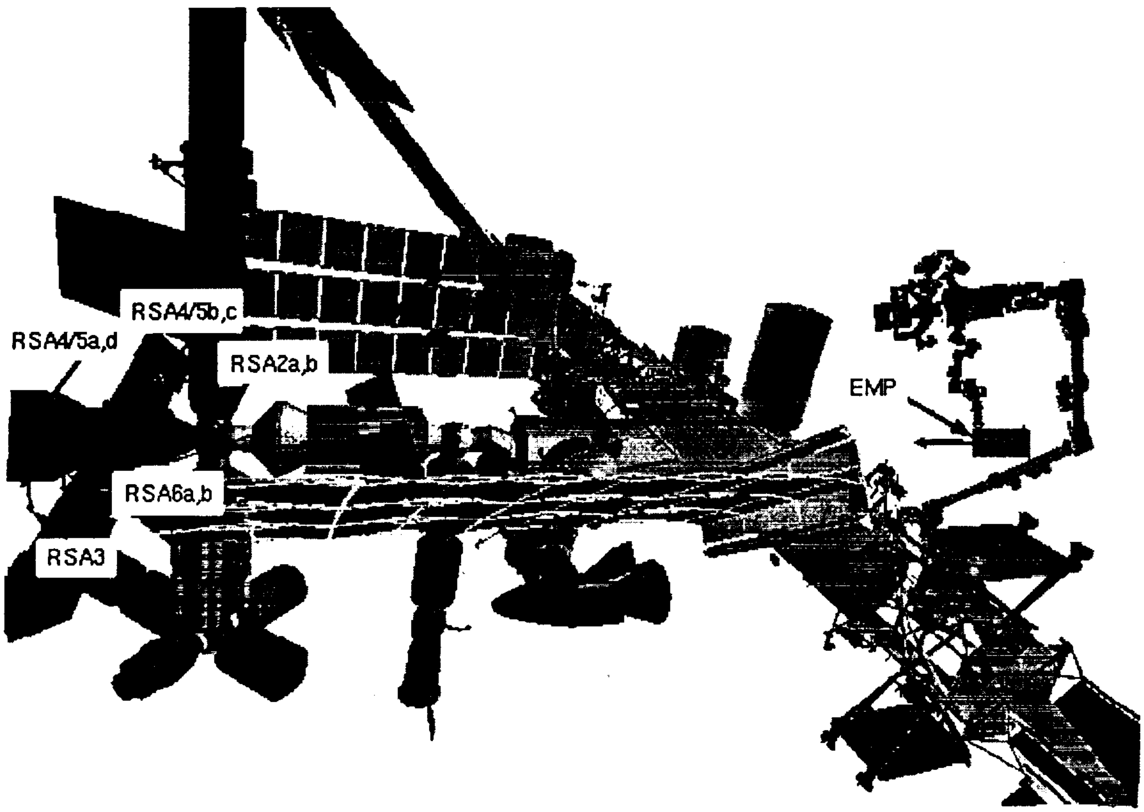

FIGURE 2. Manipulation of EMP Using the SPDM From the SSRMS

ISS EXTERNAL ENVIRONMENT

If the external environment could be visually superimposed on Figure 1 it would appear very complex. The total environment consists of the natural environment, which will be significantly perturbed by the presence of ISS, and the environment created by ISS itself. The natural environment includes the neutral atoms, primarily atomic oxygen at ISS altitudes, the ionospheric plasma environment, the solar spectrum, micrometeoroid/orbital debris, and particulate and electromagnetic radiation. Some of these environments will be measured by ISS core instrumentation, some by our International Partners and some will be monitored by EMP.

The neutral gas constituency is made up of the natural environment and that produced by outgassing, venting and other ISS operations. As ISS moves through the Earth's rarefied environment, ram-wake effects are created. The large forward projected area means there will be a large density buildup on the ram side with a large density decrease near aft facing surfaces and a resulting complex wake structure. As pointed out in SSP 30426, this buildup of density near surfaces exposed to the ram direction can be as high as 60 times the ambient density. The ambient atoms will be moving at orbital velocity relative to the ISS while those that have encountered the ISS structure will have modified velocities and may have thermal energies. There are a large number of vents around ISS which produce significantly varying quantities of gases. They will be expelled moving at a low velocity relative to ISS and they will have distributions dependent on the vent design. Xenon atoms and ions will be emitted by the plasma contactor which will be operated on ISS. Its purpose is to ground the ISS structure relative to the local plasma (Carruth, 1992). Also, thrusters used for attitude control and station reboost will contribute to the neutral and plasma environment when they are operational. Significant efforts have been made to make ISS very clean with the use of very low outgassing materials. However, some outgassing of the materials will occur contributing to the neutral environment. High molecular weight outgassing products may deposit on other surfaces and can become permanent due to interaction with solar ultraviolet (UV) radiation and/or atomic oxygen. Such deposits can darken under UV altering the properties of optical and thermal control surfaces. Therefore, this environment is of particular importance for assessing the performance of passive thermal control surfaces.

One of the ISS contamination requirements addresses the molecular column density (MCD) which is the integrated number on molecules per unit area through a given line of sight and cannot be measured directly. Because of the ability of EMP to map the environment within a large envelope provided by the SSRMS and the SPDM, the characterization of the overall neutral environment will be such that the MCD can be accurately modeled.

The ion population around ISS consists of the ambient ionospheric plasma ions as well as those produced by photoionization, charge exchange, the plasma contactor or other processes in the vicinity of the ISS. The ram buildup and the vents will be sources of neutral gas which can enhance the local plasma. The solar arrays generate 160 volts and the negative end is grounded to ISS structure. The plasma contactor will control the potential of the structure relative to the local plasma, placing the highest voltage end of the array strings near +160 volts. It is possible that some ion production by electron impact may take place in the plasma sheath around the solar arrays. The plasma contactor will itself be an ISS source of plasma and its expansion and coupling with the local plasma and magnetic fields will be measured by EMP. As specified in SSP 30420, design and operation of ISS shall be such that during quiescent periods the increase in ion density above the ambient level due to ISS outgassing and operations not exceed 1×10^{12} m^{-3} at the plasma boundary of the plasma sheath on any portion of ISS having negative high voltage (greater than 100 V relative to plasma potential) or any positive voltage exposed directly to the ionospheric plasma. The ambient level includes the natural environment and ram/wake effects. Due to the complex interaction of the ambient plasma, the enhanced plasma around ISS and the plasma contactor, an electron population will exist having more than one characteristic temperature, may be non-Maxwellian and will vary spatially. Assuming quasi-neutrality, the ion density shall be measured over the range from 10^9 to 10^{13} ions-m^{-3}.

There is an ISS requirement that the potential of the on-orbit ISS structure be within +/- 40 V of the local plasma potential. This is to prevent arcing and other effects which can be detrimental to ISS operation and lifetime. The plasma contactor will provide the means to control the potential between ISS and the local plasma. There will still be variations of voltage between parts of the extended ISS structure and the local plasma due to v x B effects. If the contactor is not present or operable then the structure potential relative to the local plasma can also go highly negative, up to -160 V due to the power system grounding to ISS structure and its coupling to the local plasma. Plasma instruments will be required to operate over all possible structure voltages. Due to the motion of ISS the ambient ions will possess a drift relative to ISS. Atoms move unaffected by magnetic fields. However, any ions formed due to ionization of neutral atoms near ISS will be picked up by the magnetic field and also gain a significant drift relative to ISS.

EMP INSTRUMENTATION

The EMP instrumentation will consist of two mass spectrometers, pressure gauges, thermoelectric quartz crystal microbalances, Langmuir probe, and Differential Ion Flux Probe (DIFP) (Stone, 1977).

The mass spectrometers will allow some redundancy but the source designs will be different. One will have a closed source. This will provide enhanced measurement of neutral atoms by allowing them to enter the ionizer at thermal energies instead of at orbital velocity. Also, the acceptance angle is very wide, with essentially a cosine dependence on flow direction reducing the importance of pointing accuracy. This source is best for low mass gasses which do not condense. High mass atoms may deposit at nominal temperatures on surfaces they intercept. The other mass spectrometer will have an open source and will be best suited for examining these atoms and the ion population. Both spectrometers will cover the mass range from 4 to 300 amu, have better than unity resolution at 150 amu, be sensitive to partial pressures at or near 10^{-14} Torr and have a dynamic range of nine orders of magnitude.

The total pressure shall be measured over a range of 10^{-10} Torr to 10^{-3} Torr which will cover the ram and wake regions as well as the vents. Pressure gauges will be mounted such that the neutral incident flux is measured in all directions except towards the EXPRESS Pallet adapter mounting surface. The combination of the general but broader acceptance angle of the pressure gauges coupled with data from the detailed mass analysis from the narrow field of view mass spectrometer will allow optimum characterization and monitoring of the neutral environment.

The total molecular mass deposition will be measured with Temperature Controlled Quartz Crystal Microbalances (TQCM) facing in different directions. MOLFLUX modeling of the ISS contamination flux predicts that long integration times will be required with standard 15 MHz crystals for measurable deposition. Therefore, some 50 MHz crystals may be used which will extend the sensitivity an order of magnitude. They will suffer from the same magnitude reduction in mass loading capability. TQCMs of different frequencies will be used to extend the sensitivity range and mass loading capability in order to cover a wide range of measurement capability. The instrumentation collecting surface will be commanded to different temperatures to examine what mass is collected as a function of temperature and evolved at warmer temperatures and to periodically remove the deposited contaminants. The range over which the collecting surface will operate will be from 213 K to 300 K.

The EMP instrumentation will include a Langmuir probe capable of monitoring structure potential relative to plasma potential, plasma density and electron and ion energy distribution. Plasma to structure potentials of from -160 to +50 V (plasma = 0 V) must be accommodated to include the possible range which can be encountered on orbit. The distribution of the drifting ion energy of the plasma environment shall be measured in the range of zero to 160 eV with a Differential Ion Flux Probe (DIFP). The DIFP will also provide the direction of drifting ions very accurately. The combination of data from the DIFP instrument, the Langmuir probe and the ion capability of the mass spectrometer will allow characterization of the plasma environment.

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