Initial Results from the Space Environment Data Acquisition Equipment aboard the International Space Station

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Abstract

Space Environment Data Acquisition equipment (SEDA), which was mounted on the Exposed Facility (EF) of the Japanese Experiment Module (JEM, also known as “Kibo”) on the International Space Station (ISS), had developed to measure the space environment of the orbit of ISS. This payload module is called SEDA – Attached Payload (AP). SEDA-AP started to measure space environment on Aug. 2009. This paper reports the mission objectives, instrumentation, and initial measurement results of SEDA-AP.

1. Introduction

To support future space activities, it is very important to acquire space environmental data related to space radiation degradation of space parts and materials and spacecraft anomalies. Such data are useful for spacecraft design and manned space activity.

On several satellites of the Japan Aerospace Exploration Agency (JAXA) since the Engineering Test Satellite-V (ETS-V), Technical Data Acquisition Equipment (TEDA) and SEDA have been installed for obtaining the data described above (TEDA and SEDA were installed on 14 spacecrafts for over 20 years).

The SEDA-AP was launched by the Space Shuttle Endeavour (STS-127) on 16 July 2009 (JST) and attached to the JEM-EF on 24 July 2009 (JST). SEDA-AP started to measure space environment on 11 Aug. 2009. The SEDA-AP comprises common bus equipment supporting launch, RMS handling, the power/communication interface with JEM-EF, an extendible mast that extends the neutron monitor sensor 1 m separate from the bus structure, and equipment that measures space environment data. Figure 1 shows a picture of SEDA-AP and the Exposed Facility. Figure 2 depicts a perspective drawing of SEDA-AP.

Fig. 1. Picture of the SEDA-AP(left) and EF on ISS/kibo

Fig. 2. Perspective drawing of SEDA-AP
2. Instrumentation

Figure 2 shows that SEDA-AP has eight environment monitoring sensors. Its total weight is about 480 kg; its dimensions are $1850 \times 1000 \times 800$ mm (neutron monitor storing condition). An overview and the principle of each instrument are as follows.

2.1 Neutron Monitor (NEM)

Neutrons are very harmful radiation because of their strong permeability attributable to its electrical neutrality. The Neutron Monitor measures the energy of neutrons from thermal to 100 MeV in real time using a Bonner Ball Detector \(^1\)[2] and a Scintillation Fiber Detector \(^3\). The Bonner Ball Detector discriminates neutrons from other charged particles using 3He counters, which have high sensitivity to thermal neutrons. It also measures neutron energy using the relative response, which corresponds to different polyethylene moderator's thickness (6 pcs.). The Scintillation Fiber Detector measures the track of incident particles using a cubic arrangement sensor on which are heaped up 512 scintillator fibers. The sensor discriminates neutrons using differences of these tracks, and measures neutron energy by measuring its track length. Figure 3 depicts an image of NEM.

2.2 Heavy Ion Telescope (HIT)

Using a Solid State Detector, the Heavy Ion Telescope measures the energy distribution of heavy ions (Li–Fe), which cause single event anomalies and damage to electronic devices. The Solid State Detector converts loss energy of heavy ions in the detector to electrical signals. The HIT measures an incident particle's mass from loss energy in each layer ($\Delta E$) and the total loss energy of each layer ($E$) using the $\Delta E \times E$ method. Figure 4 presents a picture of HIT.

2.3 Plasma Monitor (PLAM)

Using a Langmuir probe, Plasma Monitor measures the density and electron temperature of space plasma, which cause charging and discharge of the spacecraft. Figure 5 depicts the PLAM.

2.4 Standard Dose Monitor (SDOM)

The Solid State Detector and scintillator of the Standard Dose Monitor measure the energy distribution of high-energy light particles such as electrons, protons, and $\alpha$ particles, which cause single event anomaly and damage to electronic devices. Figure 6 shows a photograph of SDOM.

2.5 Atomic Oxygen Monitor (AOM)

The Atomic Oxygen Monitor (AOM) measures the amount of atomic oxygen on the orbit of the International Space Station. Atomic oxygen interacts with the thermal control materials and paints, thereby degrading their thermal control ability. The AOM measures the resistance of a thin carbon film that is decreased by atomic oxygen erosion \(^4\). Figure 7 shows a picture of an AOM.
2.6 Electronic Device Evaluation Equipment (EDEE)

The Electronic Device Evaluation Equipment measures single-event phenomena and radiation damage to electronic parts. Single-event phenomena are induced by the impact of an energetic heavy ion or proton. The occurrence of single-event phenomena is detected by bit flips of memorized data, the sudden increase of power supply current, etc. Figure 8 depicts the EDEE.

2.7 Micro-Particle Capturer (MPAC)

The Micro-Particle Capturer is a device used to capture micro-particles that exist on orbit. Silica-aerogel and gold plates are used to capture micro-particles. After the retrieval of MPAC, the size, composition, and collision energy, etc. of captured particles are evaluated [5].

2.8 Space Environment Exposure Device (SEED)

The Space Environment Exposure Device is a device used to expose materials for space use. After SEED retrieval, degradation of these materials caused by the space environment, such as high energy radiation, atomic oxygen and UV, will be evaluated. Figure 9 portrays a picture of both MPAC and SEED hardware [5].

### Fig. 5. The picture of PLAM
### Fig. 6. Photograph of SDOM
### Fig. 7. Photograph of AOM

### Fig. 8. Photograph of EDEE
### Fig. 9. Photograph of MPAC & SEED

3. Applications of the data

Applications of the data is as follows,

(1) Development of various space environmental data base for many utilization needs
   - Making and maintenance of space environmental model for space craft design
   - Support for astronauts exposed to space radiation
   - Support for space weather forecasting
   - Contributions to scientific fields
   - Investigation of space radiation degradation of parts & materials and space craft anomalies caused by space environment

(2) On-orbit verification of the “Kibo” exposed facility utilization technology
On-orbit verification of APBUS technology that utilizes the “Kibo” exposed facility
On-orbit verification of experimental payload integration technology that utilizes the “Kibo” exposed facility

4. Measurement Results
4.1 BBND Nutron measurement results
Figure 10 shows BBND S-1 sensor’s geographical plot data, and Figure 11 shows BBND S-6 sensor’s geographical plot data on 350km altitude on 1 Oct.2009.

4.2 FIB Nutron measurement results
Figure 12 shows the neutron tracks actually obtained from the onboard sensor. The left side is Y direction of sensor, and the right side is X direction. The both direction has 256 (16x16) squares shows each scintillation fiber (6x3mm) output. Figure 13 shows proton tracks which started from the first layer of the fiber (in the case of the neutron measurement mode was off).

4.3 SDOM Measurement results
Figure 14 shows electron (0.28-0.79MeV) measurement results of SDOM, that is overlapped on the world map. SAA (South Atlantic anomaly), radiation enhanced region related to the offset of earth magnetic field, and horn region of outer radiation belt are clearly shown. Figure 15 shows proton (0.78-1.09MeV) measurement results of SDOM, that is also overlapped on the world map. SAA (South Atlantic anomaly) are clearly shown.
4.4 EDEE measurement results

EDEE Observed Results (2009/8/15~2009/10/23) are showed with the name of devices under test and Single Event Upset (SEU), Single Event Latchup (SEL), and Single Event Burnout (SEB) measurement results, as following

- V70-MPU  SEU/SEL : Not observed
- 1M SRAM  SEU : 5 upsets observed/512K
  SEL : Not observed
- PowerMOSFET(@175V)  SEB : Not observed

5. Summary

Space environment data in JAXA, which include data from SEDA-AP, are available to the public as data of the Space Environment and Effect System (SEES; http://sees.tksc.jaxa.jp). Those data will be used widely by academic and industrial users in laboratories, universities, JEM experiment investigators, and others in spacecraft operation, engineering fields, and scientific research. Data from SADA-AP will also be used to develop the Japanese space environment model [6].

References

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SEDAP (Space Environment Data Acquisition Equipment - Attached Payload)

• MISSION OBJECTIVES
  • Revising of Space Environment Model.
  • Support of space radiation exposure management to astronauts from Solar Flares, and Galactic Cosmic Ray.
  • Support of the space weather nowcast.
  • Contribution to the space science.
  • Elucidation of degradation, soft error of EEE parts and materials due to space environment.

• MISSION SUMMARY
SEDA-AP started to measure space environment at the Exposed Facility of Japanese Experimental Module (JEM) on 11 Aug. 2009.
We called the SEDA A Stevenson Screen in Space

Location of 8 instruments

- SDOM: Standard Dose Monitor
- HIT: Heavy Ion Telescope
- EDEE: Electric Device Evaluation Equipment
- NEM: Neutron Monitor
- AOM: Atomic Oxygen Monitor
- MPAC&SEED: Micro-Particles Capture and Space Environment Exposed Device
- PLAM: Plasma Monitor
- Direction of flight movement (RAM)
**SEDAC-AP** (Space Environment Data Acquisition Equipment - Attached Payload)

- **SDOM**: Standard Dose Monitor
- **Heavy Ion Telescope**
- **AOM**: Atomic Oxygen Monitor
- **EDEE**: Electronic Device Evaluation Equipment
- **NEM**: Neutron Monitor (NEM-Electronic device and NEM-sensor)
- **PLAM**: Plasma Monitor
- **MPAC&SEED**: Micro-particles Capture and Space Environment Exposure Device

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**Japanese Experimental Module “Kibo” (JEM)**

- **Pressurized Module**
- **Exposed Facility**
SEDA-AP System Overview

Launch/Return Configuration
(MST stowed)

On Orbit Configuration
(MST extended)

Total Weight: Approx. 450kg
On-orbit Power Consumption: Approx. 220W
Data Communication: MIL-STD-1553B

Picture of SEDA-AP

Launch Configuration
(NEM-S is stowed in the SEDA-AP structure)

On Orbit Configuration
(NEM-S is extended 1 m from the SEDA-AP structure)
Outline of instruments

neutrons in space

SUN

Solar-Neutrons

Local (production) Neutrons

Albedo-Neutrons

proton

proton

Atmosphere

Earth Ground

Space-ship
Two types of Neutron Monitor

**BBND : Bonner Ball Neutron Detector**
- Measurement energy range: 0.025eV (thermal neutron) ~ 15MeV
- Max. count number: $1 \times 10^4$ count/sec

**FIB : Fiber-type neutron detector**
- Measurement energy range: 15 ~ 100MeV
- Max. event number: 50 event/sec

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**BBND : Bonner Ball Neutron Detector**

0.025eV (thermal neutron) ~ 15MeV

3He counter and polyethylene moderator

4 different thickness of polyethylene spheres (1.5cm, 3cm, 5cm, and 9cm)
BBND PreFlight Data on board ISS and STS

The first flight of BBND was carried out on board STS-89 (inside) in 1998, and next flight was done as a part of the HRF(Human Research Facility) on board ISS –US Lab. (inside) from March, 2001 to November 2001 (9 Moths).

The measuring results (dose equivalent) on board ISS on April 15th, 2001.

Relocation

BBND Pre Flight Data on board ISS and STS (inside)
(H.Koshiishi, et. al, Radiation Measurements, 42 (2007)
SEDA-AP
BBND Measurement Data

S-1 ~ S-2 Count Data
BBND S-2 Data

TIME: 2009/10/01 00:00:00 ~ 2009/10/02 23:59:59
Altitude: 350,000km

(C) 2009 JAXA

BBND S-3 Data

TIME: 2009/10/01 00:00:00 ~ 2009/10/02 23:59:59
Altitude: 350,000km

(C) 2009 JAXA
BBND S-4 Data

BBND S-5 Data
FIB : Fiber-type neutron detector

15~100MeV and Arrival Direction
This Detector measures neutron like a electrical version of Wilson Cloud Chamber using plastic scintillation fibers stacks (16X16 on X and Y planes)

Principle of neutron detection

Example of proton track
Nowcast of the Solar flare charged particles

Measuring the Solar neutron from Solar flare is good indicator of predicting of high energy particle, because of the neutron is not affected by Solar magnetic field. We use this detector to inform astronauts on the arrival of strong charged particle radiation after about 1 hour later (nowcast).

SEDAP-AP
Fiber-type neutron detector

Proton data and Neutron data
Neutron Measurement results of FIB

This detector measures path of recoiled proton by using scintillation of cubic arrangement of plastic scintillation fiber. The energy and arrival direction of an incident neutron could be determined by measuring path lengths and track of recoiled proton.

Actuary obtained track of neutron (With Anti)

On Orbit Measurement Data (No-Anti, Proton Track Data)

This document is provided by JAXA.
HIT: Heavy Ion Telescope

Particle:
- Li ~ Fe
  - Li: 10 to 43 MeV/nuc
  - C: 16 to 68 MeV/nuc
  - O: 18 to 81 MeV/nuc
  - Si: 25 to 111 MeV/nuc
  - Fe: 34 to 152 MeV/nuc

2 PSDs
16 SSDs

Cross-sectional view of HIT sensor

Picture of HIT sensor

Same type of HIT sensor was installed on

ADEOS (MIDORI in Japanese) observed ACR

The geographic distribution: Oxygen

Elemental distribution of trapped nuclei.

T. Kohno, H. Miyasaka, et.al., Heavy ion observed with MIDORI satellite: trapped ACR, Radiation Measurements, 1999
SEDAN–AP
HIT
Measured Count data
Cosmic Rays Hit Space Age High

September 29, 2009: Planning a trip to Mars? Take plenty of shielding. According to sensors on NASA’s ACE (Advanced Composition Explorer) spacecraft, galactic cosmic rays have just hit a Space Age high.

“In 2009, cosmic ray intensities have increased 15% beyond anything we’ve seen in the past 50 years,” says Richard Memmott of Science. “The increase is significant, and it could mean we need to re-think how much radiation shielding astronauts take with them on deep-space missions.”

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PLAM: Plasma Monitor

**Purpose**
The Plasma Monitor measures density and electron temperature of space plasma which causes charging and discharging of spacecraft.

**Principle**
The probe is a spherical metal electrode. By analyzing the current-voltage characteristics in the plasma, the electron temperature, electron density, etc. are determined.

**Specification**
- **Langmuir probe**
  - High Gain: -0.2μA ~ +0.2μA
  - Low Gain: -0.04μA ~ 0.4mA
- **Floating probe**
  - High Gain: ±5V
  - Low Gain: ±100V
PLAM: Plasma Monitor

measures plasma density
electron temperature
using Langmuir probe

This is the Third Plasma Monitor.

Another Plasma Monitors are NASA’s FPMU
(Floating Potential Meas. Unit)
and Russian’s Obstanovka

Picture of PLAM

SEDAG-AP
Measured
PLAM
Current—Voltage Graph
PLAM Mode1 (±2V) Data

ISS: -0.3V

High Gain

Low Gain
PLAM Mode2 (±50V) Data

ISS: -20V

High Gain

Low gain
SDOM: Standard Dose Monitor

**Purpose**
Measurement data of radiation flux, and the Variation by solar activity. The acquisition data contribute to investigate radiation damage of space component and anomaly of spacecraft.

**Principle**
DOM consists of some Si semiconductor detectors, measures the number and energy of incident particles, and distinguishes kinds of particles, using $\Delta E \times E$ method’s.

**Specification**

<table>
<thead>
<tr>
<th>items</th>
<th>range</th>
<th>bin</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electron</td>
<td>0.5 to 50 MeV</td>
<td>7</td>
</tr>
<tr>
<td>Proton</td>
<td>1.0 to 250 MeV</td>
<td>15</td>
</tr>
<tr>
<td>Alpha</td>
<td>7 to 250 MeV</td>
<td>6</td>
</tr>
<tr>
<td>Heavy Ion</td>
<td>ID only</td>
<td>2</td>
</tr>
</tbody>
</table>

Cross-sectional view of SDOM sensor

Same type of SDOM sensor is installed on MDS-1 (GTO)

**Electron Flux (0.4~0.9 MeV) L-t Diagram**
Flux-L value Distribution of MDS-1/SDOM

- **Start Time:** 11 Feb. 2002 01:59:30
- **End Time:** 11 Jan. 2003 05:20:11
- **Electron (0.40~0.91 MeV)**

Feb.2002 1 Year Feb.2003

(C)NASDA 2003

This document is provided by JAXA.
Measurement results of SDOM Electrons (0.28-0.79MeV)

This figure shows the high energy electron (0.28-0.79MeV) measurement results of SDOM, that is overlapped on the world map. SAA (South Atlantic anomaly), radiation enhanced region related to the offset of earth magnetic field, and horn region of outer radiation belt are clearly shown.

Horn region of Outer radiation belt

RASEDA 12/17, 2008
NASA AE-8 Model estimated results of Electrons (0.28-0.79MeV)

Trapped particles flux

Flux [LOG particles/m²/s]

180W 120W 60W 0 60E 120E 180E
80N
60N
40N
20N
0
20S
40S
60S
80S

180W 120W 60W 0 60E 120E 180E

Latitude [deg]

Longitude [deg]

(C) 2009 JAXA

Trapped particles model = AP8/AE8 model
Solar activity = Minimum
Particles = Electrons
Energy = 0.28-0.79 [MeV]
Altitude = 400.0 [km]

RASEDA 12/17, 2008

Measurement results of SDOM Proton (0.78-1.09MeV)

Electron Flux (SED A NP Proton1)

[Count/Point/Time] [0.0, 1.0, 2.0, 3.0]

-180 -160 -140 -120 -100 -80 -60 -40 -20 0 20 40 60 80 100 120 140 160 180

Latitude [deg]

Longitude [deg]

TIME: 2008/10/01 09:00:00 - 2008/10/07 23:59:59
Altitude: 777.79km

(C) 2009 JAXA

RASEDA 12/17, 2008
AOM: Atomic Oxygen Monitor

**Purpose**

The Atomic Oxygen Monitor measures the fluence of atomic oxygen in the orbit of the space station. The atomic oxygen interaction with the thermal materials and the paints causes the thermal design to be out of the control.

**Function & Principle**

AOM measures resistance of thin carbon film that is decreased by atomic oxygen erosion (Actinometer).

The rate of decreases is known by lab & flight data. The atomic oxygen fluence is calibrated by this data.

**Specification**

3×10^{17} ~ 3×10^{21} atoms/cm²
Distribution : 3×10^{17} atoms/cm²
SEDAP-APO
Measured
AOM
Data

AOM observed Data (not Compasated by Temperature)

AOM -ACTM Calibration Graph

After Temperature Compacation,
Ao Fluence is calculated using
above Calibration Graph.
EDEE: Electric Device Evaluation Equipment

Purpose
The purpose of EDEE is to monitor Single Event Effects (SEE) due to ionizing particles in space to electric devices used in JEM. Therefore, EDEE will carry several important devices among those used in JEM and evaluate their functions. The acquired data will be reflected upon trouble shoot if it happens in JEM, and also the improvement of the SEE prediction method on board.

Specification
EDEE carries four types of devices, Memory, Micro-Processor Unit (MPU), and Power MOSFET.

EDEE (1/2)

• Observed Results (2009/8/15~2009/10/23)
  – V70-MPU SEU/SEL: Not observed
  – 1M SRAM SEU: 5 upsets observed/512K SEL: Not observed
  – PowerMOSFET (@175V) SEB: Not observed

1M SRAM SEU Rate

<table>
<thead>
<tr>
<th>CREME96 Prediction</th>
<th>CREME96 Prediction</th>
<th>Observed SEU in orbit</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.84 [10⁻¹upset/(device•day)]</td>
<td>12.5 [upset/device]</td>
<td>10 [upset/device]</td>
</tr>
</tbody>
</table>

Threshold LET=5.4[MeV/(mg/cm²)], Saturated Cross Section: σₙ=3.3X10⁻⁷[cm²/bit]

RASEDA 12/17, 2008
**Observed SEU on EDEE (2/2)**

Bit Error Location (5 points) map of SEUs (1M SRAM)

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**JEM/MPAC&SEED Mission**

**Mission objective of JEM/MPAC&SEED**

- Capture space debris and micro-meteoroids on ISS orbit.
- Exposure the materials and evaluate degradation which caused by space environment such as atomic oxygen, ultra violet and space radiation.
- Exposure only. No electrical device

→ Samples have to be retrieved to the ground and analyzed.
JEM/MPAC&SEED Samples

**Gold plate on Sample Unit2**  
**Silica-aerogel on Sample Unit1**  
**Silica-aerogel and gold plate is for MPAC**

SampleUnit3

**SEED samples on Sample Unit 2&3**
- Solid lubricants / MoS₂ on Ti-6Al-4V
- White paint / NOVA 500 ASTRO WHITE
- Black paint / NOVA 500 ASTRO BLACK
- Ge-coated Black Kapton
- Black Kapton
- Polysiloxane-Block-Polyimide Film
- Modified Polyimide film/Siloxane Coated PI
- ITO coated UPIXEL-25S
- UPIXEL-125S

**Space Environment Monitoring Materials on Sample Unit 2&3**
- UV monitor / (Urethane Sheet)/DUS-601
- Dosimeter/RADFET
- Dosimeter2/ALANINE-Dosimeter
- Dosimeter3/TLD
- AO monitor/VESPEL
- Temperature/Thermo Label

**Precursor mission of MPAC&SEED, Service Module of ISS**

**SM/MPAC&SEED**

**Inspection of SM/ MPAC & SEED inside ISS**
Precursor mission of MPAC&SEED, Service Module of Russia

Three sets of MPAC&SEED is installed outside of Russian service module by EVA activity.

Picture: NASA

SEDA-AP Operation Overview - Base Line Scenario (Nominal) -

On-orbit environment measurement at the mast extended condition for three years

MPAC&SEED retrieval by EVA

On-orbit disposal of the SEDA-AP by HTV

2012 (about 3 years after launch)

MPAC&SEED Return to the Ground

Flight 2J. Launch

July 2009
Exposed facility and SEDA-AP (Real Picture)

Exposed Facility of “Kibo”

SEDA-AP Mast extended

Provided by NASA
Conclusion

Space environment data in JAXA, which include data from SEDA-AP, are available to the public as data of the Space Environment and Effect System (SEES; http://sees.tksc.jaxa.jp)

Those data will be used widely by academic and industrial users in laboratories, universities, JEM experiment investigators, and others in spacecraft operation, engineering fields, and scientific research. Data from SADA-AP will also be used to develop the Japanese space environment mode.

Contact

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SEES (Space Environment Effects System)

- WWW base database
- Environment data
- 90 environment model
- Monitors description
- S/C Operation Alert

http://sees.tksc.jaxa.jp
The SEES access statistics.

- 100 Countries.
- 1000 persons access every day.
- When a new satellite is launched, or when the space environment measurement data of the satellite is exhibited, the increase in the number of accesses

RASEDA 12/17, 2008