Measurement of Neutrons at ISS by the SEDA-AP on-board JEM

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The SEDA-AP has been designed for the measurement of the space environment, but from another point of view as solar physics, the detector may be assigned as the second generation solar neutron detector after Solar Maximum Mission (SMM).

The SEDA-AP has been on-board Japan Experimental Module on 16th July 2009 by the space shuttle Endeavor, and started to take the data from 25th, August.

I will introduce the performance of the detector.

This paper submitted for 22nd ECRS at Turk, Finland on August 3rd, 2010.
The outline of the talk

1. Brief introduction of A long history until the operation at the ISS
2. Review of the Scientific purpose of the experiment: especially the measurement of solar neutrons at the space
3. Performance of the detectors at the ISS
4. First results of the observation of neutrons at ISS
5. Future
1. A long history to have been operated at ISS

The project started in December 1991.

From 1994 a frontier study group had been organized by 19 members from university, company and NASDA (present ISAS). By them, 11 items had been selected from 20 items of observation.

As the main subject of the space environment, the measurement of neutrons had been selected with the highest priority. A proposal was written and sent to the selection committee of the government.

In April 1997, the subject; measurement of the space environment has been selected as the first use project of the ISS of the Japan Experimental Module by the committee. In 2001, the flight module (FM) has been made and it has been kept in a special room for 8 years.

In August 2009 the module has been launched on the ISS.

(totally 18 years have passed!)
2. The scientific purposes of measurement of neutrons at International Space Station

- Evaluation of the risk of cosmic rays to the astronaut (Radiation Physics)
- Prediction of arrival of dangerous radiations from the Sun in association with large solar flares (space weather forecast)
- Establishment of the acceleration process of solar cosmic rays (solar physics, cosmic ray physics)
Scientific Purposes

- Physics aim is to confirm particle acceleration model at the solar surface.
  - How and When?
  - How are particles accelerated?
  - When are particles accelerated?
  - What is the highest energy of SCR?
    - up to 100GeV? 1TeV?

However observations of protons do not give us all information to understand them. Protons are usually coming on the Earth a few hours later from the flare. So we must use neutron information.

- Another important thing: application to the space weather forecast
June 21, 1980 event  (S09 E72)

Neutron time dispersion

Satellite data
Solar Maximum Mission

The first solar neutron event can be explained by the impulsive production model with

\[ \gamma = -3.5 \pm 0.1 \text{ (diff.)} \]

100MeV \( \rightarrow \) 11 min. delay
June 3, 1982 event
(S09 E72)

Jungfraujoch neutron monitor + SMM mission data

The fast arrival part of neutrons can be explained by the impulsive production model with $\gamma = -4.0 \pm 0.2$ (diff.) but later part must be another process.

100MeV $\rightarrow$ 11 min. delay
3. The details of new neutron detector

- The energy must be measured
- To separate the impulsive production from the gradual production
- The arrival direction must be measured
The **FIB** detector can measure the energy and the direction of incoming neutrons by the scintillation fibers.

The **BBD** detector can measure the low energy neutrons less than 30 MeV.

- **FIB detector in the Space Environment monitor SEDA**

- Observable energy range of neutron

  $E_n = 10 \sim 100 \text{ MeV}$
Principle of measurement

- The energy of neutrons can be measured by the range method.

The green box corresponds to the observation target energy (30-100MeV)
The data taken by **FIB** detector in **SEDA**

The 6 surfaces are covered by the anti-counter
Properties of new neutron detector

$\Delta E/E \approx 10\% @ 50\text{MeV}$
4. First results of the observation

- Since we have not yet experienced a large solar flare after launching the detector, I would like to introduce the performance of the detector.
- Search for solar neutrons in association with the M-class flare of the solar flares on February 6th – 8th, 2010.
- We have also measured the background neutrons at ISS from the main body of ISS at normal region and over SAA.
Search for the solar neutrons in association with the flares on February 6-8\textsuperscript{th} of 2010
The position of ISS at the flare time

Up 2010.2.8 7:53UT
Down 2010.2.6 16:09UT

Up 2010.2.7 2:44UT
Down 2010.2.6 16:09UT

Up 2010.2.8 7:53UT
Down 2010.2.8 13:43UT
Results of measurement of solar neutrons

- No evidence of solar neutrons in association with the M-class solar flare of February 2010.
- Therefore we have measured the background over the South Atlantic Anomaly region and over the region except the SAA region.
- Next slides show typical examples of neutrons.
Neutron energy spectrum from ISS main body. They were induced by GCR $\sim 0.047\text{Hz}$
The energy spectrum of neutrons induced over SAA observed by the FIB detector $\sim 1.7\text{Hz}$
A sample of the counting rate for three months
5. Future

- Link with ground level neutron detectors will be very important in association with large solar flares.
- Study of the Soft Gamma-ray Repeater (SGR)

- We are waiting large solar flares and SGRs !!!
  (> X-class)
Back-up slide
Attenuation curve of neutrons in the atmosphere
by S. Shibata

- **Absorption** of neutrons in the atmosphere

- **Time dispersion**
  (the flight time depends on its energy)

- Neutrons decay in flight
  (70% @100 MeV  27%@1GeV)
The energy resolution of the FIB detector has been measured by the proton beam at Riken. It turns out as

\[ \frac{\Delta E}{E} \approx 10\% / \sqrt{E/(50\text{MeV})} \]
Expected Event Rate
by Kyoko Watanabe

Expected background
(for middle latitude)
Mission STS 127 at Kennedy space center on June 13th, 2009
Neutron flight time from the Sun
The basic knowledge to understand them
Let us remind of a fact

**Neutrons** cannot travel the space by the speed of the light.

The example of **the time dispersion**

\[
E_n \quad \text{delays} \\
1 \text{ GeV} \rightarrow 1 \text{min} \\
200\text{MeV} \rightarrow 6\text{min} \\
100\text{MeV} \rightarrow 11\text{min} \\
70\text{MeV} \rightarrow 14\text{min}
\]

Therefore the measurement of the energy of neutrons is very important to understand the acceleration process, so we have prepared a new solar neutron global network based on the plastic scintillator.
We are studying the acceleration mechanism over the Sun

The dynamical motion of the magnetic loops is the origin of the solar flare and hence the origin of the particle acceleration. **Plasma jet** is formed at the top of the Solar surface.

We are searching a deviation from the standard model.

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**A standard picture**

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**Micro processes**

- Tension
- Plasma heating
  - $\sim 3000\text{km/s}$
  - $\sim 70\text{sec}$
- from $20\text{MeV}$ to $40\text{GeV}$
- $n \sim 400$ times
- P+He collisions
- Charge exchange
Space Environment monitor SEDA will be mounted in May 2009 at ISS.