ANOMALY DETECTIVE GROUND SUPPORT SYSTEM FOR MARS PROBE "NOZOMI"

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ABSTRACT

Institute of Space and Astronautical Science (ISAS) was successfully launched Japan's first Mars probe "NOZOMI" on July 4, 1998. In order to enable the safe operation of "NOZOMI" under the severe demand of the cost reduction, ISAS provided an anomaly detective ground support system named ISACS-DOC for "NOZOMI" operation. This system is the second application of expert technique to daily operation of scientific spacecraft at ISAS. Many improvements are achieved based on the experiences of the first expert application to the anomaly detective ground support system for the geomagnetic observation spacecraft "GEOTAIL". Especially, the communication link levels can be evaluated within the error of ±3.0dBm. This performance is expected to be enough to operate "NOZOMI" safely in the Mars transfer and orbiting phase. Now ISACS-DOC diagnoses "NOZOMI" every operation, and it can warn about 450 kinds of "NOZOMI" abnormality to the spacecraft operator.

1. INTRODUCTION

ISAS operates four satellites (AKEBONO, YOHKOH, ASCA and HALCA) and two spacecraft (GEOTAIL and NOZOMI) on daily bases at the present. Scientific satellites/spacecraft are becoming more sophisticated according to more advanced scientific instruments onboard and the knowledge required to operate them is also becoming deeper and broader. On the other hand, strong demand to suppress or decrease the operating cost exists almost everywhere these days and also in ISAS. One of the solutions for these contradictory requirements is to use expert technique in the satellites/spacecraft operation. ISAS decided to take the expert technique at first for the geomagnetic observation spacecraft "GEOTAIL" that was launched in 1992 and is still in operation at Sagamihara Spacecraft Operation Center (SSOC). This system is named "ISACS", which stands for Intelligent SAtellite Control Software. ISACS consists of two functions: one is ISACS-PLaNner (ISACS-PLN) and the other is ISACS-DOCtor (ISACS-DOC). ISACS-PLN is an automatic command planner with expert technique, and ISACS-DOC is an anomaly detective ground support system with diagnostic functions. ISACS-DOC for GEOTAIL has been used for 6 years in SSOC. One of the important things learned from ISACS-DOC for GEOTAIL is that collection of many kinds of information from the various kinds of ground support systems like tracking systems, trajectory determination systems and attitude/maneuver control systems is essential to improve the reliability of diagnosis. ISAS completed establishing a new ground operation system based on client/sever workstation systems and started to use it from Japan's first Martian probe "NOZOMI" at SSOC. Figure 1 shows the outline of the ISAS new ground operation system. In this configuration, useful information from essential ground systems can easily be gathered through the network in real time. ISACS-DOC for "NOZOMI" was developed by taking the above advantage as well

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as all other experiences obtained by ISACS-DOC operation for GEOTAIL. "NOZOMI" was successfully launched July 4, 1998 from Kagoshima Space Center (KSC) in Japan and is now flying to Mars to study the structure and dynamics of the Martian upper atmosphere with emphasis on its interaction with solar wind. This paper describes ISACS-DOC for "NOZOMI" and reports some of the actual operation results.

2.OUTLINE OF ISACS-DOC FOR "NOZOMI"

2.1 Basic Concept of System Development

The followings are basic ideas in designing ISACS-DOC for "NOZOMI". Some of them are introduced based on lessons learned from ISACS-DOC for GEOTAIL.

(1) All information to diagnose the spacecraft is fed on-line through the network of the ISAS new ground operation system shown in Figure 1.

(2) Whole areas of the spacecraft are repeatedly

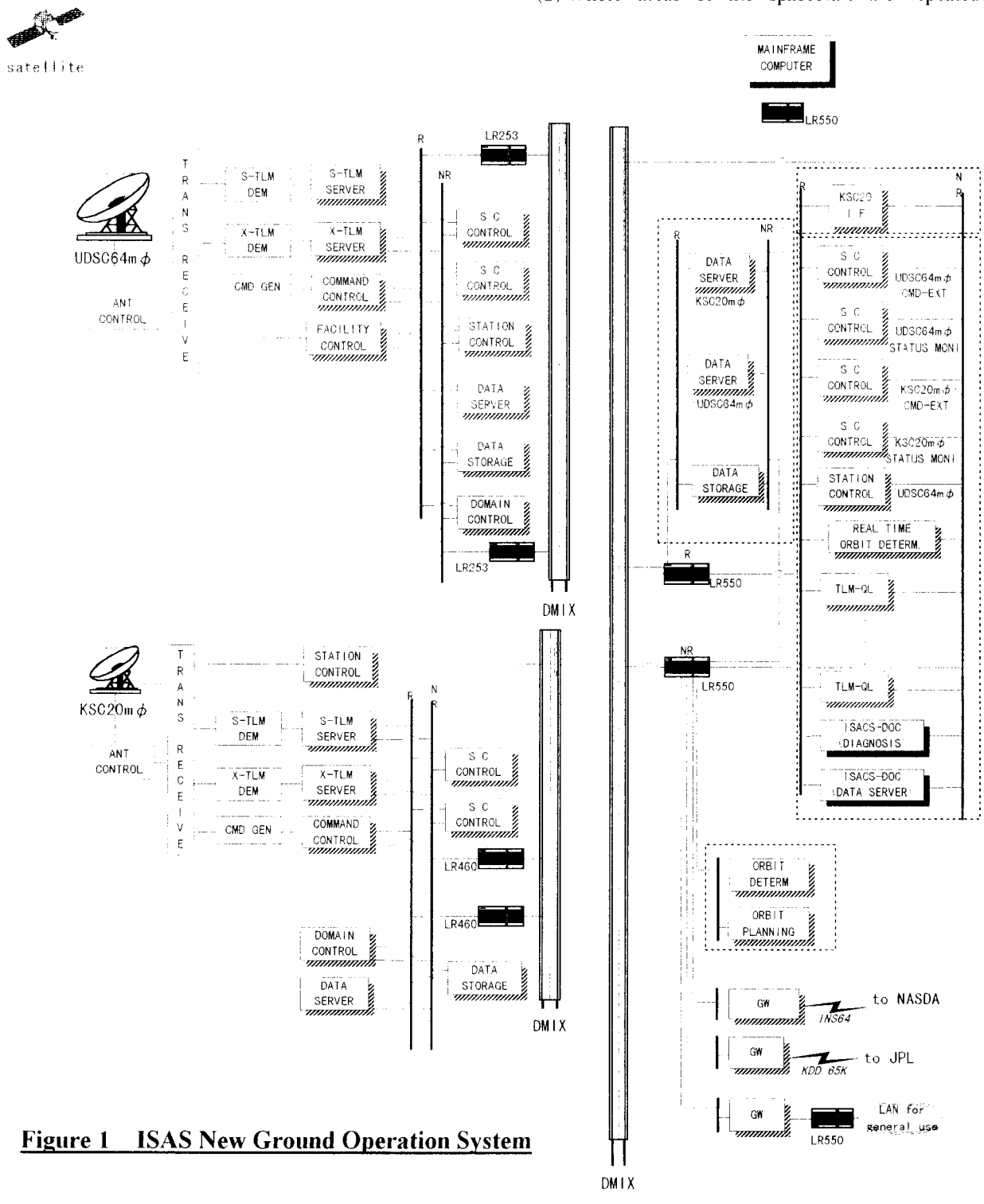

Figure 1 ISAS New Ground Operation System

diagnosed automatically during real-time operation.

(3) The diagnosis covers almost all areas of the spacecraft's communication system, electrical power system, thermal control system, data handling system, attitude and orbit control system, and all scientific instruments onboard.

(4) Diagnostic results are restricted to highly confident items to avoid confusing the spacecraft operators at SSOC. Facts or actual phenomena are only shown if the inference of the abnormality is vague.

(5) Knowledge database can be easily updated according to the new situation of the spacecraft.

(6) Communication links are carefully watched by comparing the real receiving levels of down-links and up-links with the estimated values which are calculated from antennas patterns, attitude of the spacecraft, distance between the spacecraft and the ground tracking antenna, performance of the ground station, etc.

(7) All data used for diagnosis are saved in ISACS-DOC and can be used for checking the past status of the spacecraft.

Since "NOZOMI" is a deep space mission, communication links are evaluated with high accuracy in real time. Furthermore, electrical current monitoring for all onboard subsystems is introduced in designing "NOZOMI" to make diagnosing easier.

2.2 System Configuration

ISACS-DOC for "NOZOMI" consists of two computers: one is a SPARC workstation and the other is a PC. The SPARC workstation handles on-line data feeding function. The on-line data feeding function automatically reads the latest real-time telemetry data, orbit and attitude data, and some of the ground operation systems' data through the network as shown in Figure 2. The system configuration of ISACS-DOC for "GEOTAIL" is also shown in Figure 2 for reference. This function also decodes the above data to physical values if it is necessary, and outputs a diagnostic information file by referring the Satellite Information Base (SIB) file which defines positions of telemetry frames and words, threshold values, and equations for decoding the data to physical values, etc. The diagnostic information file is automatically transferred to the diagnostic function on the PC. The PC handles the diagnostic function using a commercially available diagnostic expert tools package named APSHELL/DIAG 'Manadeshi-kun': (meaning a favorite pupil) which runs in the Microsoft Windows NT environment to reduce the development cost. The APSHELL/DIAG 'Manadeshi-kun' has three standard functions: knowledge database editor, inference engine, and knowledge database. The diagnostic expert knowledge is sorted out as a tree form. Every condition to verify a tree node is determined by questions and results. The execution of diagnosis is conducted with the forward inference engine tracing the diagnosis tree by checking the conditions (truth or falsehood) of each node. The scale of knowledge database in ISACS-DOC for "NOZOMI" is shown in Table 1.

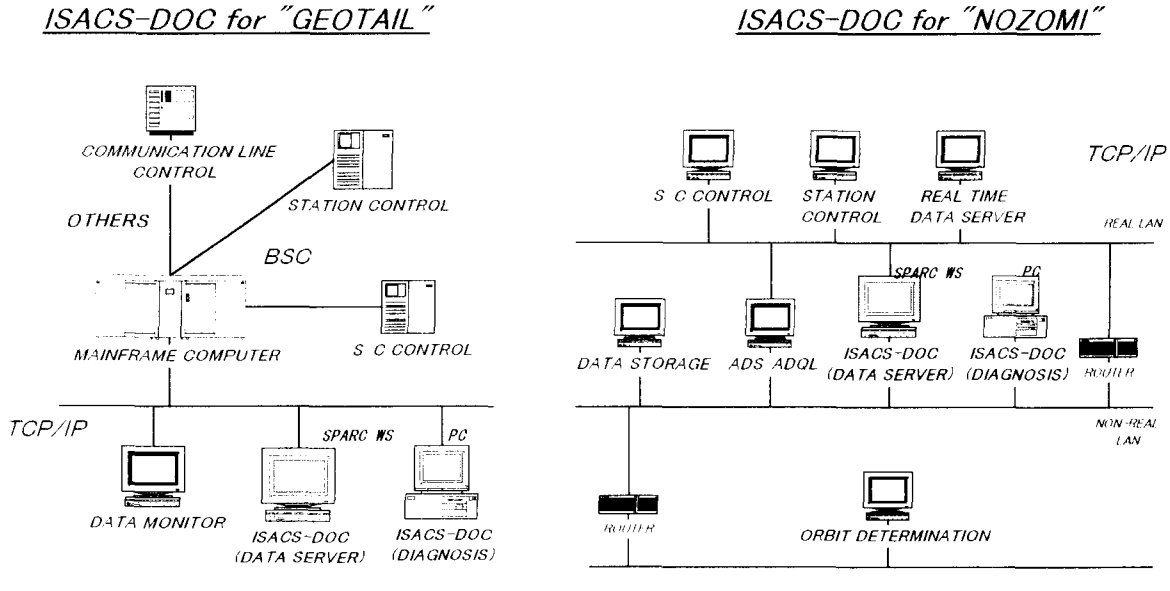

Figure 2 System Configuration of ISACS-DOC

Table 1 Scale of Knowledge Database in ISACS-DOC for "NOZOMI"

	Common Instruments					Scientific Instruments								Total
	BCM	BPS	BAO	BHK	others	PSA	PWA	MPM	MIC	IMI	MDC	TPA	NMS	
Questions	135	86	97	3	6	42	64	52	34	17	16	25	13	590
Results	61	64	101	1	-	35	64	36	29	15	14	18	12	450

BCM: Communication System
BPS: Power System
BAO: Attitude and Orbit Control System
BHK: House Keeping Items
PSA: Particles Spectrum Analyzer
PWA: Plasma Wave Analyzer
MPM: Magnetic Field Measurement/ Probe for Electron Temperature/ Extendible Mast/ Ultraviolet Imaging Spectrometer
MIC: Mars Imaging Camera
IMI: Imaging Camera
MDC: Mars Dust Counter
TPA: Thermal Plasma Analyzer
NMS: Neutral Mass Spectrometer

As mentioned above, the contents of the diagnosis knowledge database are changed according to the status of "NOZOMI". The numbers of questions and results are approximately 590 and 450 respectively at the present.

2.3 Process of Diagnosis

ISACS-DOC is a fully automatic and operator-less anomaly detective ground support system. One of the functions on the PC shown in Figure 2 refers the status of the SPARC workstation every 5 minutes regardless of the spacecraft operation time. When a set of necessary data for 10 minutes duration is prepared in the SPARC workstation, ISACS-DOC automatically diagnoses the whole areas of "NOZOMI". When the plural number of necessary data is included in 10 minutes duration, the statistical process (calculation of average, mean, maximum, minimum, or etc.) is practiced according to the data characteristics defined in the diagnostic information file. The ISACS-DOC warns the operators when it finds something abnormal. The operators can know the details of the abnormality as well as the first aid action to avoid fatal damage that may be caused by the abnormality. The diagnosis is repeatedly practiced about every 5 minutes during "NOZOMI" real-time operation excepting the duration of the recorded data reproducing. We found the diagnosis using the recorded data was very useful to know what happened while the spacecraft was invisible from SSOC. This function is strongly required to actualize more useful anomaly detective ground support system.

2.4 Display of Diagnostic Results

Five standard windows on the screen of ISACS-DOC for "NOZOMI" are prepared to display the following information:

- Abnormal items,
- Explanation of each abnormality,
- Normal and actual status/values causing the abnormality,
- Related figures/graphic data,
- Urgent level, contact information such as telephone numbers of senior engineers or scientists who can supervise the further contingency operation for the abnormality,
- Urgent commands to save the probe from catastrophe (first-aid commands), and
- Some common data like distance between the probe and the earth.

Figure 3 shows an example of the screen display, and Figure 4 is the printed results by ISACS-DOC.

3. OPERATIN STATUS OF ISACS-DOC FOR "NOZOMI"

It is very important to verify the definitions of the knowledge database in order to actualize the reliable anomaly detective system. The knowledge database has been checked and maintained by comparing the diagnosing results of ISACS-DOC with the actual spacecraft status since "NOZOMI" launching. Additionally, the "NOZOMI" initial orbit plan arriving in the Martian orbit on October 1999 was changed to arriving at the end of 2003 by a

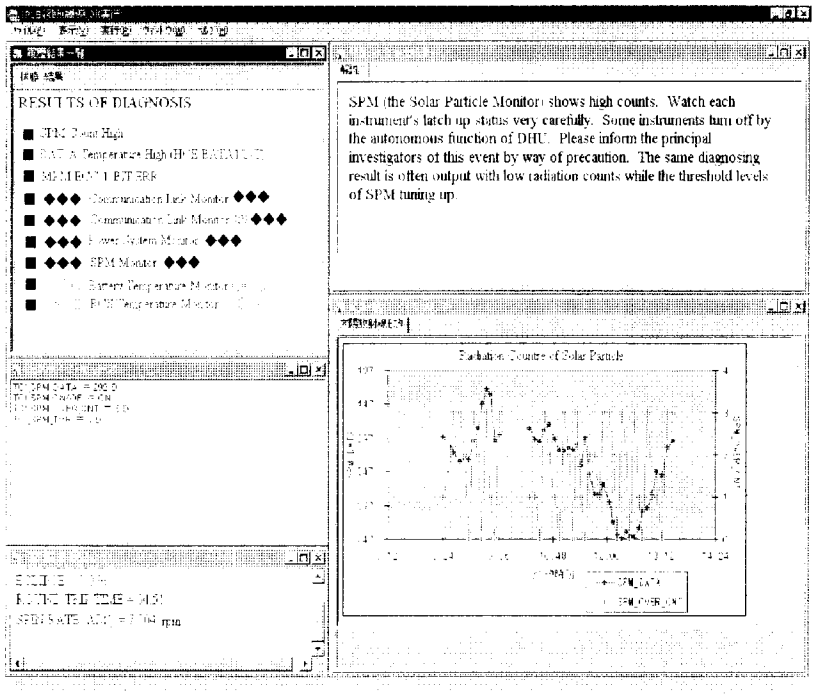

Figure 3 Example of Screen Display

malfunction of the propulsion system in December 1998. The tuning of ISACS-DOC has been almost completed and is already used to assist the daily operation of "NOZOMI". This system will be fully operated regularly from June 1999 at SSOC. For about ten months of test-running, ISACS-DOC has been refined on the following points:

(1) The communication link levels can be evaluated within ±3.0dBm accuracy.
(2) Six different kinds of trend graphs to monitor communication links, power system, propulsion system, and solar flare can be always referred regardless of the diagnosis results.
(3) The important values/status relevant to the abnormality can be referred at a glance on ISACS-DOC screen.
(4) The definition of diagnosis knowledge database has been modified according to the actual situation of "NOZOMI".
(5) The explanation of the abnormality has been modified reflecting the actual satellite operation.

Table 2 shows some examples of "NOZOMI" abnormality that ISACS-DOC found in the actual operation.

4. CONCLUSION

The development and tuning of the anomaly detective ground support system for Mars probe "NOZOMI" has almost been completed and this system will be used to keep the safer operation of "NOZOMI" on daily basis till the end of "NOZOMI" mission. The effectiveness of ISACS-DOC has already been shown by finding some abnormalities of "NOZOMI" during its test-running. Especially the communication link levels are evaluated with very high accuracy after three times revision of the calculation algorithm of the estimation. This accuracy will be sufficient enough to operate "NOZOMI" safely in the trans Mars orbit and also in the Mars orbiting phase after the end of 2003. It is strongly required to append the diagnosis function for the reproduced data in order to perform more reliable anomaly detection. We are considering the way to add this function without making much alteration to the present version of ISACS-DOC.

ACKNOWLEDGMENT

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DIAGNOSIS RESULT: Radiation Count of Solar Particle High (TCI_SPM_OVER_CNT)

COMMON INFORMATION:

- PASS No: 9905060100
- TIME: 1999/05/06/ 12:52:56
- EARTH-PROBE RANGE: 43797066.1 Km
- ECLIPSE RATE: 0.0 %
- TRANSMISSION DELAY: 04:51
- θ e (ADS): +3.1374 degree
- θ s (ADS): +45.600 degree
- SPIN RATE (ADS): 7.804 rpm

EXPLANATION OF ABNORMALITY

STATUS: CAUTION! TCI_SPM_OVER_CNT= High

SPM (Solar Particle Monitor) shows high counts. Watch latching up of each instrument carefully. Some instruments may be turned off by the autonomous function of DHU. Report to the persons in charge of today's operation. False diagnosis results may be output with low radiation level till adjustment of SPM threshold levels is completed.

REFERENCED DATA:

TCI_SPM_DATA = 1 D
TCI_SPM_ON/OF = ON
TCI_SPM_OVER_CNT = 2 D
TCI_SPM_THR = ***

REFERENCE GRAPH:

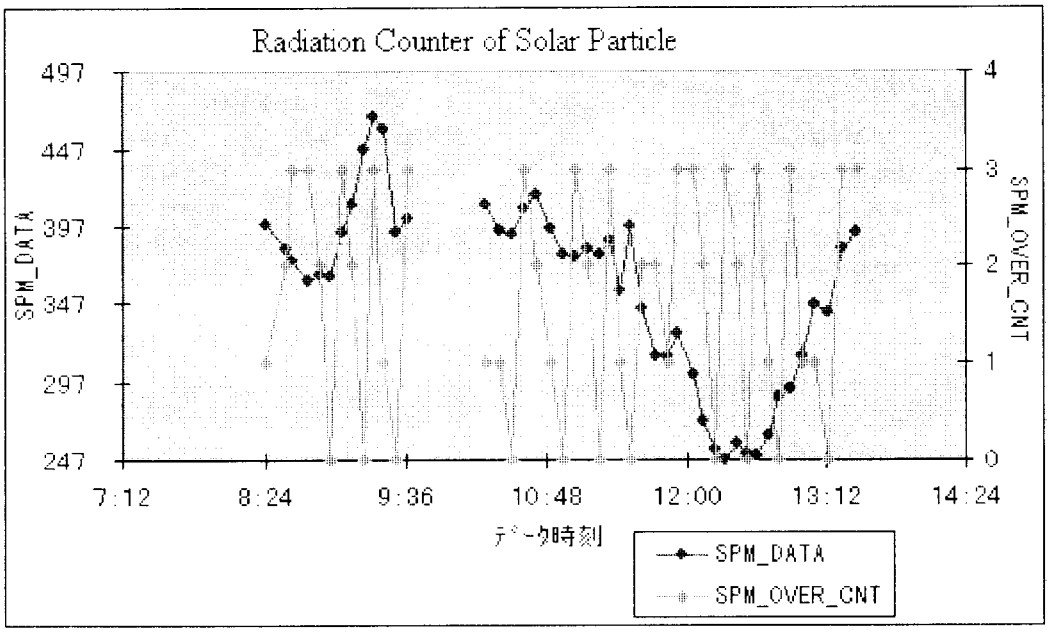

Figure 4 Example of Abnormalities Found and Printed out by ISACS-DOC

Table 2 Examples of "NOZOMI" Abnormality

1	**TMS Temperature Out of Upper Limit** ➔ Required range = -20～45 C. It occurred during near-earth orbit. TMS temperature was carefully watched.	Oct., 1998
2	**Latching Valve Status Error (LV-2 = CLOSE)** ➔ Malfunction of the propulsion system occurred during maneuver operation. Orbit plan of "NOZOMI" was changed.	Dec.,1998
3	**MPM ECC 1-BIT Error** ➔ MPM ECC 1-bit error occurred. It was recovered by sending commands.	Mar.,1999
4	**BAT-A Temperature Out of Upper Caution Limit** ➔ Required range = 5～15 C. It occurred during near-earth orbit Battery-A temperature was carefully watched.	Mar.,1999
5	**MDC Impact Counter Full** ➔ Dust impact counter memory was full. Impact data were downloaded.	Apr. 1999
6	**TMS-BASE_BAND S/N Out of Lower Limit** ➔ Communication link margin was small. Telemetry bit rate was lowered.	May. 1999
7	**Solar-Particle-Counter High** ➔ It was caused by Solar high activity. Activity level was carefully watched.	May. 1999

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