MONITORING AND DIAGNOSTIC EXPERT SYSTEM FOR SAMPLE-RETURN PROBE MUSES-C

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ABSTRACT

This paper reports the third generation monitoring and diagnostic expert system developed for the sample-return probe MUSES-C renamed HAYABUSA after the launch in May 2003. This system is operated daily to help guarantee the safe operation in the spacecraft operation center of the Institute of Space and Astronautical Science in Japan. The effectiveness of this system is already proved through the actual operation even during the tuning stage after the launch. The operation status as well as the details of the system are described.

1. INTRODUCTION

MUSES-C is currently heading for the asteroid 1998SF36. The probe was renamed HAYABUSA meaning a falcon after the successful launch on May 9, 2003 by M-V-5 rocket from Japanese Kagoshima Space Center (JKSC) of the Institute of Space and Astronautical Science (ISAS). Figure 1 shows HAYABUSA attached to the top of the M-V-5 rocket. HAYABUSA has two long cruising phases of totaling 3 years and 9 months. The number of operators for HAYABUSA in Sagamihara Spacecraft Operation Center (SSOC) at ISAS is minimized during these phases due to the strict resource constraint. A monitoring and diagnostic expert system for HAYABUSA was developed to reduce the operation

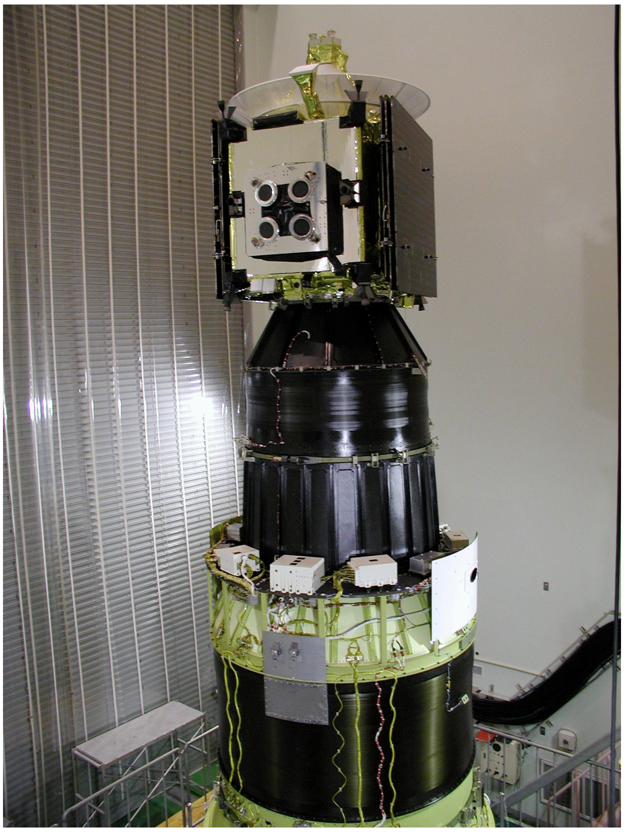

Figure 1. HAYABUSA attached to the top of the M-V-5 rocket.

risk mainly during these phases. This system has been almost tuned and is daily operated at SSOC. This paper describes the latest operation status as well as the details of the system.

2. OUTLINE OF SAMPLE-RETURN PROBE HAYABUSA

2.1 Objectives of HAYABUSA

HAYABUSA is an ambitious engineering spacecraft to demonstrate the ability of ion engines as the main propulsion system, the autonomous navigation system, the sampling system from the asteroid 1998SF36, and the returning system with the samples to the Earth. The observation data and samples will contribute to the study of the solar system's origin and evolution.

2.2 Operational Features of HAYABUSA

HAYABUSA has the following features from the operational viewpoint.

1) It has two long cruising phases. One is from the launch to the arrival at 1998SF36 (2003 May to 2005 September). The other is from the departure from the asteroid to the return to the Earth (2006 January to 2007 June). The number of operators for HAYABUSA at SSOC of ISAS cannot but be minimized during these two phases due to the strict resource constraint.
2) HAYABUSA uses almost continuously the Ion Engine System (IES) with 3-axis attitude control during the cruising phases. The orbit should be carefully observed to keep the trajectory as planned during these phases.
3) Communication downlink during the cruising phases is delicate and the bit rate could be down to 8 bps at lowest. HAYABUSA uses the middle gain antennas or low gain antennas during the cruising phases because the high gain antenna and solar cell paddles are fixed in the same direction of the body and they are pointed toward the sun to get enough electric power for IES.
4) Summary of actions executed by the onboard autonomous function of HAYABUSA and the urgent information are sent as report-packet telemetry at the beginning of the daily contact with SSOC. The operators for HAYABUSA at SSOC should examine the information most carefully.

3. MONITORING AND DIAGNOSTIC EXPERT SYSTEM FOR HAYABUSA

3.1 Past Experiences in Developing Monitoring and Diagnostic Expert Systems

Before developing the system for HAYABUSA, we developed the monitoring and diagnostic expert systems called ISACS-DOC standing for Intelligent Satellite Control Software-Doctor. The first one is for the geomagnetic observation satellite GEOTAIL launched from Kennedy Space Center (KSC) in 1992 as one of the International Solar Terrestrial Physics (ISTP) program. The second is for the Mars probe NOZOMI launched from JKSC in 1998. These two spacecrafts are still operated at SSOC and two ISACS-DOCs for them are also daily watching the health of the spacecrafts. The third generation of ISACS-DOC for HAYABUSA has the hardware structure similar to that of ISACS-DOC for NOZOMI as shown in Figure 2. However it has incorporated many lessons learnt from experiences in two previous ISACS-DOCs.

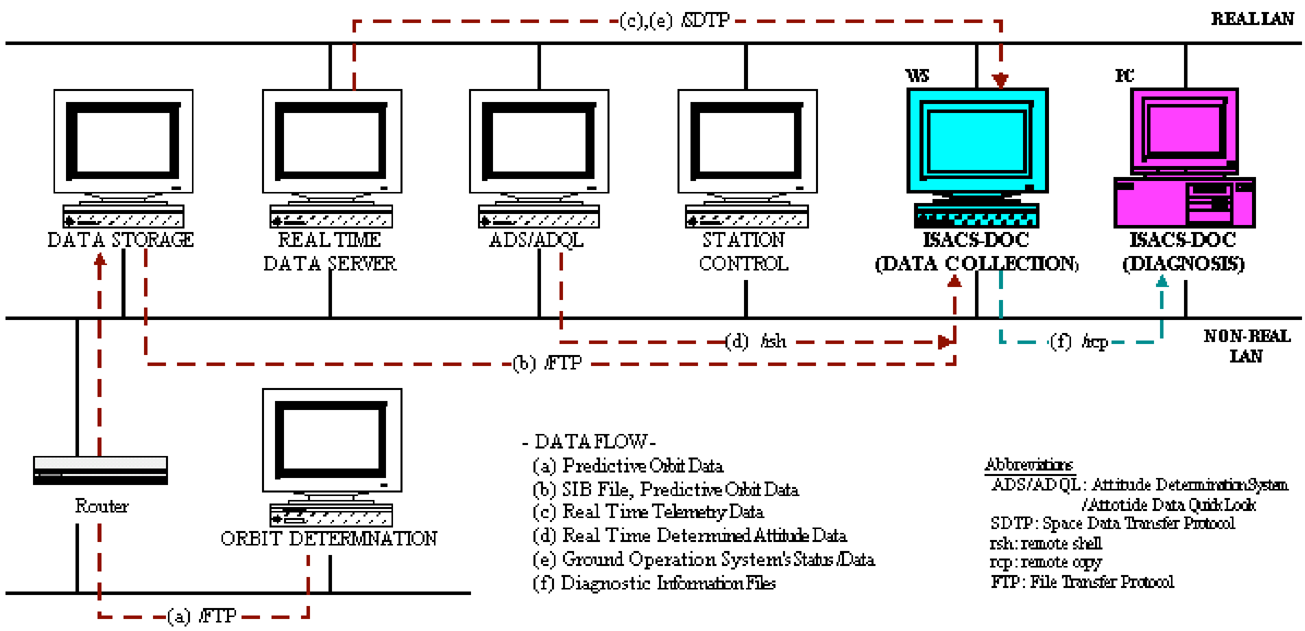

Figure 2. System structure of ISACS-DOC for HAYABUSA.

3.2 Main Purpose of ISACS-DOC for HAYABUSA

Many experts involved in designing HAYABUSA watch the probe carefully and try to guarantee its safety at the launch, mission, and reentry phases of HAYABUSA. The probe is, however, monitored and operated by the limited number of operators during the two cruising phases. Main role of ISACS-DOC for HAYABUSA is monitoring, watching and suggesting the first-aid actions to the operators who may not have enough skills to cope with troubles during the cruising phases.

3.3 Features of ISACS-DOC for HAYABUSA

ISACS-DOC for HAYABUSA has different features from the former ISACS-DOCs for GEOTAIL and NOZOMI because it copes with the features of HAYABUSA described in section 2.2. Followings are the features of ISACS-DOC for HAYABUSA.

1) Diagnosis flow

The diagnosis flow of ISACS-DOC for HAYABUSA is changed from the previous ISACS-DOCs for NOZOMI and GEOTAIL corresponding to the features of HAYABUSA. Figure 3 shows the diagnosis flow practiced in ISACS-DOC for HAYABUSA.

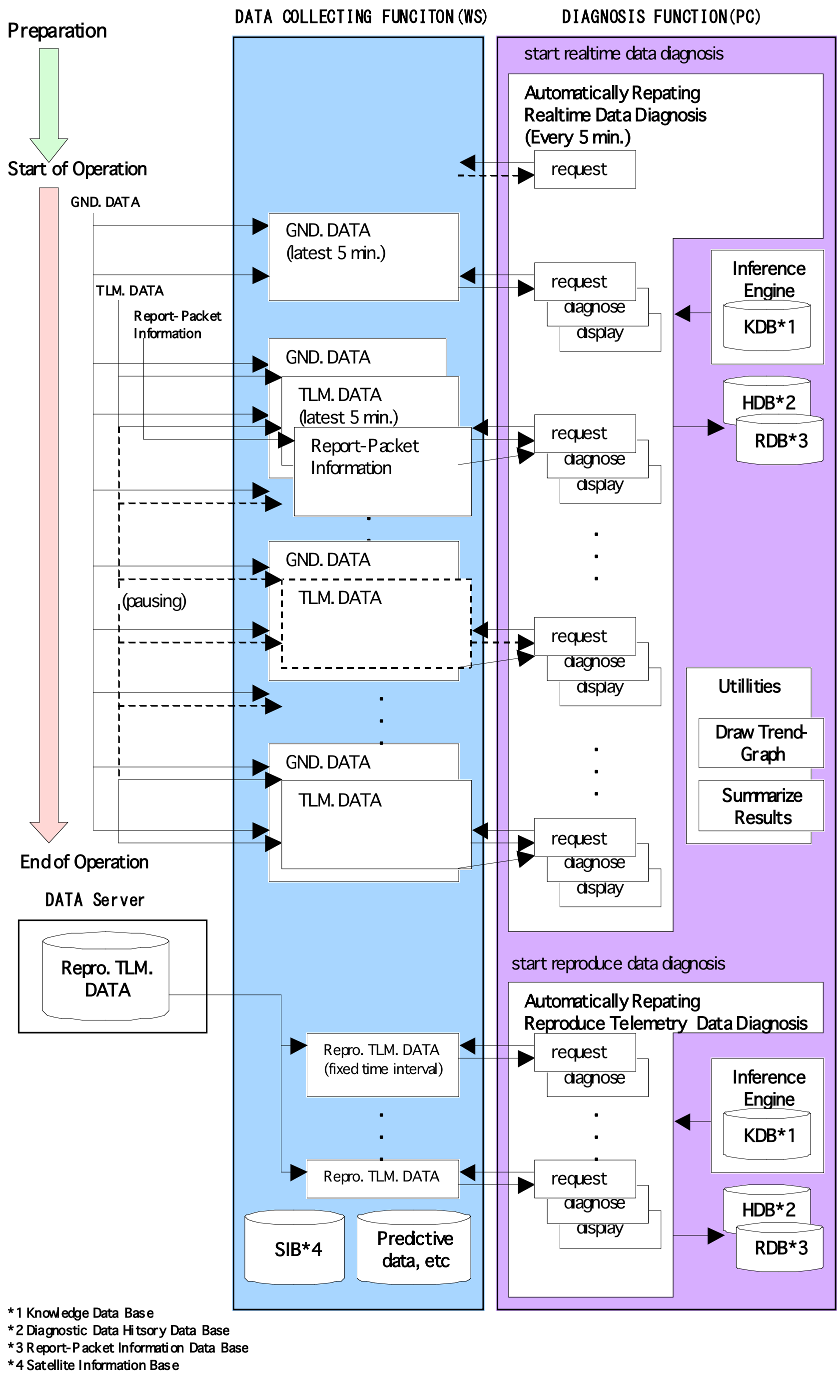

Figure 3. Diagnosis flow in ISACS-DOC for HAYABUSA.

The PC requests the data to the WS in Figure 3. If the WS can collect some diagnostic data, the WS transfers the data files to the PC. The WS also informs the PC about the types of the data collected at that time such as ground data, real time telemetry data, report-packet data, reproduced telemetry data, etc. If only the ground data are given, ISACS-DOC can also diagnose using only the ground data. If the real time telemetry data are given, ISACS-DOC collects the ground data at the received time of the real time telemetry, and diagnoses using both the ground data and the real time telemetry data. If the report-packet information is given, ISACS-DOC keeps the information in the database. ISACS-DOC always displays the recent key actions of the spacecraft informed from the report-packet. When the spacecraft is visible from the ground station, ISACS-DOC diagnoses it using the real time data. The downloaded reproduced telemetry data for a week are sorted according to their TI-time (the time by the Time Indicator on the spacecraft). ISACS-DOC diagnoses using the sorted reproduced telemetry data in a batch processing mode, then prints the history of the diagnosis, and displays the trend-monitor graphs for the week.

2) Period of the data used for a diagnosis

ISACS-DOC for HAYABUSA uses previous one week data stored in the database of ISACS-DOC as well as the real time data because the real time data in one tracking pass is very limited when the distance between HAYABUSA and the ground station is far and the low gain antenna is used (only one or two telemetry data sets). Referring the past data is useful in finding the data tendency and improve the reliability of diagnosis.

3) Knowledge database

Monitoring and diagnosis are emphasized for the cruising phases. Particularly IES is the first practical use as main propulsion engines onboard Japanese spacecrafts. So the construction of knowledge database is concentrated in watching the performance of IES. An extensive expert knowledge on IES is integrated such as warning of high voltage breakdown, informing autonomous actions executed onboard, and monitoring the xenon-tank pressure and the remaining fuel. Monitoring the range-rate difference between the measured values by range-rate measurement system on the ground and the expected values calculated from the trajectory plan is also very useful in examing quickly if the acceleration by IES is performed as planed. The report-packet telemetry is also very important because it is the summary of onboard autonomous actions. ISACS-DOC for HAYABUSA gives the operators familiar explanations of the information on the display. Diagnosis of the reaction control system (RCS) using chemical propellants is also important because RCS is necessary when big thrust is required. Watching leakage of fuel, oxidizer, gas, and temperatures is essential for keeping RCS in good shape for a long time.

3.4 Operational Results

ISACS-DOC for HAYABUSA is daily operated at SSOC. It has already warned the operators some abnormalities and helped with their operations. Some of the diagnostic displays are illustrated here.

1) An example of diagnostic results

Figure 4 is a simple example of diagnostic displays shown on May 23, 2003.

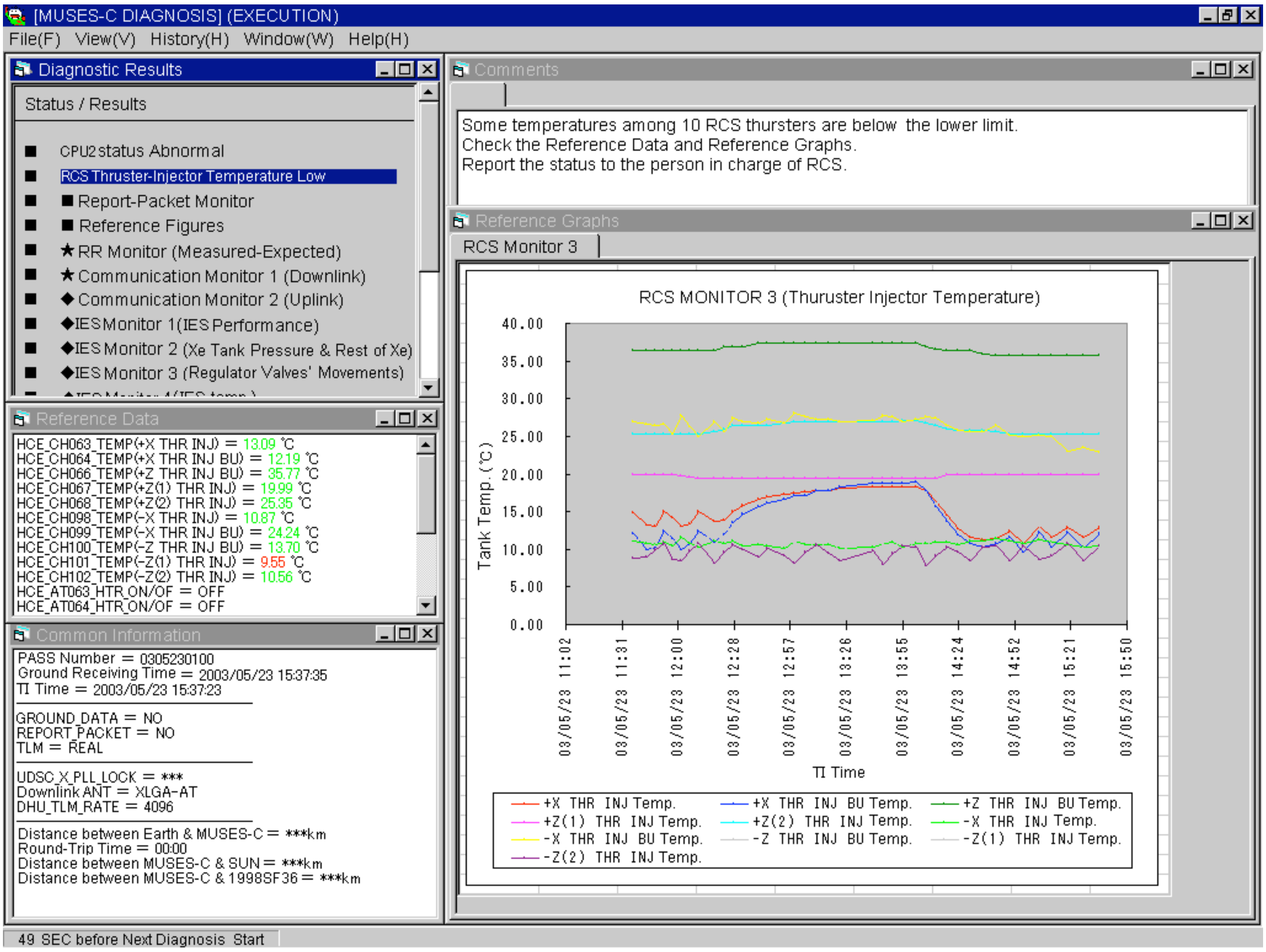

Figure 4. A diagnostic result of RCS abnormality.

It warns that the temperature of a thruster injector of RCS falls below the lower limit. It displays the related reference data, comments, trend graph as well as common information and other diagnosed result items.

2) Examples of monitor displays

ISACS-DOC can always display some monitors on important items of HAYABUSA regardless of abnormality occurrence. Figure 5 shows IES Monitor 2. The remaining IES propellant of xenon calculated from the pressure and the temperature of xenon tank is always shown as the trend graph as well as the related reference data. The pressure and temperature of helium gas, hydrazine fuel, NTO oxidizer for RCS should be carefully watched and monitored. Figure 6 shows RCS Monitor 1 for this purpose. Reasonable lower limits of the pressures are calculated to show on the display.

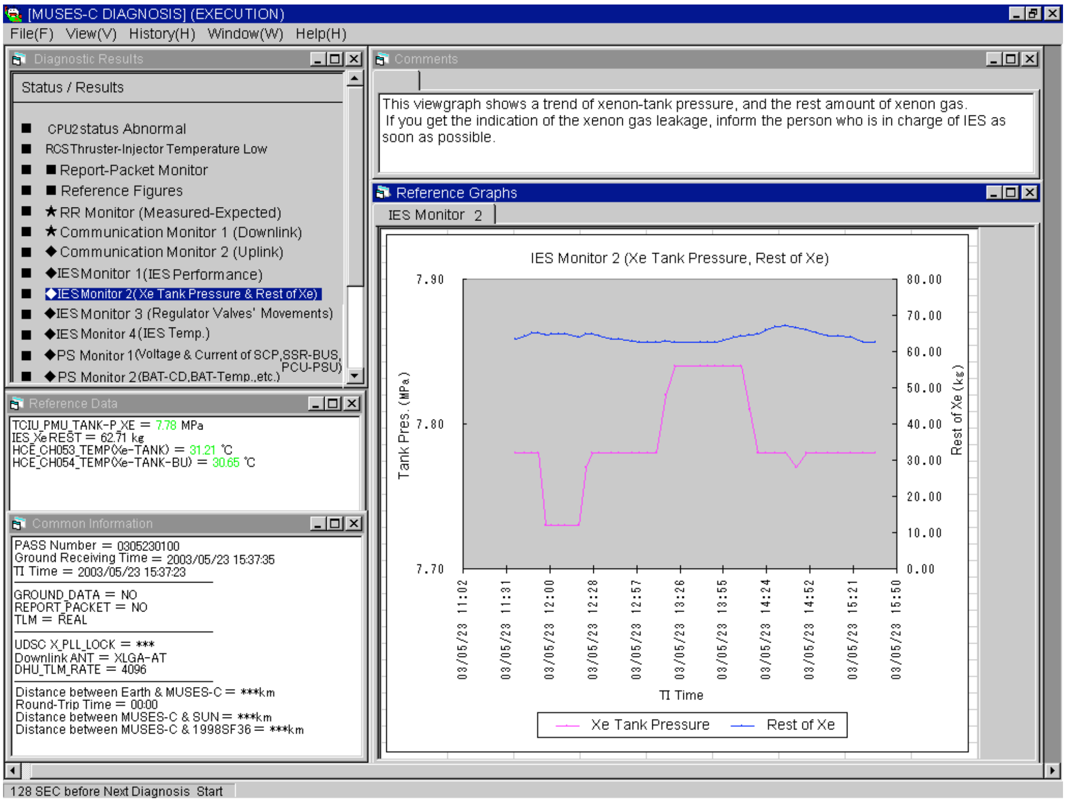

Figure 5. IES Monitor 2 (Pressure of Xe tank and Rest of Xe).

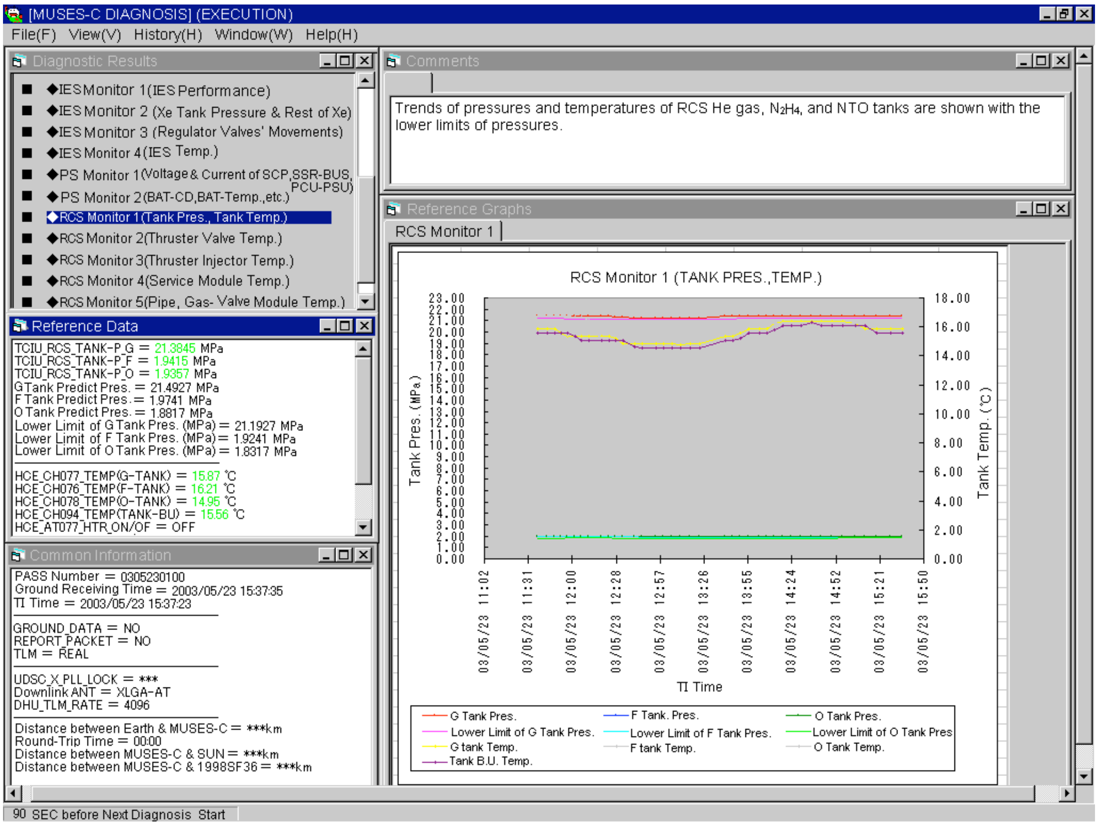

Figure 6. RCS Monitor 1 (Tank pressures, lower pressure limits, and temperature).

4. CONCLUDING REMARKS

The third generation of ISACS-DOC for HAYABUSA was reported with some examples diagnosed in the actual operation of the probe. Its effectiveness was also proved through the daily operation even in the tuning stage of the operation. This system has a big flexibility to respond to the situation change of the probe. Further improvements of ISACS-DOC for HAYABUSA will continue using the flexibility. The authors would like to thank all the people who provided the precious knowledge for this system. We also would like to make an acknowledgement to Professor Jun'ichiro Kawaguchi at ISAS for his great support.

5. REFERENCES

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