MDS-1 搭載用積算吸収線量計によるトータルドーズ計測結果について
Totaldose effect analysis by dosimeter onboard Tsubasa(MDS-1) satellite

木本　雄吾＊1、越石　英樹＊1、松本　晴久＊1、五家　建夫＊1

Yugo Kimoto, Hideki Koshiishi, Haruhisa Matsumoto, Tateo Goka

Key Words: MDS-1, RADFET,Totaldose, SHIELDOSE-2

***Abstract*—The total dose data from a Tsubasa (MDS-1) satellite, flying in a highly eccentric orbit, is analyzed. The total dose is measured by the small dosimeter utilizing RADFETs. The RADFETs have been calibrated with the Co60 gamma ray source and 56 devices (denoted DOS-S) were mounted in several experimental modules in the satellite. The total dose data behind certain Aluminum shield domes have been analyzed initially. The total dose change is affected by electron flux in the thin shield. In thicker shield, electron and proton affect the total dose profile.**

I. Introduction

Mission Demonstration test Satellite-1 (MDS-1) "Tsubasa", launched in February 2002 and still in orbit, has some experimental devices to verify the function of commercial parts and components, and to measure space environment data. The satellite has a highly elliptical orbit. One of the space environment data measurement systems, Dosimeter (DOS), measures the integrated radiation dose, i.e. total dose at each sensor location.

Damage and errors caused by high-energy particles in space have been of prime concern for use of modern electronics in space application. The on-board particle detector has been flown for understanding such an environment and some electrical parts have been flown for evaluation. NASDA has measured in flight data on space environment received by monitors mounted on board of not only NASDA's satellite but also Space shuttle and International space station [1][2][3]. The collected data have been integrated in the Space Environment & Effects System (SEES) and released via http://sees.tksc.nasda.go.jp/.

We have analyzed the effect of space radiation environment to spacecraft by using NASA models AE-8, AP-8, and SHIELDOSE-2 for designing spacecraft in a known orbit. These particle models are based on observations from satellites that had been launched from 1958-1978. It has been pointed out recently that there may be discrepancies between these results and observation data in some orbits. Meanwhile, new space radiation models have been developed [4][5].

The purpose of DOS experiment in MDS-1 is not only to measure the total dose at each section but also to construct the high accuracy total dose effect model. In this paper, we briefly present the total dose data at different positions with known shield thickness. The scope of the data is from the satellite lunch 4 February 2002 to 1 May 2003. In addition, the comparison between the flight data and environment model is presented.

＊1 宇宙航空研究開発機構　総合技術研究本部

II. Spacecraft & Instrument

A. *Tsubasa (MDS-1) satellite*

The MDS-1 satellite has a highly elliptical orbit (500 km × 35700 km) and an inclination of 28.5 degrees with a period of ten hour and thirty minutes. It is a spin stabilized satellite with the spin rate of 5 rpm.

This satellite's mission is to verify the function of commercial parts and new technologies of bus-system components in space, and to measure space environment. It was equipped with six experimental modules for this mission [6].

For collecting space environment data, Space Environment Data Acquisition Equipment (SEDA) is on board the satellite. SEDA consists of Standard dose monitor (SDOM), Heavy Ion Telescope (HIT), Magnetometer (MAM), and Dosimeter (DOS). SDOM measures the electron and proton fluxes with Solid-state Silicon detectors (SSDs) and plastic scintillator with photo-multipliers (PMT) [7][8]. SDOM discriminates particles and energy by algorithm which is determined by the combination of pulse height by each sensor. This algorithm is based on the ground-based calibrations and simulations. Five electron channels in the energy range 0.4-20MeV, 12 proton channels in the energy range 0.9-212MeV, 4 alpha particle channels in the energy range 6.5-137MeV and a heavy ion channel in the energy range 24-950 MeV are defined [8]. HIT measures flux of heavy ions from He to Fe, and MAM monitors the magnetic field in the satellite pass. These data support the evaluation of other experimental modules data in orbit.

B. *Dosimeter (DOS)*

DOS consists of two modules with installed sensors and two with readout electronics. Fifty-six very small sensors (DOS-S), shown in Fig.1, have been installed. The readout electronics (DOS-E) can measure thirty-two sensors by multiplexing them.

The eight DOS-Ss are installed into two DOS-Sensor Shield Modules (DOS-SSM), each of which has four hemispherical aluminum shield domes with thickness of 0.7, 3, 6, and 10 mm. The back of DOS-SSM is shielded by the walls of the satellite.

One DOS-SSM (DOS-SSM1) is attached in +Z direction of the satellite outside the satellite, another DOS-SSM (DOS-SSM2) is attached to –X direction. The +Z direction corresponds to the sun direction, and the –X direction corresponds to the direction perpendicular to the spin axis (+Z axis). Fig.2 shows MDS-1 and the position of the DOS-SSMs on the satellite. Other DOS-Ss are installed into some experimental components that are required to measure the total dose.

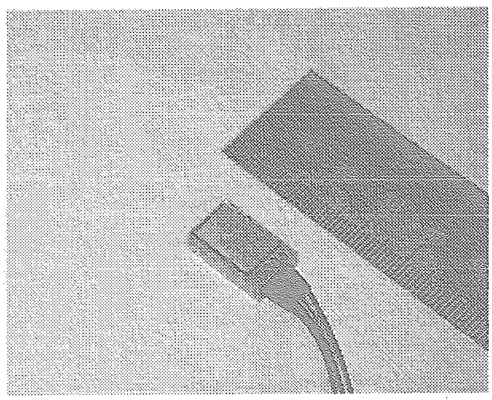

Fig. 1. Photograph of DOS-S. DOS-S is 17 mm×10 mm×5 mm and 7.4 g

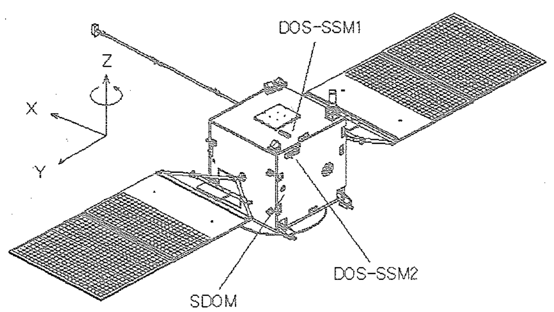

Fig. 2. The position of DOS-SSM1 & 2 and SDOM on MDS-1 satellite. Z axis is a spin axis. DOS-SSM1 is attached to +Z direction of the satellite, the other DOS-SSM2 is attached to –X direction. The field of view of SDOM is also –X direction.

A DOS-S includes a bare die of RADFET (Radiation-Sensitive Field Effect Transistor) and a Pt thermometer. The RADFET is a specially designed PMOS transistor with a thick gate oxide, optimized for increased radiation sensitivity. The RADFET is suitable for space use in respect of cost, weight and low power consumption. The RADFET used in MDS-1 are 400nm implanted gate oxide devices manufactured by National Microelectronics Research Centre (NMRC) in Ireland. The bare chip and Pt thermometer are shielded by a thin package cover and this part is assembled with DOS-S final cover. These shields are estimated at 1mm Al equivalent shielding. The RADFET in a DOS-S can be connected in two modes. One is a mode where all pins are grounded during exposure (Expose mode). Every twenty minutes, RADFET is put into another mode (Measure mode), where source/bulk is connected to a constant current (10μA), the voltage (Vgs) at the source with drain/gate grounded is measured for 20 seconds and telemetered to the spacecraft's communication & data handling unit. The Vgs is measured in the range from 0 to 20 V in 12-bit resolution. Fig.3 shows the measure mode for RADFET in DOS-S. Temperature is also measured in twenty minute intervals. The measurement range of Pt thermometer is from – 130 to + 130 °C.

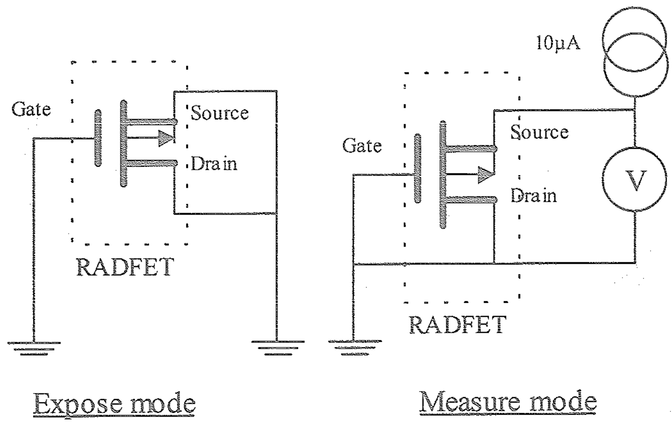

Fig. 3. The RADFET mode is changed from Expose to Measure every 20 minutes in each DOS-S.

III. Ground Irradiation Test

Ground irradiation tests were conducted with the Co^{60} gamma-ray source. The dose rate was 10 Gy (Si)/hour. The same RADFETs as used in DOS-S, but packaged in standard 14-lead Dual-in-Line packages, were irradiated at room temperature. RADFETs were irradiated and read out in the same configuration as during the flight: irradiation was done in the Expose mode and every 20 minutes the configuration was switched to Measure mode for 20 seconds. The second group of measurements were done at certain dose levels using the computer controlled parameter analyzer. In the dose rate of 10 Gy(Si) per hour, RADFETs were measured at 1, 3, 10, 30, and 100Gy (Si).

Fig. 4 shows the Vgs shift from the initial value (dVgs) with the total dose. The data shows that the dVgs dependence on the total dose (D) can be described by a power law function given by

$$dVgs = aD^b \quad (1)$$

where a and b are fitting constants.

The fitting constants were calculated as a = 0.1336, b = 0.6245, assuming dVgs is given in V, and D in Gy(Si).

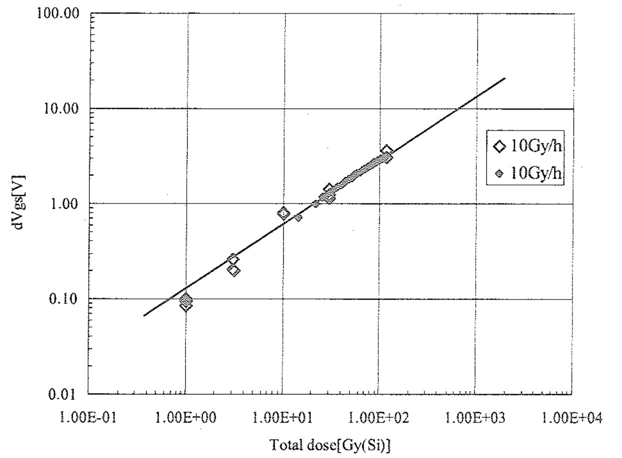

Fig. 4. Radiation response of the RADFETs. X axis shows total dose [Gy] and Y axis shows the difference of Vgs from the initial value (dVgs). The black dots are data measured every 20 minutes, while white dots are data measured after a certain total dose levels.

The factors that in practice affect the accuracy of the total dose calculation based on the calibration curve are temperature dependence, threshold voltage drift, and the annealing effect [9][10]. In this initial analysis, these effects were not taken into account. It is estimated that the aggregate effect of the above factors is less than 10%, which translates in the error of dose estimation within 16%.

IV. Flight Data And Analysis

After MDS-1 was launched, its orbit control and check out of the bus system and the experimental modules were done several times. DOS was powered on 9 February 2002, but some of the data was lost for this satellite house keeping. So, we have analyzed the data starting from 26 February 2002, when the operation of DOS and other experimental modules and the data acquisition were stabilized, to 1 May 2003. This period corresponds to for 430 days and 974 orbits.

Fig.5 shows the total dose versus orbit pass for four different shieldings of DOS-SSM2, direction of which is –X, on a log scale. These data are averaged for each pass. For 430 days (974 orbits), the total dose at each shield is 1.57×10^3, 3.31×10^2, 82.0 and 56.4 Gy (Si), respectively.

Fig. 6 shows the temperature change in DOS-SSM1 (+Z) and DOS-SSM2 (-X). The temperature of the four DOS-Ss in DOS-SSM1 and DOS-SSM2 is almost the same. The differences are less than in ±1°C, and the temperature average is 28 and 21.1°C respectively. The temperature in the +Z direction is higher than in the –X direction because +Z direction is the direction towards Sun. Except for a drop in the end of March 2002, these temperatures are stable, and their deviation from the average is ±2°C. The current in the source/bulk of the RADFET for the Measure mode is a current value at the zero temperature coefficient (ZTC) point, where the temperature dependence of Vgs is only 0.4 % [11]. Therefore, the observed temperature changes do not significantly affect the dosimetry result.

Fig. 7 shows the total dose versus date for different shield domes of –X and +Z direction (DOS-SSM1 & 2). For all shields, the total dose increases gently, but sometimes slopes are changed. In the 0.7, 3, and 6 mm shields, the total doses in -X direction have a tendency which is greater than in +Z direction: 14, 4, and 11 percent higher, respectively. Meanwhile, in the 10mm shield, the total dose data in +Z direction is 7% greater than the total dose in –X direction. This difference is within the error of measurement. However the differences between –X and +Z direction are becoming bigger with time, suggesting that the total dose is different on the satellite position even with the same shield thickness.

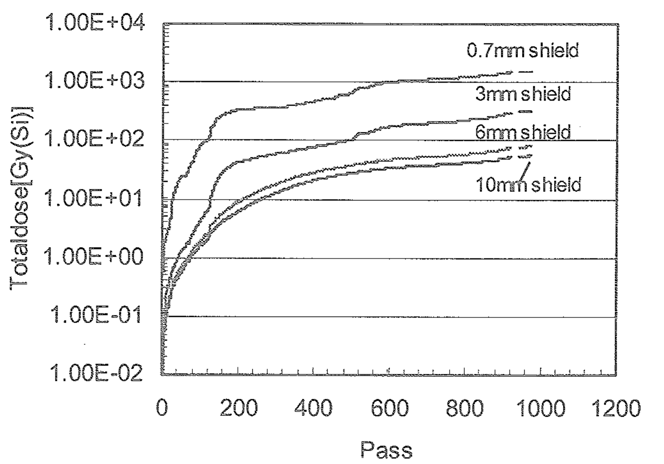

Fig. 5. Total dose in four shield domes versus pass number in –X direction (DOS-SSM2).

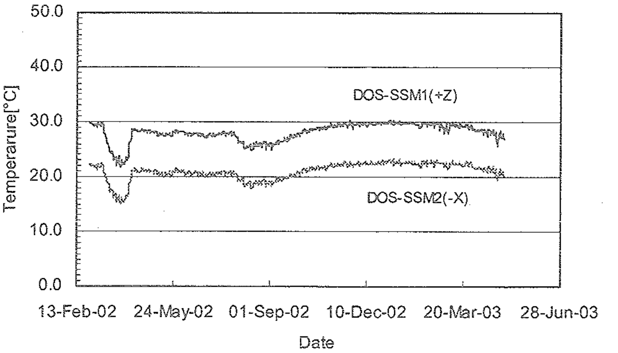

Fig. 6. Temperature in DOS-SSMs 1 and 2 versus date.

Electrons with energies above 0.5, 1.6, 2.8 and 4.3 MeV and protons with energies above 10.0, 23.7, 35.7, and 48.3 MeV are able to penetrate the aluminum shield thickness of 0.7, 3, 6, and 10mm of DOS-SSM, respectively. In practice, these energy levels are further increase somewhat because of the shield effect of DOS-S itself.

Fig. 8. shows the total dose change per day versus date for 0.7mm shield in – X direction and electron flux with average

energy at 1.45 MeV from SDOM. In this shield, the change of electron flux at 1.45 MeV contributes to the change of the total dose. In thicker shields, electrons and protons affect the total dose in a more complicated manner.

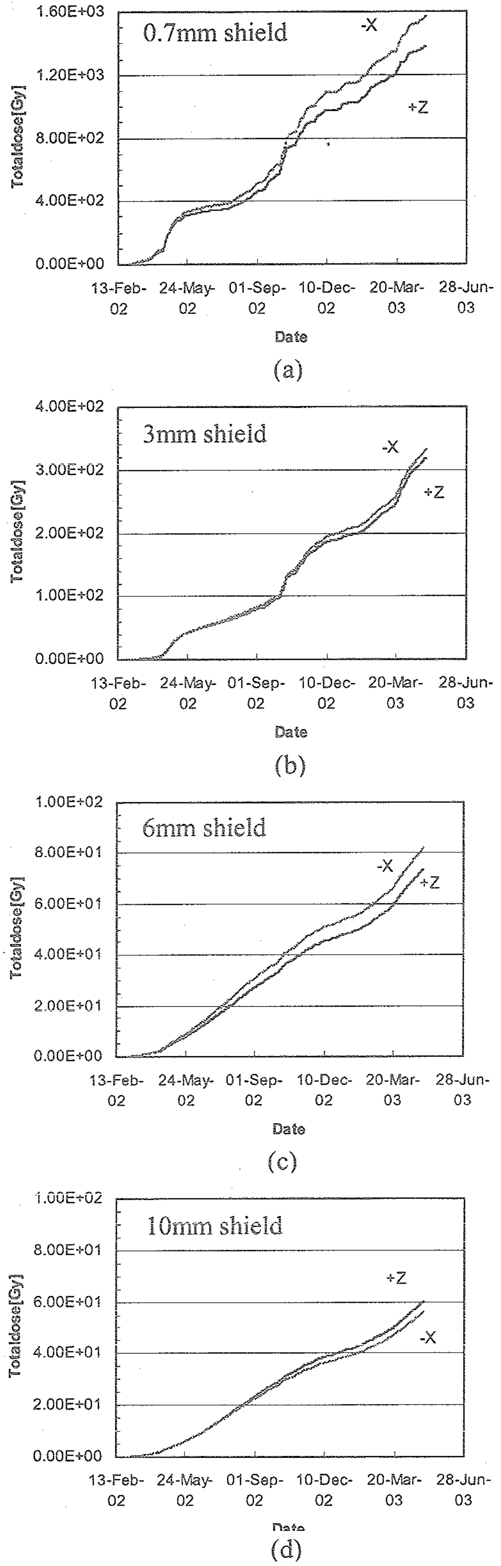

Fig. 7. Total dose in four shield domes versus date for –X and +Z direction (DOS-SSM1 and DOS-SSM2).

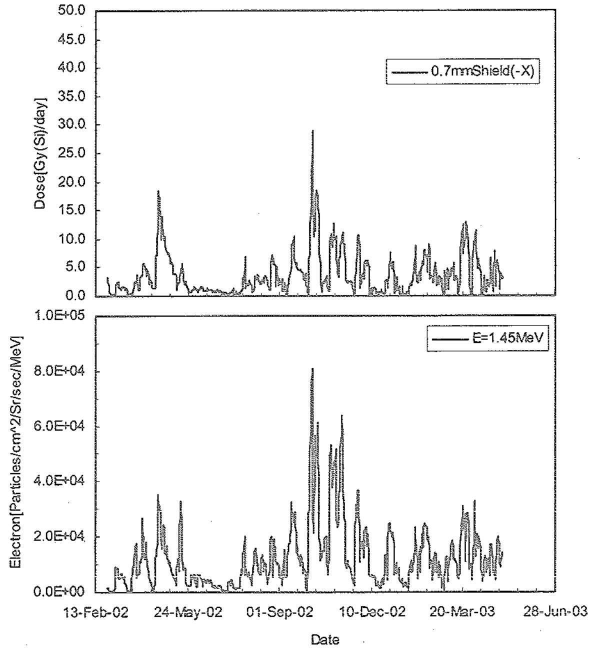

Fig. 8. Total dose change per day versus date for 0.7mm shield in –X direction and electron flux with average energy at 1.45 MeV from SDOM.

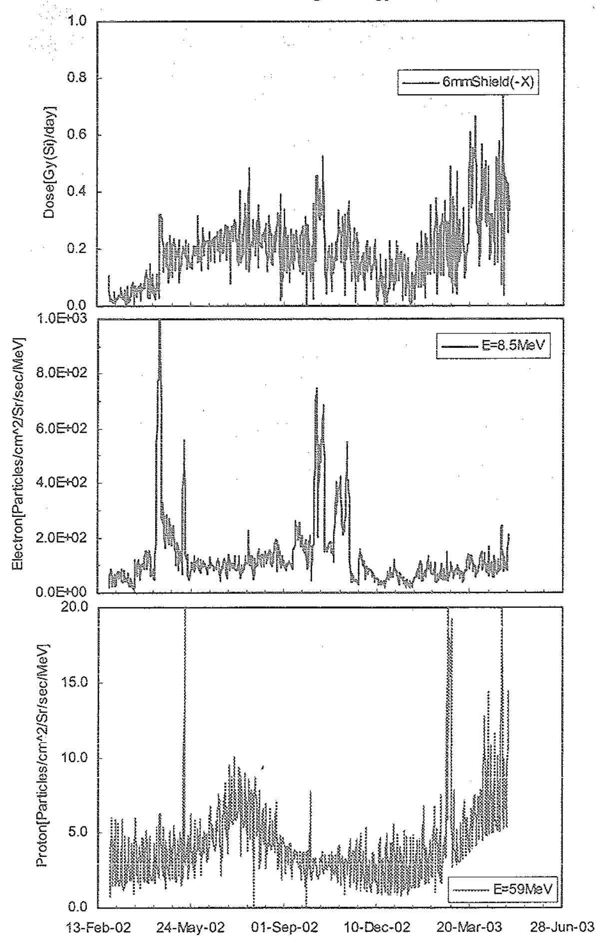

Fig. 9. Total dose change per day versus date for 6mm shield in –X direction and proton flux with average energy at 59 MeV and electron flux with energy at 8.5 MeV from SDOM.

Fig. 9. shows the total dose change per day versus date for 6mm shield in –X direction and electron flux with at 8.5 MeV, and, in addition, proton flux with average energy at 59 MeV. This shows a major effect is caused by electrons, but when proton events happen the total dose is affected by protons.

V. DISCUSSION

Fig.10 shows total dose versus date for the four shields of DOS-SSM2 in –X direction and the model calculation on a log scale. AP8, AE8, JPL1991, and SHIELDOSE-2 models in SEES model were used for the model calculation for a period from 26 February 2002 to 1 May 2003. The reliability of JPL1991 is 75%. The target material is Silicon. Solid sphere is used in shield geometry and the data are halved on the assumption a half of the sphere is shielded. The orbit data of MDS-1 is updated every month and it is assumed that the orbit data aren't changed during the month. Every month data are integrated. The thickness of DOS-S is estimated to be 1mm in this calculation. There are differences between the flight data and the model calculation, particularly for 0.7 and 10mm shields. The flight data in 0.7mm shield are estimated to be about 40% lower than the model result. The flight data in 10mm shield are greater by a factor of 4 than the model calculation. As the period of data acquisition is getting longer, the flight data in 3mm shield approaches the model calculation.

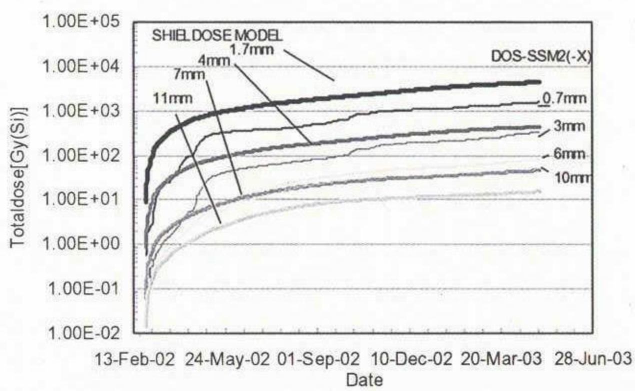

Fig. 10. Comparison of flight total dose profile with SHIELDOSE-2 model calculation. Each thick line shows the model calculation.

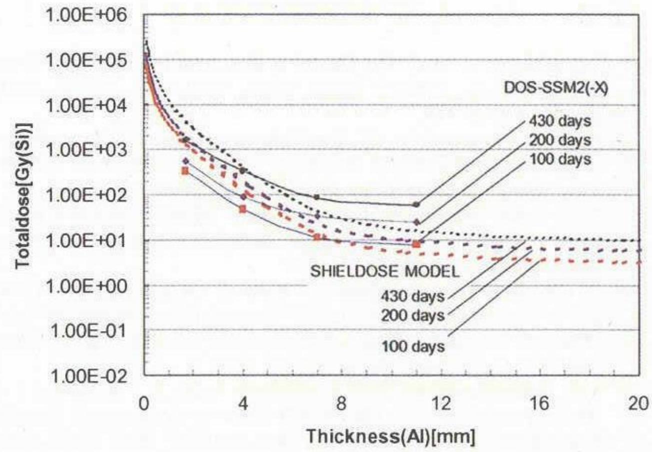

Fig. 11. Dose-depth curve from the flight data and SHIELDOSE-2 model calculation.

Fig 11 shows the total dose data versus Aluminum shield thickness, that is a dose-depth curve, of the flight data and model calculation. The dose-depth curve is calculated for 100, 200, and 430 days. This shows the model might overestimate the total dose in the shield under 2mm and underestimate the total dose in thick shield over 8mm. One of the reasons for discrepancies between the flight data and model calculation is the difference of electron and proton fluxes within some energy range [6][12]. Namely, electron fluxes with the energy under 4MeV from flight data are lower than the model flux and, while those with the energy over 5 MeV are higher than the model flux. Proton fluxes with the energy under 20 MeV from the flight data are lower than the model data, and those with the energy over 30 MeV are higher than the model data. The current analysis is based on the data collected only one year. It is necessary to measure and analyze the data continuously in a loner term to establish more reliable conclusions.

VI. SUMMARY

The very small dosimeter utilizing RADFETs has been developed and flown on Tsubasa (MDS-1) satellite. Initial results, the total dose at eight points covered with different Aluminum shielding, were analyzed. The major effect on a total dose is caused by electrons, but when proton events happen the total dose is affected by protons.

VII. ACKNOWLEDGMENT

We wish to thank Hideharu Ohira for his assistance in calibrating RADFETs and Keiichi Yano for his support in writing some of the data analysis software. We also appreciate the work of all the people involved with development and operation of the MDS-1 satellite.

VIII. References

[1] Tateo Goka, et al., "The On-orbit Measurement of Single Event Phenomena by ETS-V," IEEE Trans. Nucl. Sci. NS-38, No.6, pp.1693-1699, 1991

[2] Haruhisa Matsumoto et al. "Real-time measurement of Low-energy-range Neutron Spectra On Board the Space Shuttle STS-89 (S/MM-8)," Radiation Measurements 33, pp.321-333, 2001

[3] Tateo Goka, Haruhisa Matsumoto, Shunji Takagi, "Empirical model based on the measurements of the Japanese spacecraft," Radiation Measurements 30, pp.617-624, 1999

[4] D. Heynderickx, M. Kruglanski, V.Pierrard, J. Lemaire, M.D. Looper and J. B. Blake, "A Low Altitude Trapped Proton Model for Solar Minimum Conditions Based on SAMPEX/PET Data," IEEE Trans. Nucl. Sci. Vol.46, No.6, pp.1475-1480, 1999

[5] M.S. Gussenhoven, E.G. Mullen, Michele Sperry, K.J. Kerns and J. B Blate, "The Effect of the March 1991 Storm on Accumulated Dose for Selected Satellite Orbits: CRRES Dose Models," IEEE Trans. Nucl. Sci. Vol.49, No.6, pp.1765-1772, 1992

[6] Tateo Goka, et al, "Space Environment & Effect Measurements From The MDS-1 (Tsubasa) Satellite," 23rd ISTS,Matsue, Shimane, Japan, proceeding, pp.1747-1754, 2002

[7] H. Koshiishi, H. Matsumoto, Y. Kimoto, H. Liu and T. Goka, "Space Environment Data Acquisition Equipment on Board Mission Demonstration Test Satellite, " COSPAR Colloquia Series "Solar-Terrestrial Magnetic Activity and Space Environment" Edited by H. Wang, R. Xu, Elsevier: St. Louis, pp.369-371, 2002

[8] Haruhisa Matsumoto, Hideki Koshiishi, Tateo Goka, Yugo Kimoto, B.D. Green, et al., "Compact, Lightweight Spectrometer for Energetic Particles." IEEE Trans. Nucl. Sci. NS-48, No.6, pp.2043-2049, 2001

[9] Y.H.Shin, K.W. Min, J.G.Rhee, D.H. Lee, S.H. Kim, H.S. Kim, S.D. Park, K.K. Sung, and S.D. Choi, "Analysis of Anomalous TDE Data on-board the KITSAT-1, " IEEE Trans. Nucl. Sci. NS-46, No.6, pp.1586-1594, 1999

[10] Z. Savic, B.Radjenovic, M. Pejovic, "The Contribution of Border Traps to the Threshold Voltage Shift in pMOS Dodimetric Transistors," IEEE Trans. Nucl. Sci. NS-42, No.4, pp1445-1454, 1995

[11] M. O'Sullivan, A. Kelleher, J.Ryan, B. O'Neill, and B. Lane, "Temperature compensation of PMOS dosimeters," Proc. ESA Electronics Components Conf., ESTEC, Noordwijk, Netherlands, pp.281-285, 1991

[12] Kiyokazu Koga, Haruhisa Matsumoto, Hideki Koshiishi, Hong Liu and Tateo Goka, "New Results from Space Environment Measurements on the TSUBASA (MDS-1) Satellite," Proceedings of The 5th International Workshop on Radiation Effects on Semiconductor Devices for Space Application, Takasaki,Gunma, Japan, pp.17-20, 2002