Report on Space Debris Related Activities in Japan
(For UNCOPUOS/STSC February, 2009)

Activities related to studies of space debris, mainly conducted in JAXA and Kyushu University, have been concentrated on the following works.

1. Space debris observation on the ground

Observation of objects in geosynchronous orbit (GEO) and determination of their orbit characteristics are routinely conducted using optical telescopes. Research to develop software that can automatically detect smaller objects in GEO is progressing.

For objects in a low earth orbit (LEO), observations are conducted using radar telescopes. Research to observe objects in LEO is conducted using high-speed tracking optical telescopes. Furthermore, light curves of some spacecraft have been observed and their tumbling motion characteristics have been analyzed (Annex-A).

2. Modeling and analysis tools

Low Earth Orbital Debris Environment Evolutionary Model *(LEODEEM)* developed by Kyushu Univ. and JAXA (Fig.1), and Debris Mitigation Standard Support Tools (*DEMIST*) (Fig.2) are being upgraded. A debris collision risk analysis tool is also under development. So far, only debris impact probability could be analyzed (Fig.3), but damage risk assessment is being implemented now by considering the ballistic limit equations.

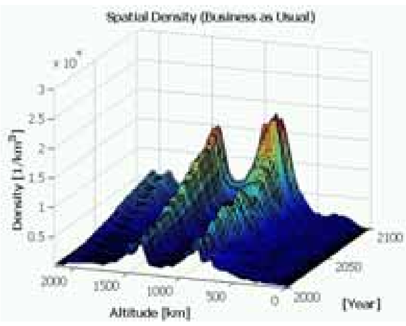


Fig. 1 Example of future debris environment analysed by LEODEEM

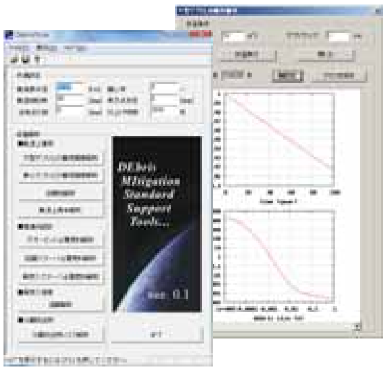


Fig. 2 Example of user interface in DEMIST

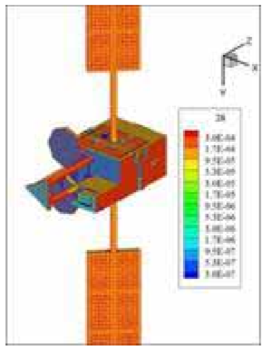


Fig. 3 Result of debris impact probability analysis

3. Orbital Debris Evolutionary Models

Kyushu University plans to contribute to “Benefits of Active Debris Removal on the LEO debris population,” an internal action item of the working group 2 of the Inter-Agency Space Debris Coordination Committee (IADC), on behalf of the Japan Aerospace Exploration Agency (JAXA). This action item aims to reach a consensus on stability/instability of current orbital debris population in low-Earth orbit (LEO). A parametric study on the effects of active debris removal and comparison of results from different tools will be conducted. NASA will lead study participants of ASI, BNSC, ISRO, and JAXA to provide the first result by next April at the next IADC meeting.

The international space communities have recommended placing aged geosynchronous spacecraft in drift orbits with higher altitude so that they may not interfere with operational spacecraft. Actually, over 80 % of aged geosynchronous spacecraft were re-orbited above the nominal geosynchronous altitude in the past eight years. However, some of them were not able to reach the altitude recommended by the Inter-Agency Space Debris Coordination Committee (IADC). Kyushu University has predicted orbital debris population in the geosynchronous regime for next 100 years by applying the actual disposal practices to some future projections. Future projections have indicated the directions of our efforts to preserve GEO: 1) post-mission disposal as the international space communities have recommended, and 2) safe keeping procedures for all rocket bodies and spacecraft after completion of their mission. Future projections also have indicated the technical issues to place aged spacecraft in drift orbits with higher altitudes at the end-of-life because of 1) difficulty in evaluating fuel consumption (or residual fuel), and 2) system reliability at the end-of-life (or malfunctions).

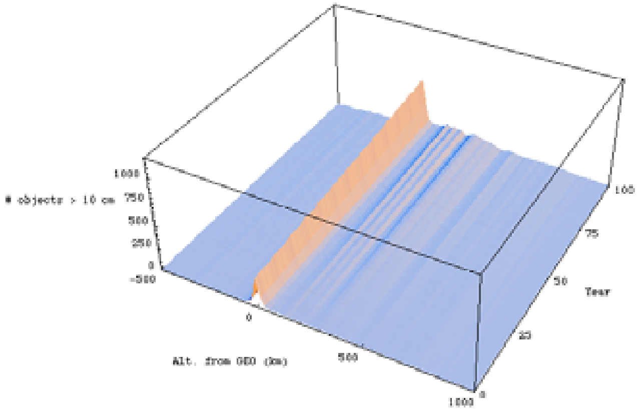


Fig. 4 Population growth in the geosynchronous regime for next 100 years.

Kyushu University and JAXA plan to develop a full-scale model (LEO-to-GEO model) to account all Earth-orbiting objects. Upon this plan, Kyushu University has started to upgrade its GEO model based on more realistic modeling techniques adopted in the LOE model.

4. Hyper-velocity impact testing

Hyper-velocity impact tests were carried out for aluminum plates and CFRP plates by using two-stage gas guns of Tohoku University and Padova University. During the tests, the fracture behavior of target was observed by a high speed camera (Fig.5). There were differences of damage size and debris clouds between aluminum alloys and epoxy-based CFRPs. A two-stage gas gun was newly introduced by JAXA to promote additional test data acquisition (Fig.6).

The shaped charge impact device was also used for the hyper-velocity impact tests. This method has given projectile speeds of over 10 km/s to projectiles with the mass of over 1 g. A jet removal system was developed to obtain only result of main jet collision.

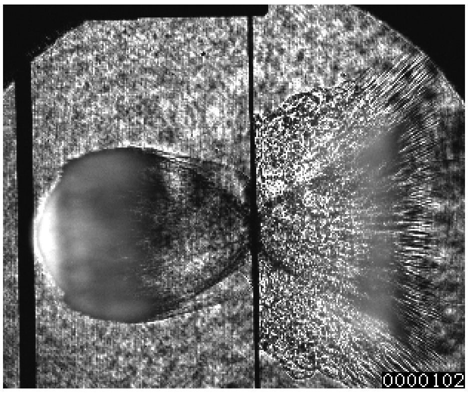


Fig. 5 Shadowgraph of a two-stage gas gun impact test for an AL6061-T6 bumper and a projectile of 7.1km/s, 1.05g.

Fig.6 Newly introduced two-stage gas gun at Sagamihara Campus of JAXA.

5. Micro-satellite Impact Testing

Kyushu University and the NASA Orbital Debris Program Office have collaborated on a series of micro-satellite impact tests. Two micro-satellites covered with Multi-Layer Insulation (MLI) and equipped with a solar panel were used as targets. They were 20 cm by 20 cm by 20 cm in size and approximately 1,500 grams in mass. The objectives conducting these impact tests are to investigate MLI and solar panel pieces, and to compare the outcome of these impact tests with the NASA standard breakup model. The impact speed was about 1.7 km/s; the ratio of impact kinetic energy to satellite mass for the two tests was about 40 J/g. Impact phenomena were captured using an ultra-high speed camera of Japan Broadcasting Corporation (Nippon Hoso Kyokai). The results will be utilized to improve our understanding of high area-to-mass ratio objects, and to improve breakup models for better orbital debris environment modeling.

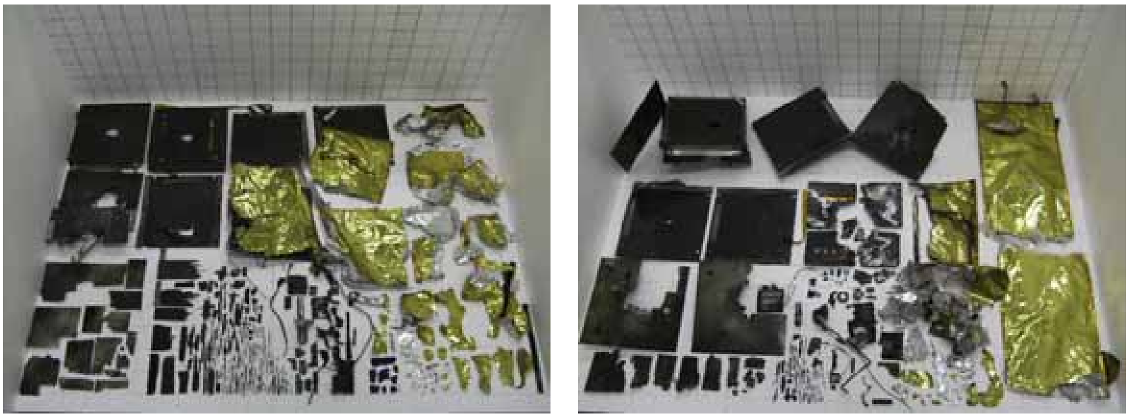


Fig. 7 Figure: Major fragments observed from impact tests.

Fragment shape is important for improving the estimation of the area-to-mass ratio of each fragment. However, fragment shape is also important for conducting a reliable assessment of the probability of non-penetration of spacecraft such as the International Space Station. All fragments collected from the previous impact tests (see also last year's report) were analyzed based on their three orthogonal dimensions, *x, y*, and *z*, where the *x* is the longest dimension, *y* is the longest dimension in the plane perpendicular to *x*, and *z* is the longest dimension perpendicular to both *x* and *y*. Two groups can be observed in the *x*/*y* versus *y*/*z* distribution of fragments; fragments with larger *x*/*y* values represented by a needle, and fragments with smaller *x*/*y* values represented by a plate. The fragments with smaller *x*/*y* values can have wide variety of *y*/*z* values and they can be box-like with smaller *y*/*z* values, thin-shaped with larger *y*/*z* values, and plate-like with intermediate values of *y*/*z*.

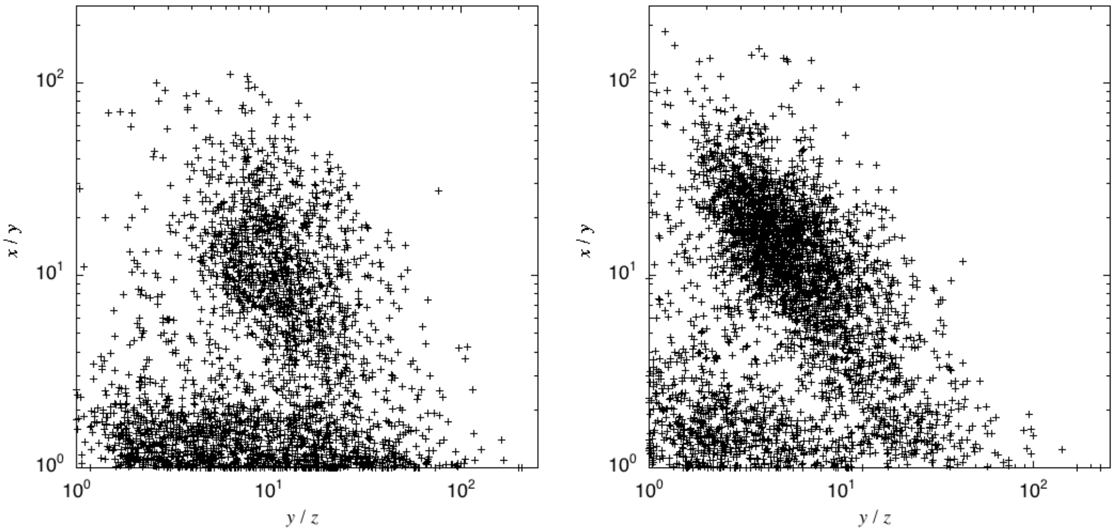


Fig. 8 Shape distributions of fragments observed from impact tests.

6. Electrodynamic tether to hasten orbital decay for unused spacecraft

To mitigate debris generation alone is insufficient for preserving the orbital environment because the chain reaction of collisions among existing debris has already been observed in specific orbital regions. The ultimate measure to improve the environment would be the removal of large objects positively from densely populated orbital regions. The removal missions should be conducted in a cost-effective manner, and a technical solution would be the electrodynamic tether system, which slows unused space objects and reduces their orbital lifetime. Research and development activities related to electrodynamic tether systems have been conducted in JAXA (Annex-B). The current efforts are directed to develop a small electrodynamic tether system aimed at on-orbit demonstration using a small satellite (Fig.9).

Fig.9 Conceptual image of electrodynamic tether demonstration

7. Mission Success Rate of Electro-dynamic Tether for Active Debris Removal

The Inter-Agency Space Debris Coordination Committee (IADC) had conducted “Potential Benefits and Risks of Using Electro-dynamic Tethers for End-of-life De-orbit of LEO Spacecraft” as one of its action items. A tether strand is thin but long enough to have a large area so that it is vulnerable to smaller particles. This vulnerability might be the weakest point of a tether system against orbital debris. In order to overcome this weakest point, a double tether system, in which two tether strands are tied together at even intervals to form equally spaced loops, has been suggested as one of the promising candidates. To participate in the action item, Kyushu University has developed a mathematical model evaluating the survival probability of the double tether system.

Kyushu University has extended the aforementioned mathematical model after the completion of the aforementioned action item. The resulting model can provide us with the maximum mission success rate that a double tether system with a finite clearance can attain regardless the number of loops. Kyushu University is applying this new model to evaluate the mission success rate of an electro-dynamic tether system proposed by the Japan Aerospace Exploration Agency (JAXA). Details on this topic will be published to the Journal of Advances in Space Research.

Annex-A
Space Debris Optical Observation Technologies in ARD/JAXA

Toshifumi Yanagisawa, Hirohisa Kurosaki and Atsushi Nakajima

Aerospace Research and Development Directorate (ARD), Japan Aerospace Exploration Agency (JAXA)

Space debris observation on the ground

The Innovative Technology Research Center at JAXA has two small optical observation facilities of LEO and GEO debris observation. They are used for technological development and data acquisition. The LEO debris tracking facility is located at the JAXA headquarters in Tokyo, with a 35 cm telescope on a three-axis tracking mount system for large space structure tracking as ISS and LEO debris attitude estimation using shape or light curve observations and also monitoring of near re-entry objects. Figure 1 shows the error distribution of the rotation axial direction in the sky for LEO debris: a Cosmos 2082 rocket body which was obtained from its light curve. The GEO debris observation facility, Nyukasayama Observatory, is on Mt. Nyukasayama in Nagano Prefecture. Two small-aperture telescopes of 35 cm and 25 cm are supported on equatorial mount systems. Figure 2 shows the facility. An important study item in our R&D is to develop an automatic GEO small-debris detection software. We have proposed a stacking method for detecting noise-level faint GEO debris by accumulating signals of numerous images. The preliminarily developed software was evaluated with image data taken using the above telescopes. Figure 3 portrays an example obtained using the software. Some new algorithms and an FPGA-based analyzing system are being developed to make the method fast enough for the operation of space debris observations.

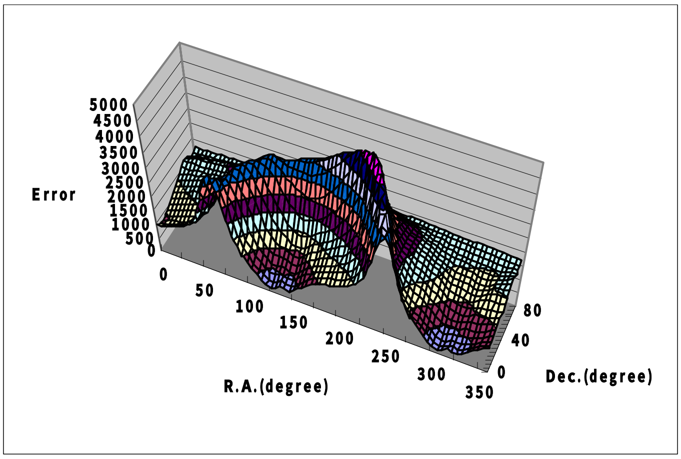


Fig. 1 The error distribution of rotation axial direction in the sky for a LEO debris, a Cosmos 2082 rocket body, which was obtained from its light curve. The analysis of the light curve of the LEO debris indicates that the directions are R.A.=305.8-degree and Dec.=2.6-degree.

Fig.2 Nyukasayama Observatory of ARD/JAXA.

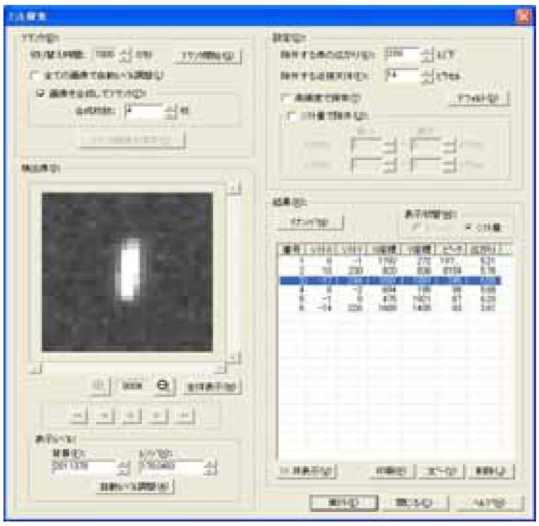


Fig. 3 Example of GEO Debris Automatic Detection software

Annex-B

Research and Development of Electrodynamic Tether System for Space Debris Mitigation in JAXA

Yasushi Ohkawa, Satomi Kawamoto, Shoji Kitamura and Shin-ichiro Nishida
Aerospace Research and Development Directorate (ARD), Japan Aerospace Exploration Agency (JAXA)

Overview

Research and development of an electrodynamic tether (EDT) system to reduce the orbital lifetime of spacecraft is being conducted. The EDT is an advanced propulsion technology that uses no propellant or working gases, in principle. Because debris de-orbit systems require highly efficient propulsion systems, the EDT is an attractive candidate. The EDT system studies using in-space demonstration tests and the current development status of its components are as follows.

Electrodynamic Tether System

Because the generation of thrust by EDT has not been demonstrated in space, it is indispensable to perform on-orbit experiments in the near future. At JAXA, system studies of simple EDT systems are being conducted with the intention of eventual demonstration. Figure 1 shows a typical example of the EDT system. To demonstrate thrust generation, it is desirable to equip a tether longer than 1 km and an electron emitter with emission capability of over several hundred milliamps. In addition, electrostatic and magnetic probes and GPS receivers are necessary for investigating EDT behavior on orbit.

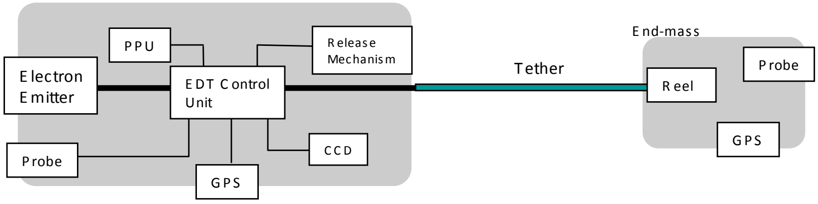


Fig. 1 Typical configuration of electrodynamic tether system.

Tether Dynamics

Investigation of tether dynamics is necessary for EDT development. Because experiments using full-length tethers are difficult to conduct on the ground, we have investigated the dynamics using numerical simulations. Figure 2 shows results of numerical simulations of tether deployment. Influences of deployment assistance by small thrusters or non-conductive tethers were evaluated last year. Suppressing libration of tethers is another important point for tether dynamics. Changes in the in-plane libration angle of the tether with and without control using GPS are shown in Fig. 3. Results show that GPS information is useful to control the tether attitude, even though the information includes a certain level of measurement error.

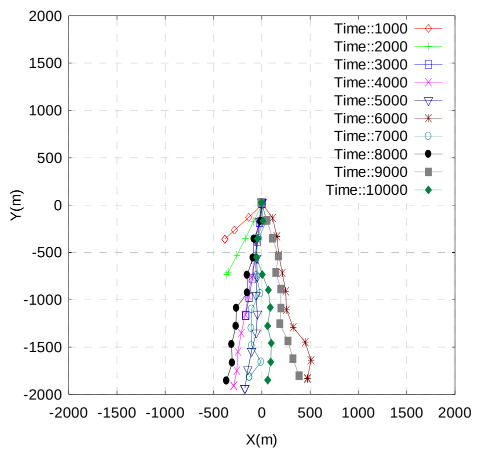


Fig. 2 Typical result of numerical simulation on tether deployment.

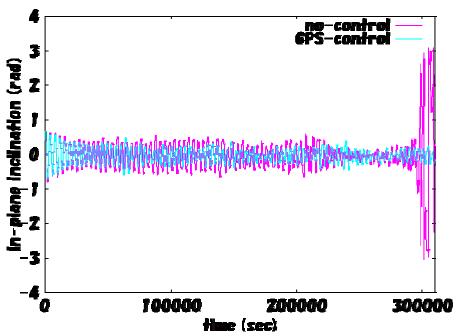
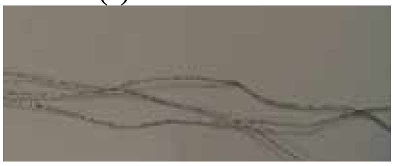


Fig. 3 Change in the in-plane libration angle of the tether with and without control using GPS.

Component Development

Bare Tether Trial-and-error fabrication and testing of bare tethers has been performed. The tether functions as an electron collector, a power source (i.e. generating electromotive force), and a thrust generator in the EDT system. Samples of fabricated bare tethers are shown in Fig. 4. In these tethers, aluminum wires and carbon fibers are braided or twisted to impart strength, flexibility, and electric conductivity. Tolerance to debris impact is also important for tethers; we expect that a mesh tether provides superior anti-debris performance and electron-collection capability because it behaves like parallel tethers. Electron collection experiments were also conducted in a plasma chamber. Figure 5 depicts a typical result using parallel bare tethers. The figure indicates that an optimum distance between the tethers exists for collecting higher electron current.

(a) Braided tether



(b) Mesh tether

Fig. 4 Bare tethers.

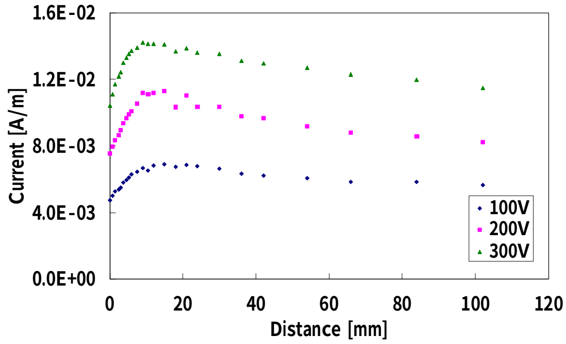


Fig. 5 Electron current collection by parallel bare tethers. Collection currents are plotted against the distance between the tethers.

Reel & Release Mechanism A bare tether is wound around a reel in the initial condition; it is deployed using a release mechanism. In our EDT systems, the combination of a spool-type reel and a spring-type release mechanism is the most likely candidate because of its simplicity and robustness. Figure 6 shows a video cut from a tether deployment test on an air table using the spool-type reel mechanism and the release mechanism with a double helical spring. In this test, the release velocity, friction resistance of tethers, and braking force were measured, confirming that those characteristics were as expected.

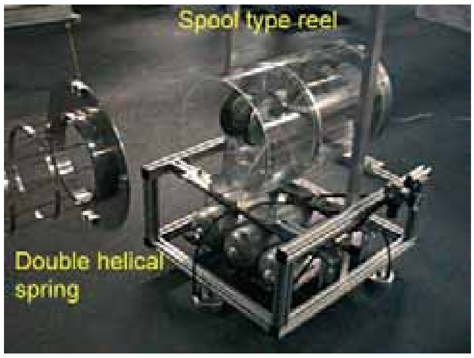


Fig. 6 Tether deployment test on air table.

Electron Emitter An electron emitter is another important component of EDT systems. We have studied field emission cathodes (FECs) using carbon nanotubes (CNTs) as a candidate because of its attractive characteristics. Development of FEC assemblies and its endurance tests were performed in parallel. Figure 7 shows a laboratory model of CNT cathodes fabricated last year. A typical result of the endurance tests of CNT cathodes in an oxygen environment is shown in Fig. 8. In the figure, the voltage required for constant-current-emission is plotted against elapsed time. The figure illustrates that the electron emission capability of the cathode deteriorates over time. However, the trend apparently moderates after several hundred hours. Design studies of hollow cathodes are also being conducted in addition to FEC studies.

Fig. 7 Laboratory model of carbon nanotube cathode.

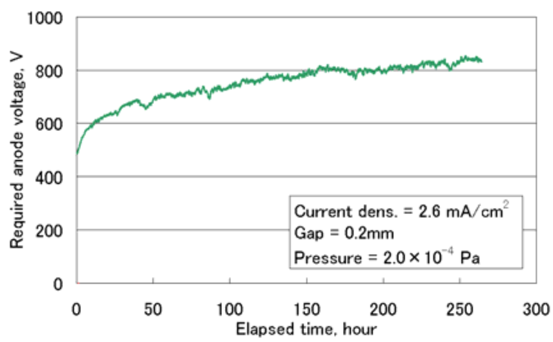


Fig. 8 Endurance performance of carbon nanotube cathode in an oxygen environment. Voltage required for constant-current-emission against elapsed time.