Report on Space Debris Related Activities in Japan
(For UNCOPUOS/STSC February, 2008)

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 of debris population

The following debris model and analysis tools are being developed in Japan:

a) "*Low Earth Orbital Debris Environment Evolutionary Model (LEODEEM)*" to predict future debris distribution at Kyushu University in collaboration with JAXA;

b) "*Debris Mitigation Standard Support Tool (DEMIST)*" to support assessment of compliance with the JAXA Space Debris Mitigation Standard and to assess debris-related risks in orbit; and

c) a debris collision risk analysis tool to calculate the collision probability for each space system part.

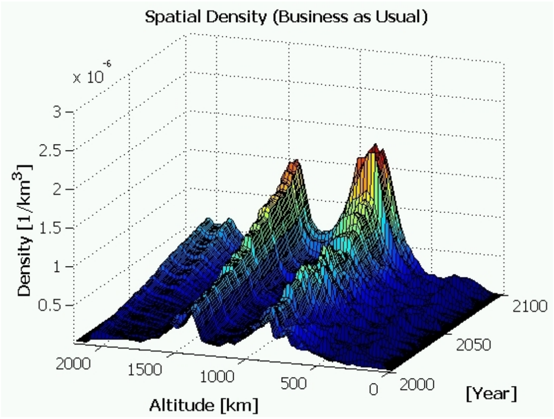

Fig.-1 Example of future debris environment analysed by LEODEEM

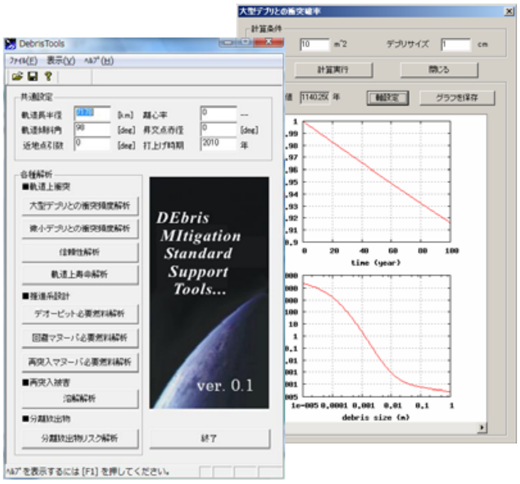

Fig.-2 Example of user interface in DEMIST

A study to identify points of agreement among the world debris environment models was conducted and reported to ISO, IADC, and other international bodies. Results revealed that the distribution of small debris in LEO differs among those models. Particularly, the size range of a hundred micrometers to several millimeters (Annex-B) differs among them. Results indicate the necessity of more intensive research on small debris. Recently, JAXA has begun a basic study to develop in-situ measurement devices to detect small debris ranging from a hundred micrometers to several millimeters.

(3) Hyper-velocity impact testing

A shaped-charge impact device was designed. Then the correlation between tests by shaped charge impact devices and a two-stage gas gun was assessed to improve design standards for protection against debris impact. In addition, correlation between low-speed impacts and high-speed impacts was analyzed. The analysis tool was improved using these results. .

Kyushu University and the NASA Orbital Debris Program Office have collaborated on a series of impact tests on micro satellites. Three target satellites of approximately 1,300 grams each were used for these tests. The impact speed was about 1.7 km/s; the ratio of impact kinetic energy to satellite mass for the three tests was about 40 J/g. Impact phenomena were captured using an ultra-high speed camera. The fragments numbered approximately 1,000–1,500, depending on the impact angle to inner layers. Details of these three tests and results of preliminary analyses will be presented at the COSPAR

Scientific Assembly to be held in Montreal, Canada in July 2008.

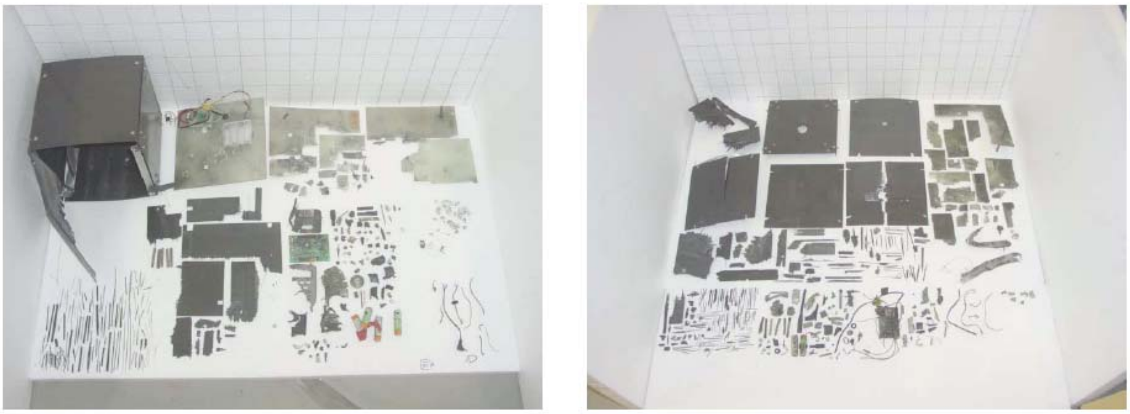

Fig.-3 Major fragments generated in impact tests

(4) Electro-dynamic 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 concept that “every new launch should be accompanied by removal of another spent satellite” might be an acceptable future agreement. A technical solution would be the electrodynamic tether system, which slows unused space objects and reduces their orbital lifetime. **Annex-C** presents recent results of research and development activities related to electrodynamic tether systems aimed at on-orbit demonstrations in JAXA.

(5) Mission assurance and safety

Since 1999, JAXA has controlled the launch window for all launches to avoid causing close approaches to manned orbital vehicles. During the past two years, two among seven launch operations were determined specifically to shorten launch windows.

For major operating satellites, JAXA researchers are studying Collision Avoidance Maneuvers (CAMs) for use against orbital debris. Catalogued data for orbital objects are provided by the U.S. government. Conjunction prediction is monitored daily. In cases where a high collision probability is predicted, more accurate radar observation is conducted. The decision to conduct CAM would be made if the exact distance between two objects were obviously dangerous. During 2006, JAXA experimented with some observations using radar; JAXA is preparing a CAM rehearsal at the beginning of 2008.

(6) Assessment of debris mitigation measures

For all projects, JAXA imposes the Debris Mitigation Standard and ensures that no mission-related objects are released. Moreover, orbital break-ups are prevented through design and operations, as well as removal of spacecraft from useful orbital regions after mission termination. Compliance with the standard is reviewed at each lifecycle phase as a part of System Safety Program activities.

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

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Space debris observation on the ground

The Institute of Aerospace Technology (IAT) 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 photographed using the above telescopes. Figure 3 portrays an example obtained using the software.

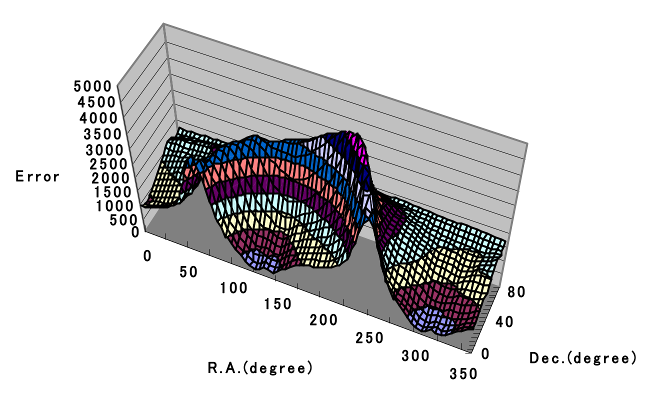
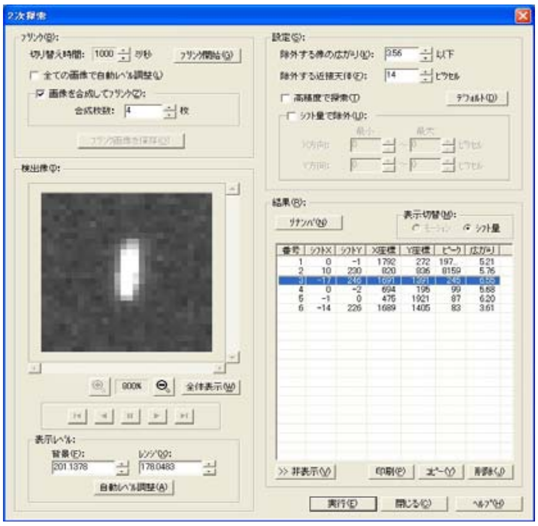


Fig. 1 The error distribution of rotation axial direction in the sky for a LEO debris, a Cosmos 2082 rocket body, which was obtained from its light curve. The analysis of the light curve of the LEO debris indicates that the directions are R.A.=305.8-degree and Dec.=2.6-degree.

Fig.2 Nyukasayama Observatory of IAT/JAXA.



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☐ 全ての画像で自動レベル調整(L)
☑ 画像を合成してブリンク(Z):
合成枚数: 4 枚
表示レベル:
背景(F): 201.1378
レンジ(Q): 178.0483
除外する像の広がり(W): 3.56 以下
除外する近接天体(E): 14 ピクセル
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番号	シフトX	シフトY	X座標	Y座標	ピーク	広がり
1	0	-1	1792	272	197	5.21
2	10	230	820	836	8159	5.76
3	-17	246	1691	1391	245	6.55
4	0	-2	694	195	99	5.68
5	-1	0	475	1921	87	6.20
6	-14	226	1689	1405	83	3.61

Fig. 3 Example of GEO Debris Automatic Detection software

Annex-B
Comparison of Debris Environment Models: ORDEM2000, MASTER2001 and MASTER2005

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Yukihito Kitazawa (IHI Corporation /JAXA) and Tateo GOKA (JAXA)

World space agencies in advanced countries have Space Debris Environment Models to estimate debris flux as a function of the size, relative impact velocity, and impact angle. However, it is known that the results acquired from those models are not entirely consistent. Therefore, an international standardized process is necessary to implement those models depending on their characteristics. Japan proposed development of such a standard to a space-related ISO committee.

During the first step in developing an international standard, a clear discrepancy was found among models, particularly in flux for small debris of less than 1 mm. As shown in Fig. 1, comparison among the major three debris models, NASA-ORDEM2000, ESA-MASTER2001, and MASTER2005, the debris impact flux in low Earth orbit are different according to the size of debris > 100 μm and > 1 mm (Fig. 2).

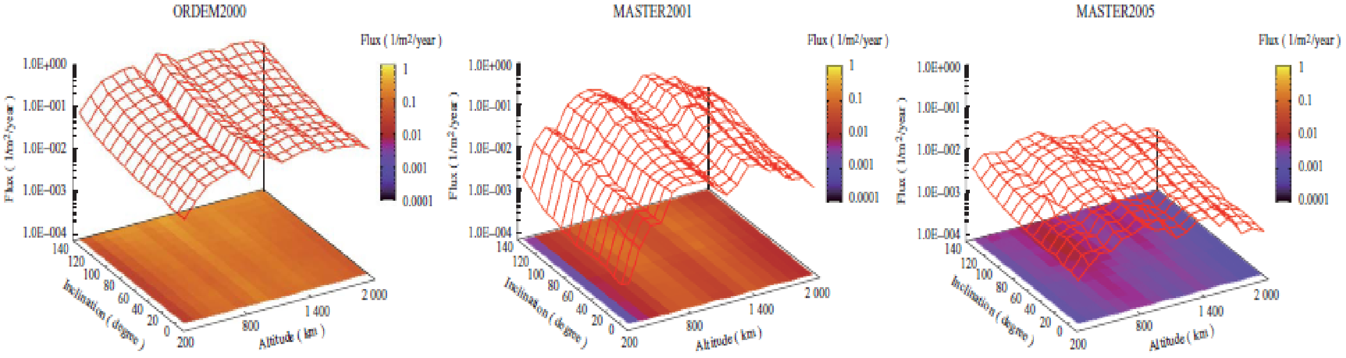
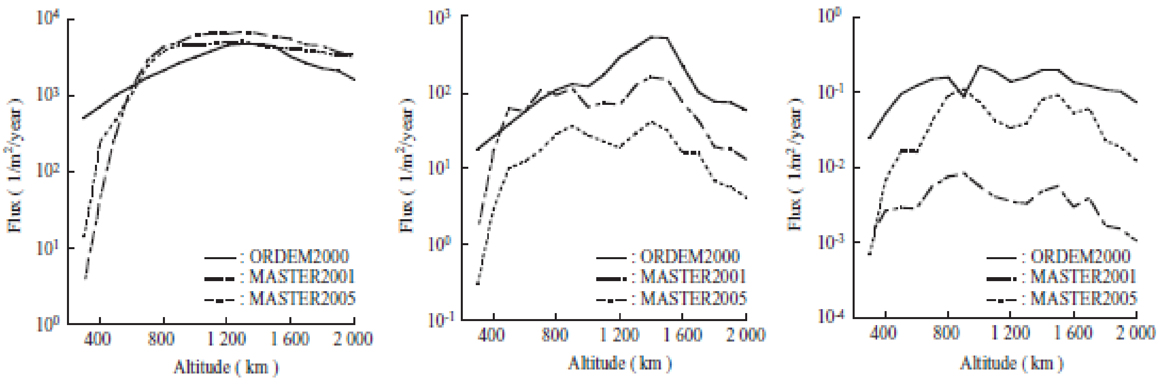


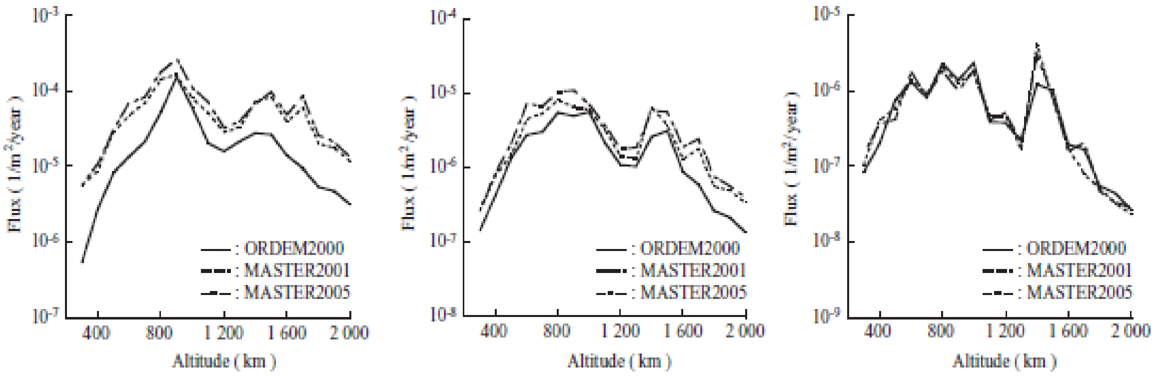
Fig. 1 Examples of flux calculation results of the three models against altitude and inclination (Object diameter > 100 μm)



(a) Debris diameter > 10 μm

(b) Debris diameter > 100 μm

(c) Debris diameter > 1 mm



(d) Debris diameter > 1 cm

(e) Debris diameter > 10 cm

(f) Debris diameter > 1 m

Fig. 2 Flux against altitude at an inclination of 100 deg

Annex-C

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

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Overview

The 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.

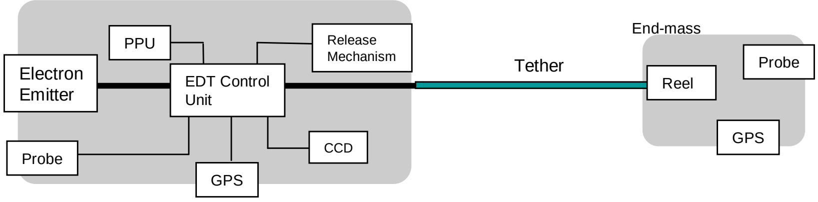

Fig. 1 Typical configuration of electrodynamic tether system.

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.

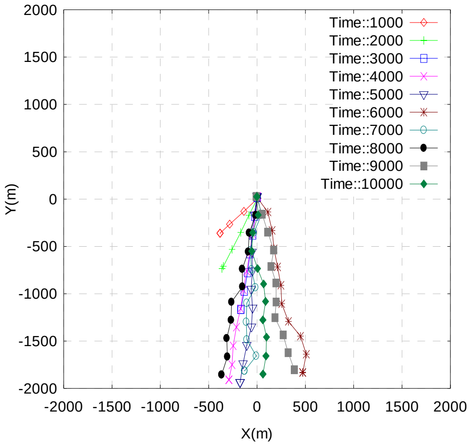

Fig. 2 Typical result of numerical simulation on tether deployment.

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.

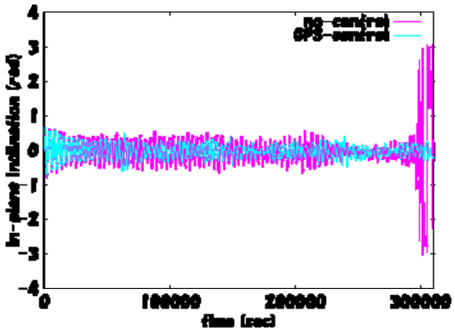

Fig. 3 Change in the in-plane libration angle of the tether with and without control using GPS.

(a) Braided tether

(b) Mesh tether

Fig. 4 Bare tethers.

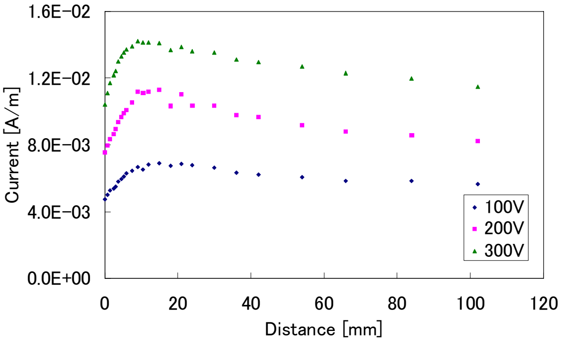

Fig. 5 Electron current collection by parallel bare tethers. Collection currents are plotted against the distance between the tethers.

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.

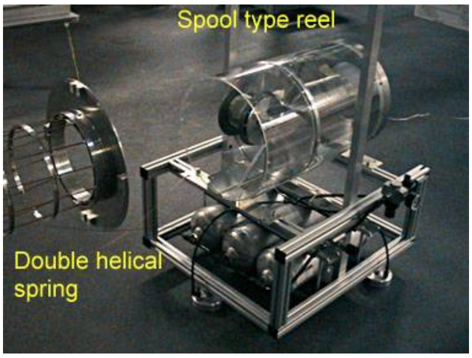

Fig. 6 Tether deployment test on air table.

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.

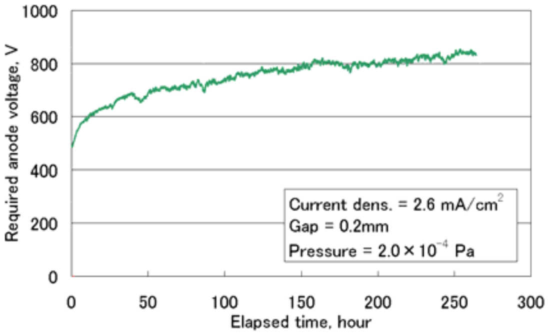

Fig. 8 Endurance performance of carbon nanotube cathode in an oxygen environment. Voltage required for constant-current-emission against elapsed time.