# ACTIVITIES ON SPACE DEBRIS IN JAPAN

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## ABSTRACT

Recent space debris related activities in Japan are briefly reviewed in this report. They include a discussion of the recent status of the planned Equatorial MU radar of Kyoto University, CRL's optical observation system, GEO environment modeling at Kyushu University, shaped charge hypervelocity impact tests and their associated hydrocode analysis, shield design for the Japanese Experimental Module (JEM) of Space Station Alpha, and NASDA's Space Debris Mitigation Standard which was established in March 1996. Some representative results from the post-flight impact analysis of SFU are also presented.

## 1. INTRODUCTION

The collision hazard in space is no longer an abstract problem, but a real and serious threat, as illustrated by the collision between the French satellite CERISE with a fragment of the Ariane third stage on July 24 1996 [1][2].

One of the world's earliest warnings about the possibility of satellite collisions was made in Japan in 1971 by M. Nagatomo and his colleagues of the Institute of Space and Astronautical Science (ISAS)[3]. Since that time, independent research on space debris has been carried out by various organizations in Japan. However, no systematic or organized activities were performed until 1990, when the Japan Society for Aeronautical and Space Sciences (JSASS) founded the Space Debris Study Group [4]. The Study Group, consisting of over 30 members from space related organizations and industries, issued an interim report in January 1992 and a final report in March 1993. Some of the recommendations presented in the report have been taken up by the three newly formed JSASS Study Groups.

Japan (NAL, NASDA, ISAS, and other space related organizations) has also been a member of the Inter-Agency Space Debris Coordination Committee (IADC) since 1992, and maintains a level of debris awareness by means of information exchanges and discussions held at the IADC, IAF, COSPAR, ISCOPS and other international and domestic conferences.

In this report a brief overview of recent research progress in Japan is presented, with emphasis on the post-flight analysis of the Space Flyer Unit, modeling of the GEO debris environment and hypervelocity impact tests with their associated computer simulations.

## 2. SPACE DEBRIS MEASUREMENT

### 2.1 Optical observation

Optical observations of geostationary objects have been made by the Communication Research Laboratory (CRL), utilizing an optical observation system in Koganei, Tokyo (35.42° N, 139.29° E). It consists of a 1.5 m telescope, a peltier cooled CCD camera with the chip size of 1242 x 1152 pixels, an image processing computer and other scientific and communication equipment. The system was originally built as a fixed ground station for space communication experiments using geostationary satellites. At CRL objects as small as 20 cm can theoretically be observed at GEO altitudes. It is therefore expected to make a major contribution to an international cooperative project to measure the debris population in and around Geostationary Orbit (GEO).

As a collaborative study with the National Space Development Agency of Japan (NASDA), the National Astronomical Observatory in Japan (NAO) has been conducting observations of the GEO satellites since 1992, using the Schmidt telescopes of the Kagoshima Space Center (KSC) of ISAS(31.13°N, 131.04°E) and the Kiso Observatory of University of Tokyo(35.48°N, 137.38°E). The use of other telescopes in Japan is also found to be promising. For more detailed and long lasting observations, however, a dedicated debris observation system will be required. JSASS and NASDA have been conducting joint studies on a GEO satellite to detect space debris in GEO since July 1995. Even a small satellite equipped with a camera could provide data on small GEO objects which are very difficult to detect with present technology.

### 2.2 Radar Observation

Space debris monitoring by means of a bistatic radar system has been studied by T. Takano and his group at ISAS. They have successfully demonstrated the applicability of this system in the observation experiment of "Yokoh", which is a scientific satellite with a mass of 420 kg deployed in a circular orbit of

600km altitude and 31.3° inclination. In the experiment they used the 20 m diameter antenna at KSC as a transmission station and the 64 m diameter antenna at the Usuda Deep Space Center (UDSC) of ISAS (36.13° N, 138.37° E) as a receiver station. The distance between the two stations is about 1000 km. By means of modern communication technology, objects as small as 2 cm at 500 km altitude can be detected.

Debris observations have been made by T. Sato at Kyoto University utilizing the Middle and Upper atmosphere (MU) radar. The MU radar is a monostatic pulse Doppler radar operating at 46.5 MHz with an active phased array antenna 103 m in diameter and peak output power of 1 MW. The large output power and large antenna size compensate for the reduced sensitivity at this lower frequency. It has roughly equal sensitivity for detecting space debris as the radars used for USSPACECOM catalogue maintenance. The greatest advantage of the MU radar is its fast beam steerability, which makes it possible to observe the radar scattering cross-section (RCS) variation of unknown objects for a period of 20 seconds and to observe in different directions almost simultaneously. The Kyoto University group has been planning to construct the Equatorial Radar system (a VHF Doppler radar system for observing the Earth's entire atmosphere up to 1000km altitude) at Bukittinggi (0.5° S,100.5° E), West Sumatra, Indonesia, with cooperation from other countries [5]. As a preliminary step, the Portable Atmospheric Sounding System (PASS) is planned, which will provide similar capabilities as the first stage of the Equatorial Radar, whose construction plan is still indefinite, but at a substantially lower cost. The first stage plan is a 47 MHz monostatic Doppler radar with an active phased array. The peak power is 1 MW, and the antenna diameter is 100 m. The second stage plan consists of 2,736 Yagi antennas with a total peak power is 2.7 MW, and a diameter of 291m.

## 2. 3 Post-Flight Analysis

The JSASS study group, the National Aerospace laboratory (NAL) and other organizations are jointly performing the post-flight analysis of the Space Flyer Unit (SFU). SFU is an unmanned, re-usable, sun-pointing, 3-axis stabilized satellite, and constitutes the first of its kind built by Japan. It is octagonal in shape, consisting of 5 modular payload units, two special payload units and one module designed to support the Infrared Telescope (IRTS). It measures 4.46 m in diameter and 3 m in height, and weighs about 4 tons. It was deployed in circular orbit at an operational altitude of 480km and an inclination of 28.5° by the H-II third flight on March 18, 1995 and was retrieved by Shuttle STS-72 on January 13 1996. During retrieval, the two solar array panels with a total tip-to-tip length of 24.4 m and a width of 2.36 m were jettisoned owing to a failure of the latching mechanism.

On retrieval of the satellite, a post-flight analysis programme was immediately commenced by means of a visual inspection and routine ground operations at Kennedy Space Center (KSC), including hydrazine safing. Some payload disintegration was performed at this stage for shipping back to Japan.

In total some 20m$^2$ of exposed surfaces are available on SFU for analysis. The main surfaces consist of muti-layer insulation (MLI), second surface mirrors (SSM) and the painted aluminum alloy structure.

Impact surveys are making good progress and preliminary results are summarized as follows:

a) No significant outgassing or offgassing have been detected.
b) 337 impacts with diameters greater than 200 μm have been observed in visual surveys.
c) 180 impacts with diameters greater than about 200 μm have so far been observed in high-resolution surveys of some of the surfaces.
d) The largest impact site is located on IRTS payload MLI. The diameter of maximum damage is about 13.4 mm, with an impact crater diameter of 2.5 mm.

A high-resolution image of a typical impact on SSM material is shown in Fig. 1, corresponding to the payload unit PLU-4. Detailed surveys are continuing at NAL, and results are due to be presented at this meeting [6], and future international meetings [7].

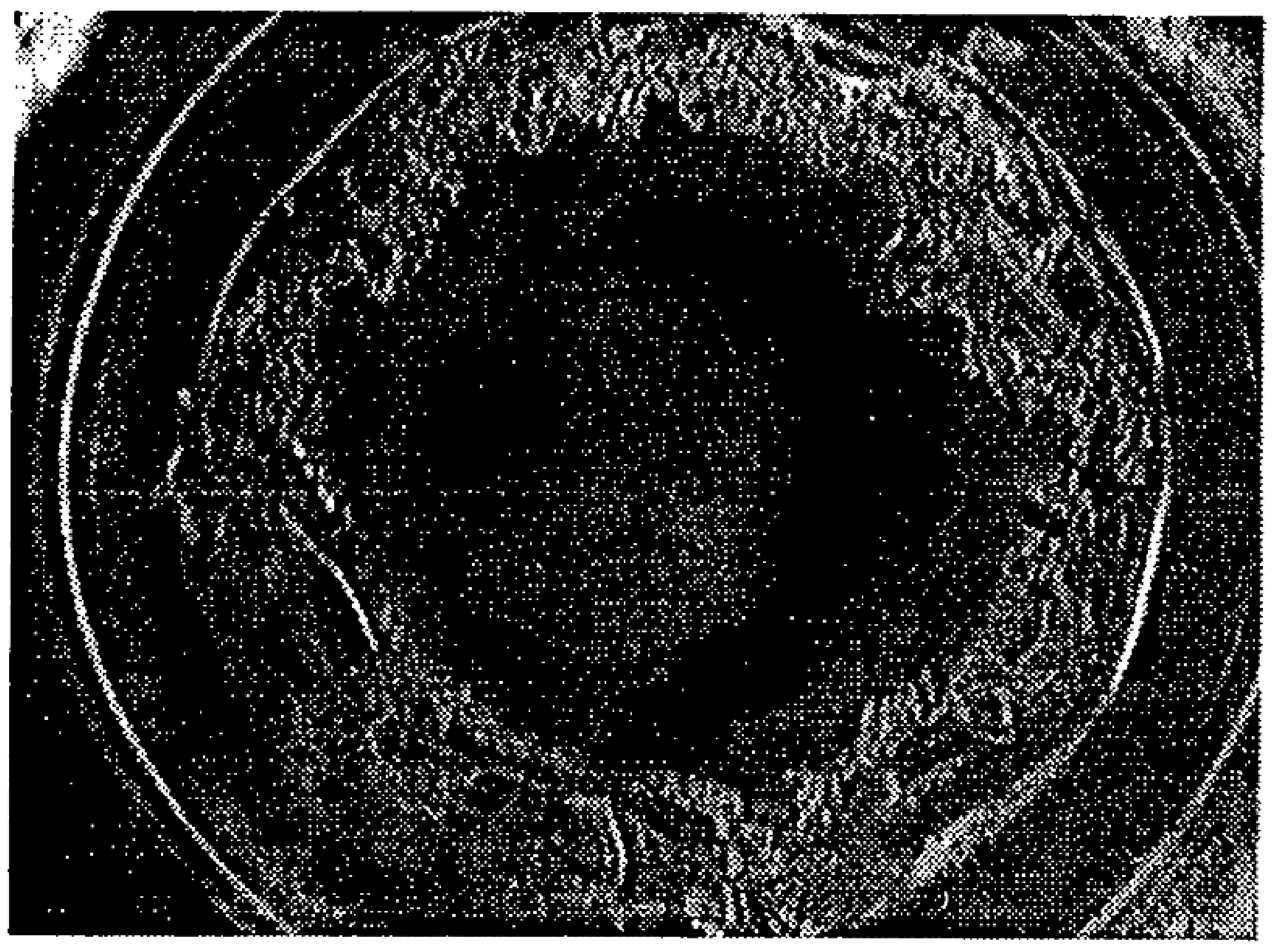


Fig.1 Impact onto PLU4 SSM
(Lip diameter ~ 200 μm)

A verification test for the manipulator system of the Japanese Experimental Module (JEM) of International Space Station Alpha (ISSA), known as the Manipulator Flight Demonstration (MFD), is planned to be flown and performed on board Space Shuttle flight STS-85. The Parts and Materials Laboratory of NASDA are planning to take this opportunity to fly their Experiment of Space Environment on Materials experiment (ESEM) on the same flight. It will be mounted on top of the MFD experimental apparatus in the Shuttle payload bay and will be exposed in the Shuttle flight direction for 40 hours. This programme is slated for July 1997.

## 3. MODELING OF SPACE DEBRIS ENVIRONMENT

Space debris modeling is important for design specification, design cost reduction, predictions about the future environment and mitigation plan establishment. Modeling studies of the debris population in LEO were performed by M. Nagatomo and his group at ISAS [3][8]. They obtained the debris flux as a function of altitude by considering objects in the same group of ballistic coefficient is considered as a continuum whose density corresponds to the number of orbiting objects. Their results showed that the debris flux peaks at the altitudes of 1000 km and 1500 km, and that the flux at these altitudes in the year 2000 will be twice the 1982 value of about $10^{-5}$ objects/($m^2$year).

In GEO, no fragments have ever been tracked, even though there have been at least three explosions: a Russian Ekran communications satellite and two Titan Transtages. Models are therefore important for understanding the dynamics and behavior of the GEO debris environment. T. Yasaka and his group at Kyushu University have been conducting extensive studies using various models for the GEO environment. They are conducting experimental and theoretical studies on low velocity impact fragmentations in order to derive a GEO breakup model. Fig. 2 shows typical test results which show that the fragment mass distribution follows a power law. Using this mass distribution, and making several assumptions, the dispersion of fragments was simulated [9].

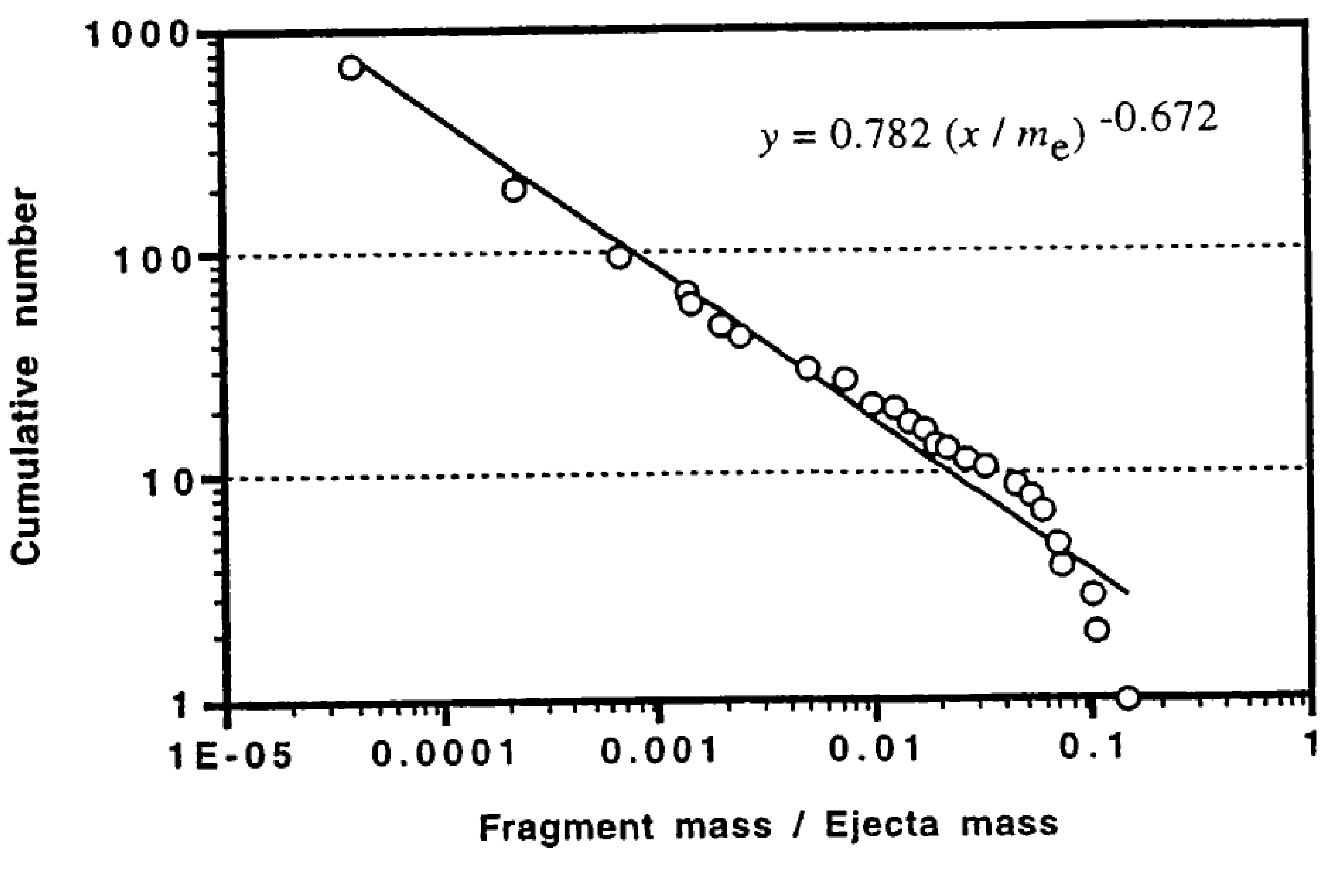


Fig.2 Cumulative Mass Distribution of Fragments at Low Speed Impact

They have also been investigating object accumulation model in GEO. The estimated number of objects that routinely cross the geostationary band, including operational satellites whose maximum population is assumed to be 1,000, is shown in Fig. 3 (several assumptions need to be made in advance) [10]. It shows that the most significant parameter is the explosion rate, followed by the rate of reorbit at the satellite end of life. Therefore passivation measures for spacecraft are necessary to reduce the possibility of explosions in GEO. In this context, reorbiting maneuvers into a graveyard orbit will be effective in both exhausting remaining propellants and minimizing the probability of collision with other satellites.

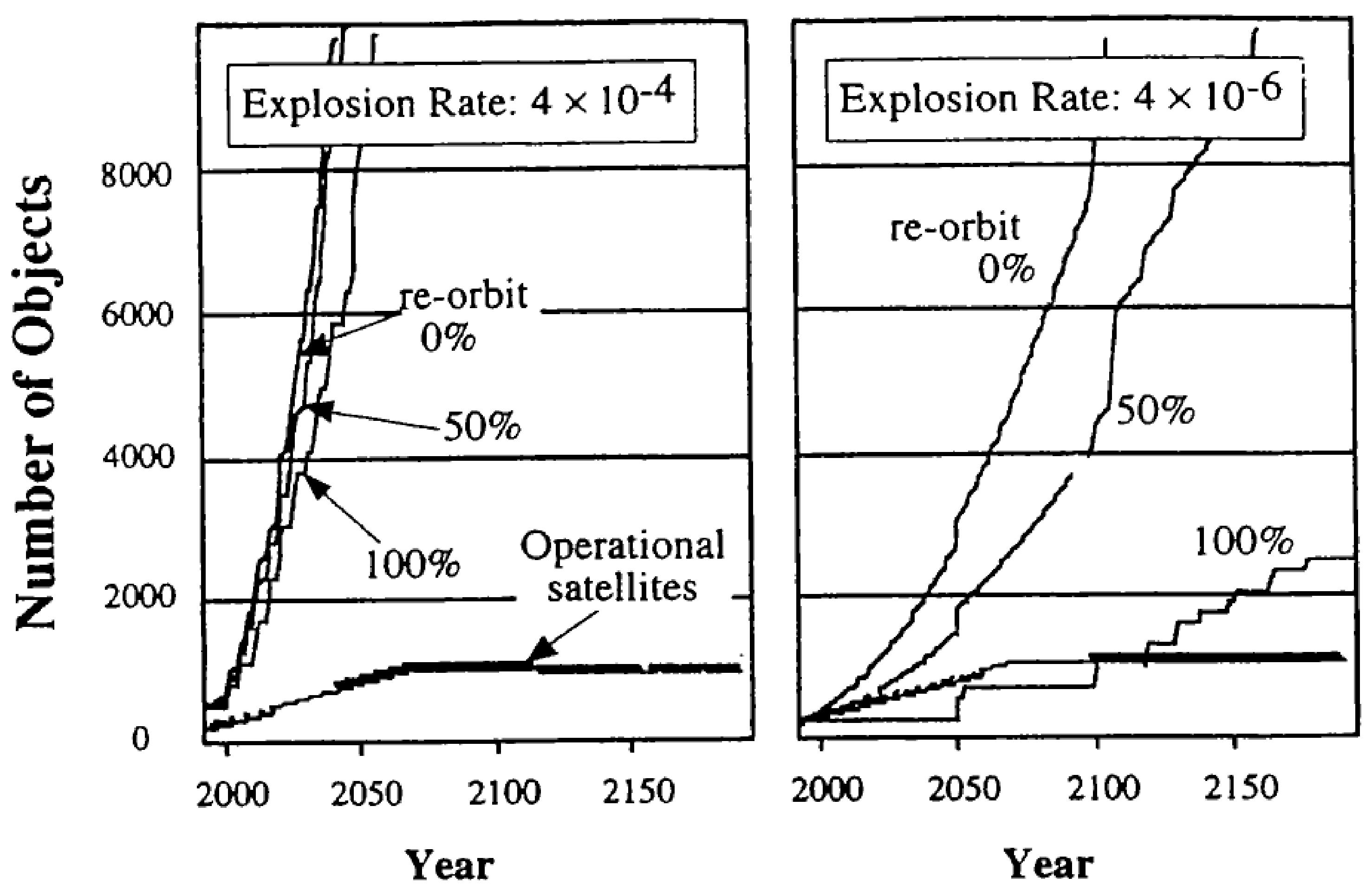


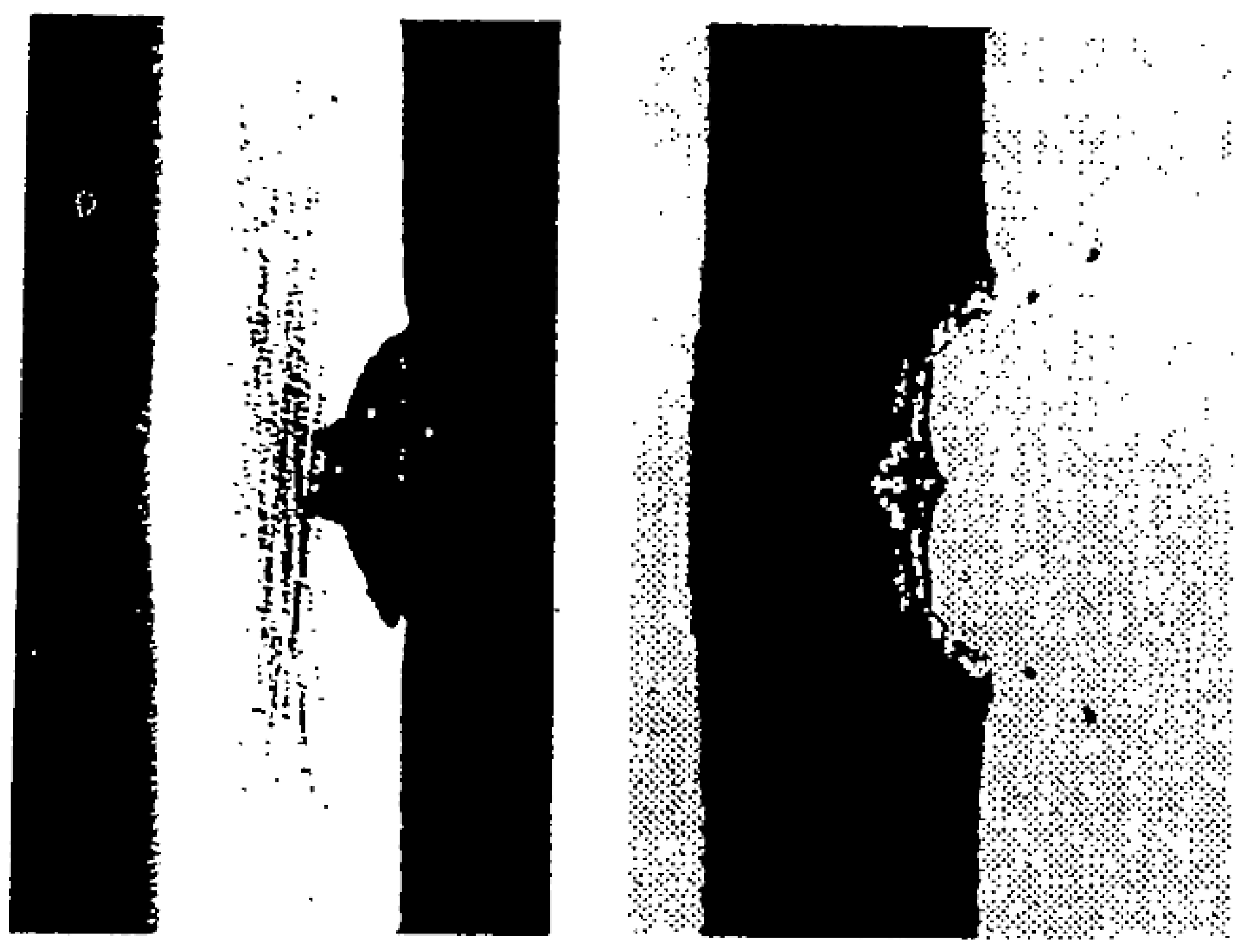
Fig.3 Object Number Growth in GEO

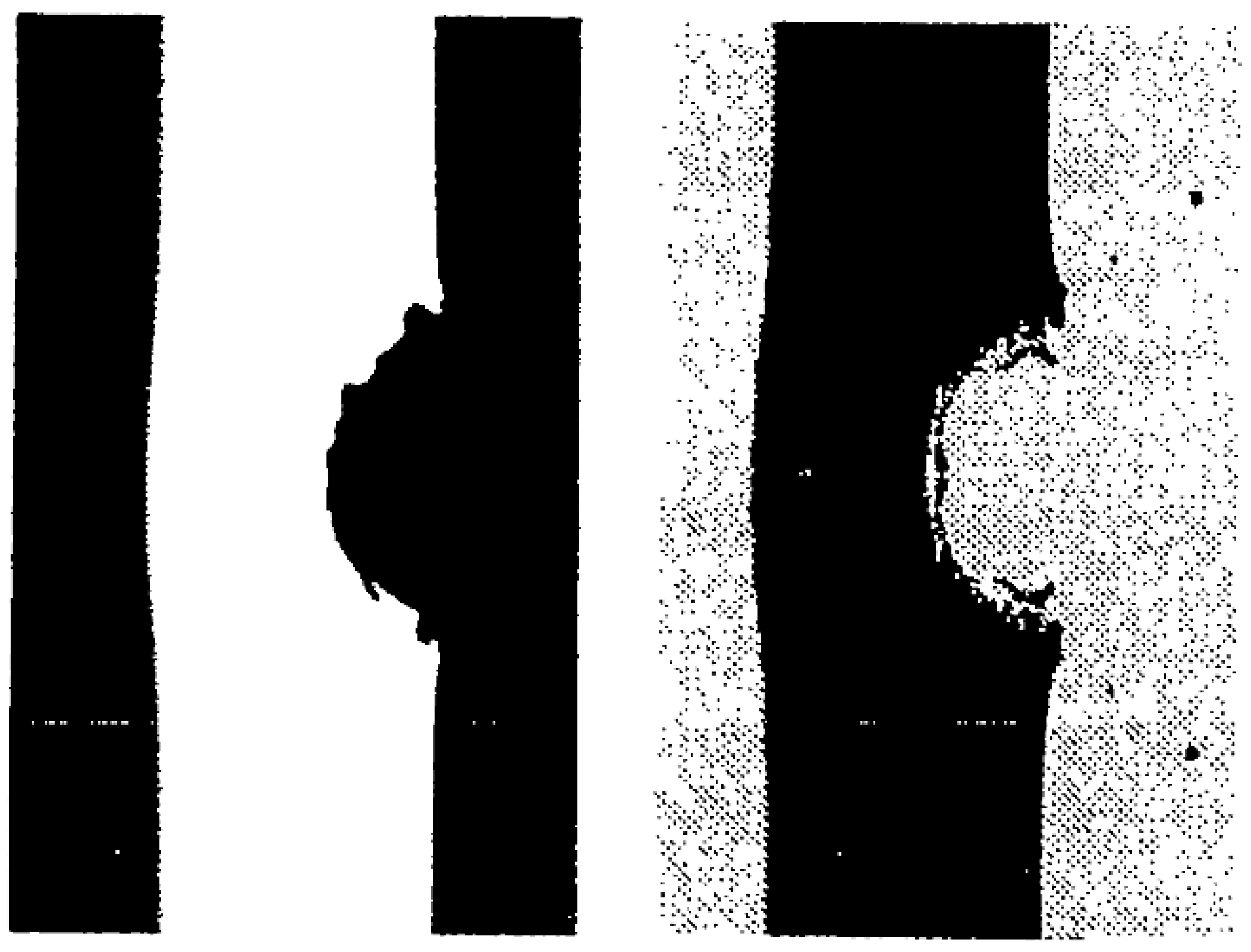
## 4. HYPERVELOCITY IMPACT RESEARCH

The main hazard of space debris is their high impact velocity. The orbital velocity of objects in Low Earth Orbit (LEO) is about 7.5 km/s. The relative impact velocity between two objects depends on the angle of intersection of the orbits and is estimated to be about 10-13 km/s on average. Impacts occuring at these velocities are "hypervelocity impacts" and can result in severe damage or even total breakup of spacecraft if they are hit. Hypervelocity impact research, therefore, is important not only for designing protective shields for spacecraft but also for developing basic hypervelocity impact science and understanding debris creation and dispersion phenomena.

NAL has been conducting hypervelocity impact research in collaboration with various organizations in Japan. Experimental studies have been performed using three types of launcher systems for accelerating the projectiles to the three different impact velocities, but with comparable kinetic energy: (1) a powder gun to accelerate 14g projectile up to about 2.2 km/s, (2) a two-stage helium light-gas gun to accelerate 3.7 g projectile up to about 4.0 km/s, and (3) a rail gun to accelerate a 1.0 g projectile up to 7.5 km/s. Theoretical studies are also being conducted extensively using a two-dimensional hydrocode model based upon the explicit finite difference method. The typical experimental and numerical results for an aluminum alloy monolithic plate 38.9 mm thick are shown in Fig.4 [11].

Shaped charge explosive launching systems are also being studied at NAL in collaboration with MHI and Chugoku Chemicals. The objectives of shaped charge study are to investigate hypervelocity impact phenomena and to validate hydrocode results to velocities in excess of 10 km/s. The charges used are 7.0 cm in diameter and 14.7 cm in length; the liner angle is 30 degrees, and the thickness of the aluminum liner is 2.1 mm. The copper inhibitor, which has a hole diameter of 20 mm, was selected through intensive parametric studies of both the inhibitor method and reactive plate method. Using this inhibitor, a single cylindrical jet without a trailing jet was obtained. The mass of the tip jet is about 1.9 g, and the velocity obtained is about 10.6 km/s [12]. The comparison of numerical and experimental results is tobe discussed at the session 3 in this meeting [13].


Experiment Computation
(a) mass=14.0g, velocity= 2.16km/s


Experiment Computation
(b) mass=3.65g, velocity=3.99km/s

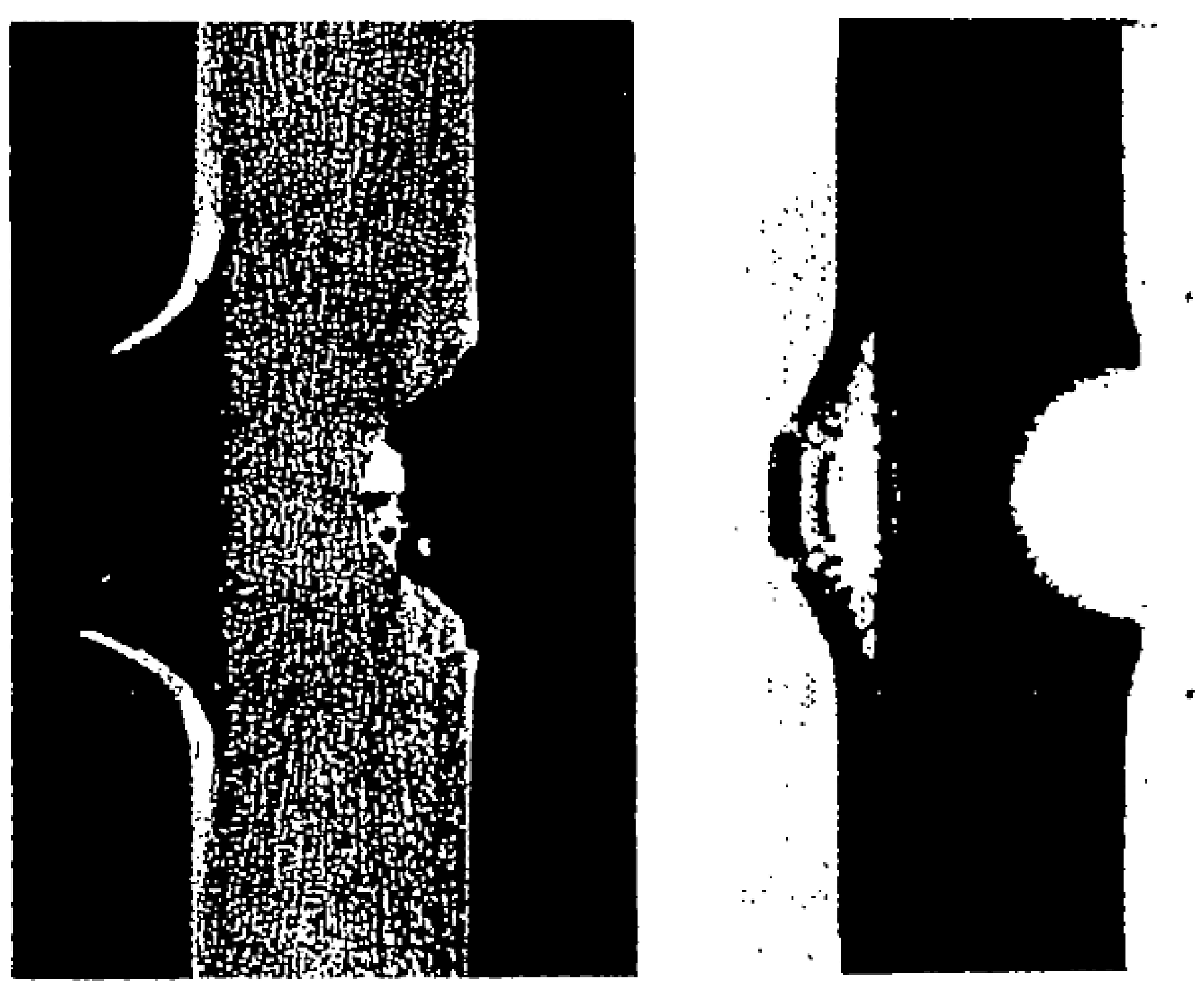

Experiment Computation
(c) mass=0.94g, velocity=7.45km/s

Fig.4 Impact Damage on 2024 Aluminum plates.

A series of hypervelocity impact tests is also being conducted as part of the SFU post-flight analysis programme in order to calibrate the various materials. An empirical law describing hole size as a function of particle parameters, such as size, mass and velocity, is highly desirable, particularly for the SFU materials in question, since their behaviour in the hypervelocity impact regime is not well understood at present.

NASDA has conducted a series of impact tests, using a two-stage hydrogen light-gas gun, for the design of the JEM stuffed Whipple bumper and for a carbon fiber reinforced plastic tube to be used on the arm of the JEM Remote Manipulator System [14].

## 5. SPACE DEBRIS REDUCTION PRACTICES

NASDA has implemented the draining of residual propellants (LOX, LH2, N2H4) and residual helium gas of the H-I/H-II second stage. The release of mechanical devices at satellite separation and solar paddle deployment has been avoided except in some particular missions such as the separation of spent apogee motors for the geostationary meteorological satellite. In order to prevent the unintended destruction of H-II second stages in space, the command destruct system is disabled immediately after injection into orbit and its pyrotechnics are thermally insulated to prevent spontaneous initiation.

The number of objects in geostationary transfer orbits (GTO) is increasing; they are considered to be hazardous for the future space activities because of their long orbital life. An effort is currently being made to decrease the orbital life of the H-II second stage [15]. The second stage (1994-056B) of the H-II second flight of August 28, 1994, for instance, was deorbited from the ETS-VI GTO with an apogee of 36,346 km and a perigee of 251 km to GTO with an apogee of 32,298 km and a perigee of 150 km by performing an idle mode burn and depleting residual propellants [8][9]. This measure resulted in the orbital life of the ETS-VI H-II second stage (1994-056B) being reduced to about 7 months (It re-entered on March 31, 1995).

In 1985, NASDA began reorbiting GEO satellites after their end of life (EOL). At present the target is to inject defunct satellites into an orbit at least 250 km higher than the GEO band.

Measures to limit space debris generation must be developed and implemented on a multilateral basis by the spacefaring nations. The JSASS committee on space debris prevention design standards published their final report [16] for NASDA standards and design criteria in March 1996. Based on this report, NASDA established the NASDA-STD-18 "Space Debris Mitigation Standard" on March 28, 1996 [17]. A comparison of the guidelines and assessment procedures developed in the NASA Safety Standard 1740.14 and the NASDA Standard 18 was discussed at the 20th International Symposium on Space Technology and Science, Gifu, Japan, May 19-20, 1996 [18]. Details of the standard are to be presented by A. Kato of NASDA at this meeting [19].

## 6. CONCLUSION

Space environment conservation with respect to space debris is necessary to ensure long-lasting and safe human space activities. Japan will aim to develop such systems that will leave as little space debris as possible. With regard to existing space debris, Japan will cooperate with other countries in considering ways of reducing it. With the aim of serving to protect the space environment and sharply reducing transportation costs, Japan will proceed with advanced R&D activities focusing on the design of new fully-reusable transportation vehicles based on novel design concepts by upgrading the results of the development of an advanced H-II launch vehicle and HOPE technologies [20].

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