Future Effort of Ministry of the Environment to Address Space Debris Issues
Interim Summary

Ministry of the Environment Internal Review Team on Space Debris Issues

1. Aims and Background to Ministry of the Environment efforts to address space debris issues

(1) Aims

The greenhouse gas observation project utilizing the GOSAT series commenced in 2009. It is considered an international public good necessary for monitoring progress towards the targets of the Paris Agreement. The project has received international acclaim and it is hoped that it will continue.

The Basic Plan on Space Policy, instituted following a Cabinet decision in June 2020, highlighted the growing importance of space systems as a type of societal infrastructure. The plan also highlighted the significant roles these systems can play in addressing global challenges such as issues relating to energy, climate change, the environment, food security, public health, and major natural disasters, as well as the importance of leveraging their wide-ranging capabilities to contribute towards achieving the United Nations Sustainable Development Goals (SDGs).

The increase in the volume of space debris in recent years has, however, become a major source of concern regarding the ongoing uninterrupted use of space. The Basic Plan on Space Policy also includes provisions for space debris mitigation measures, such as the measures required for decommissioning defunct government satellites.

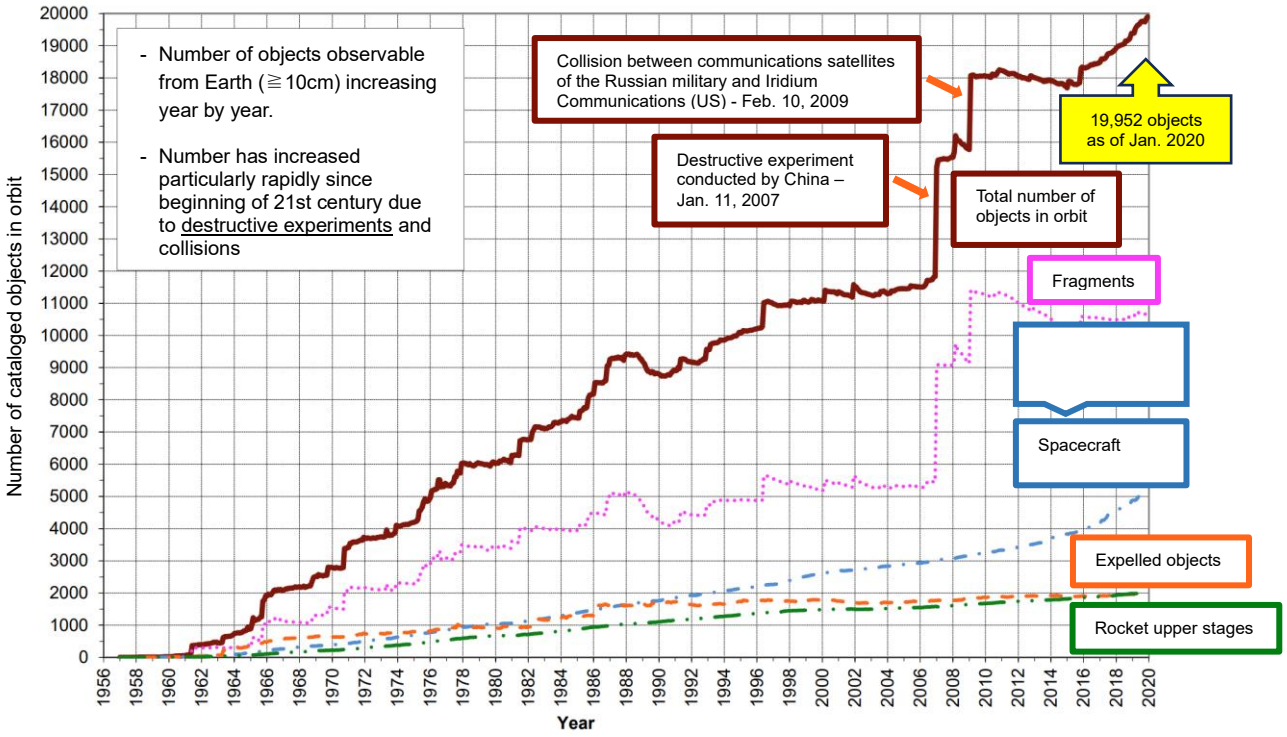
As leader of the project to carry out greenhouse gas observation utilizing the GOSAT series, the Ministry of the Environment is responsible for the proper operation and disposal of the satellites, and it is preferable that the ministry takes on the responsibility for their proper disposal.

As the first step towards this, the ministry established an internal review team in March 2020 to gather and share information regarding the ongoing uninterrupted utilization of space, and space debris mitigation measures for the GOSAT-1 satellite, which had been in orbit for 11 years. This team examined measures in collaboration with relevant organizations, including the Japan Aerospace Exploration Agency (JAXA).

(2) Current space debris situation and related threats

“Space debris” is a general term for manmade objects remaining in orbit after they are no longer required. More specifically, this includes defunct or malfunctioning manmade satellites, the upper stages of rockets, components released during missions, fragments resulting from explosions or collisions, and solid rocket motor slag (post-burn residue).

The number of space objects in orbit has increased over the years, and the increase has been particularly rapid since the beginning of the 21st century as a result of destructive experiments and collisions. Currently, there are approximately 23,000 objects in orbit that can be observed from Earth (approximately 10cm in size or larger). Of these only about 6% are operational satellites, with the rest presumed to be debris.



Observational limit (nominal value): Low-orbit objects ≧10cm, geostationary orbit objects ≧1m

Source: NASA Orbital Debris Quarterly News, Volume 24, Issue 1, February 2020

Figure 1. Number of objects in orbit published by the United States based on terrestrial surveillance data

The number of launches conducted by private companies is increasing, including launches of small and mini satellites in large constellations. If appropriate decommissioning measures for post-operational satellites are not implemented, the low-Earth-orbit zone will become even more congested, and it is predicted that the number of space debris objects will continue to increase.

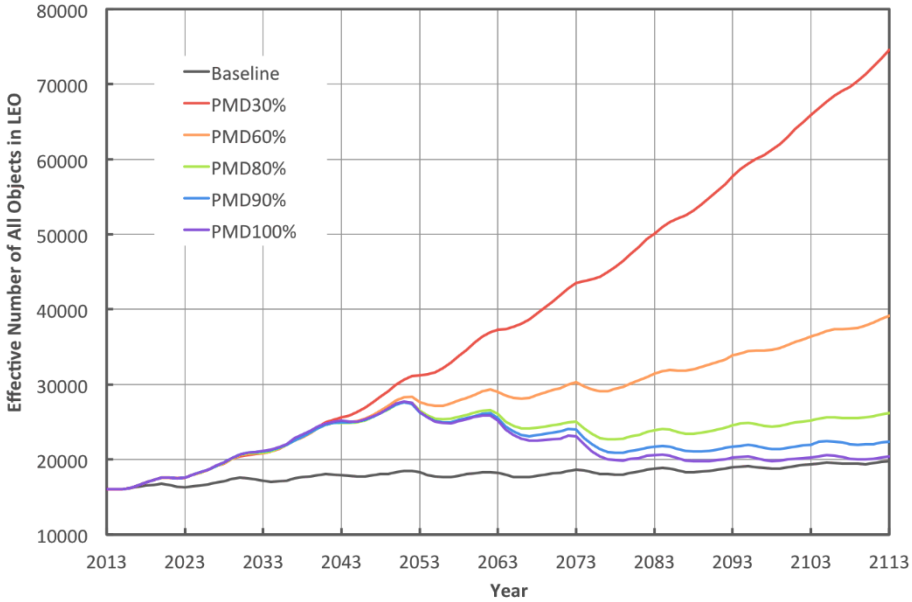


Figure 2. Predicted number of low-Earth-orbit debris objects for each successful post-mission disposal (PMD) probability

Source: JAXA

One collision avoidance maneuver has been carried out for GOSAT-1 during its 11 and a half years of operation, due to an increase in space debris that is expected to continue. Two collision avoidance maneuvers have been performed for GOSAT-2, during its approximately two years of operation since being launched in October 2018.

(3) **Current Initiatives and Challenges in Japan and Abroad**

(International initiatives)

Discussions on space debris mitigation measures have been held by the Inter-Agency Debris Coordination Committee (IADC), a committee composed of representatives from the space agencies primarily of advanced countries. The IADC was established as a platform for discussions among researchers focusing on space debris. In 2002, the committee issued **the IADC Space Debris Mitigation Guidelines**. Building upon these guidelines, **the United Nations Committee on the Peaceful Uses of Outer Space (COPUOS)** has been engaged in discussions on research assistance, information sharing, the establishment of laws and principles, and other matters relating to space activities. In 2007, the committee issued **the COPUOS Space Debris Mitigation Guidelines**, and these stipulate that the latest version of the IADC Space Debris Mitigation Guidelines are to be referred to.

COPUOS Space Debris Mitigation Guidelines stipulate:

- The limitation of space debris released during operations, minimization of the potential for break-ups, restriction of the probability of accidental collisions in orbit, avoidance of intentional destruction and other harmful activities.
- Minimization of the potential for post-mission break-ups, limitation of the long-term presence of spacecraft in low-Earth orbit, and limitation of the long-term presence of spacecraft in geosynchronous Earth orbit.

These guidelines **cover newly launched satellites. They lack legal binding force and rely on voluntary efforts by each country.** It is therefore crucial to promote understanding and international cooperation, including among new commercial entrants to the space industry.

The International Organization for Standardization (ISO) established the ISO 24113 “space debris mitigation requirements” for satellites in 2010. In 2019, revisions were made, which included incorporating requirements for satellites already in operation.

(Domestic initiatives)

In Japan, **the Act on Launching of Spacecraft, etc. and Control of Spacecraft** (Act No. 76 of 2016; **commonly known as the “Space Activities Act”**) stipulates space debris mitigation measures for future satellite launches. This means that Japan already has in place legislation that is in compliance with international rules.

Specifically, the conditions for satellite launch permission and the criteria for rocket type certification include measures to curb the creation of orbital space debris and remove orbital insertion stages of rockets from protected areas. Conditions for permission to manage satellites also incorporate space debris mitigation measure requirements for satellite structures, management plans, and end-of-life disposal methods.

While space debris mitigation measures such as those mentioned above are being implemented domestically and internationally, **there are no specific space debris prevention regulations in place regarding the operation and continued use of existing satellites already in operation**. Decisions regarding such matters are left to the discretion of each individual satellite operator.

2. Direction for GOSAT-1 Initiatives

GOSAT-1, the world's first dedicated satellite for greenhouse gas observation, was launched in 2009. Its mission is to capture the global distribution of the key greenhouse gases, carbon dioxide and methane, as well as facilitate the estimation of emission and absorption of greenhouse gases on a subcontinental scale. The satellite is still in operation despite only being designed to remain operational until 2014. The decision to continue operations was made in light of the importance of quantifying the average concentration of greenhouse gases across the entire planet in calculating and predicting the risks of global warming resulting from increases in greenhouse gases. It is the longest-serving greenhouse gas observation satellite in the world. GOSAT-2 was subsequently launched as a successor in 2018, and it has been in constant operation since February 2019.

There are only two greenhouse gas observation satellites that offer the same level of reliability (verifiability) as GOSAT-1 and that provide open, long-term observation data: the U.S. OCO-2 satellite (for carbon dioxide), and the European Sentinel-5P satellite equipped with the TROPOMI sensor (for methane). The scarcity of data like GOSAT-1's greenhouse gas observation data means it is cnsidered to be of exceptionally high value in the global science community. In recent years, with the increased frequency of extreme weather events, which is associated with the climate crisis, the value of such greenhouse gas observation data is considered to have increased not only in the realm of science but also in politics, governance, and in the civic sector.

Given these factors, when considering space debris mitigation measures for GOSAT-1, it is crucial to ensure that not only does GOSAT-1 have space debris prevention measures in place but also rapidly ensure that GOSAT-2 has at least the same capabilities as GOSAT-1, and that it can take over the mission from GOSAT-1, thus ensuring the long-term continuity of observation utilizing the GOSAT series.

Note that GOSAT-1 falls outside the scope of the Space Activities Act since it was launched prior to the act's enforcement. Proactive measures are, however, being considered, including the application of the latest domestic and international regulations and guidelines.

Based on the considerations mentioned above, the space debris mitigation measures for GOSAT-1 can be categorized into the following areas:

(1) Issues to address to mitigate space debris

- The following occurrences need to be prevented in order to curb the increase of space debris:
  a. The release of objects during normal operations
  b. Self-destruction while in orbit.

c. Failure to exit a protected orbital zone after a mission ends
d. Destruction resulting from collisions with other orbiting objects

Since GOSAT-1 is not equipped with any objects that can be intentionally released, space debris mitigation measures should be based on b., c., and d., and should reference the requirements of the IADC Space Debris Guidelines and ISO 24113. These measures can be categorized and organized into two groups: measures for when the satellite's observation operations are underway (observation operations period) and the period from the end of observation operations until disposal (decommissioning operations period).

During the "observation operations period", it is necessary to constantly monitor the satellite's condition to prevent in-orbit self-destruction. In the event of anomalies in the propulsion system or other factors that may lead to destruction, ground control should be able to take action to avoid the risk of breakup. GOSAT-1 already has this capability. Additionally, to prevent destruction due to collisions in orbit, it is important to monitor close approaches with objects whose orbits can be confirmed from Earth. When there is deemed to be a high risk of collision, proactive collision avoidance measures are implemented.

For the period after observation operations end, it's essential to prevent destruction due to residual stored energy. To address this, the satellite is equipped with features to expell remaining propellants and disconnect battery charging circuits. As part of efforts to limit the number of space debris objects in the protected low Earth orbit region, it is preferable to move satellites down to an orbit that will cause them to re-enter the Earth's atmosphere within 25 years from the end of the observation operations period, with a success probability of at least 90%. Previously, reliability was only evaluated during the decommissioning operations period. However, with the revision of ISO 24113 in 2019, the decrease in reliability from the start of operations is also considered, and proper lifetime management is also required for currently operational satellites. Given the importance of post-operation measures, further details on this will be provided in section (3).

(2) **Evaluation criteria for terminating operations of GOSAT-1 (draft)**

GOSAT-1 was launched in 2009, and accomplished its mission requirements by 2014. GOSAT-1 is, however, still operating as the plan is to have the successor satellite take over the mission. The satellite was initially intended to be kept operational for a certain period of time while assessments of the soundness of the satellite's equipment were carried out.

Previously, satellites were not actively disposed of after accomplishing their missions. Satellites have been kept operational while their soundness is monitored, as is the case with GOSAT, but there have been some instances where unforeseen malfunctions have occurred in orbit, leading to satellites becoming inoperative and remaining in orbit as space debris.

Taking such situations into account, a new approach to making judgments about the continued operation of GOSAT-1 to ensure it does not remain in orbit as space debris is to be introduced based on the following considerations:

A) **Continuity of the GOSAT observation mission**
(Assessment of feasibility of transition from GOSAT-1 to GOSAT-2)
It is necessary to determine whether there is a need for GOSAT-1 observation operations to continue. The mission of GOSAT-1, which included measurement of the global concentration distribution of greenhouse gases with high precision within the five-year observation operation period, has been accomplished. Meanwhile, continuous monitoring of greenhouse gas concentrations is crucial for promoting international efforts to combat global warming. It is thought that GOSAT-1's role in this can be ended by transferring the mission of greenhouse gas concentration observation to GOSAT-2, launched in 2018, as its successor. Currently, the National Institute for Environmental Studies (NIES) is working to confirm whether the mission can be continued, and a decision needs to be made taking into account the institute's findings.

B) **Satellite soundness (securing the functionality required for decommissioning measures)**

JAXA is responsible for assessment of satellite soundness, based on a trilateral agreement concerning the development and utilization of the greenhouse gas observing satellite (GOSAT) sensor between the Ministry of the Environment, NIES, and JAXA. While there were established JAXA rules (NASDA1996) for evaluating the reliability of GOSAT-1 at the time of its design, there were no rules for evaluating the reliability of the functionality required for decommissioning measures at the current stage of the mission, now more than 11 years after the launch.

JAXA is currently revising the JMR-003 space debris mitigation standard in line with the 2019 revised version of ISO 24113, the latest international rules. JAXA will try to evaluate GOSAT-1 in accordance with this updated standard.

It is also preferable to conduct a similar soundness assessment for the successor satellite, GOSAT-2, as it was designed with a nominal lifespan of 5 years and will reach the end of this lifespan in November 2023.

(Assessment of remaining service lifespan and soundness of functionality required for decommissioning measures)

① Management of resources required for decommissioning maneuvers:
Ensure sufficient remaining propellant for decommissioning maneuvers.
② Evaluation of remaining lifetimes of components required for decommissioning:
Check that there are no components exceeding their operational lifetimes among the lifetime-managed components.
③ Evaluation of soundness of equipment required for decommissioning and emergency response:
Verify that no components required for decommissioning have exceeded their limit values due to elements degrading due to aging. Ensure that the conditional reliability of the functionality required for decommissioning does not fall below 0.9, using the beginning of the fiscal year as the reliability starting point.

JAXA recently compiled the decommissioning procedures depicted in Figure 3. The status of measures implemented for GOSAT-1 are also presented.

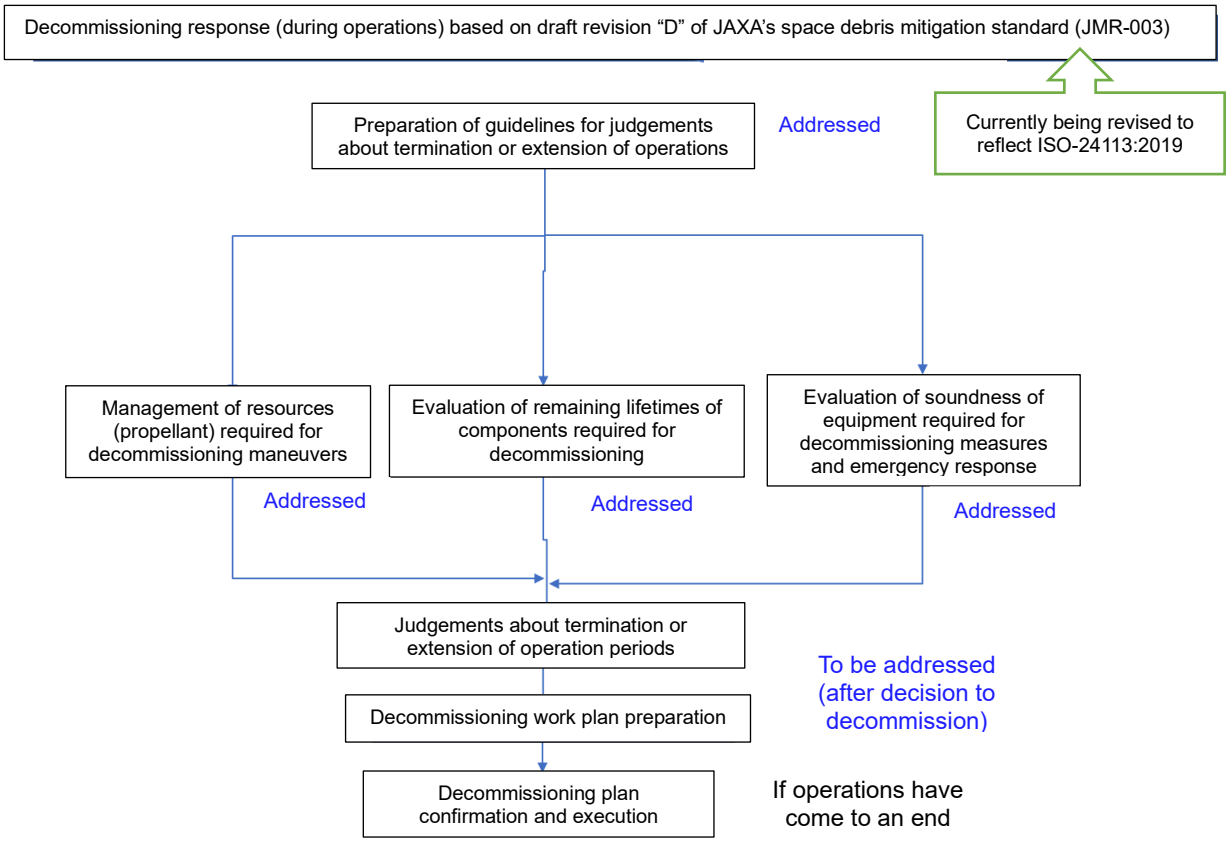


Figure 3: GOSAT operation continuity evaluation criteria

Source: JAXA

(3) **Disposal methods**

As for low-Earth orbit disposal methods, it is preferable to implement the following measures while referring to ISO-24113 and taking into account the current state of technological development and the functionality that was in place at the time of GOSAT-1's design.

① **Controlled re-entry of the satellite into the atmosphere.**

② **Decommissioning of the satellite by making it descend to an orbit where it will naturally fall to Earth within 25 years.**

Method ② was the disposal method assumed during the design process of GOSAT-1. It involves making the satellite descend from its current altitude of 666km to an orbit below about 600km, where the satellite will naturally fall to Earth within 25 years. However, if not managed properly, the potential for collisions with other space objects cannot be ruled out. To avoid potential for generating additional space debris, it is preferable to opt for the disposal method of controlled re-entry of the satellite into the atmosphere (method ①). Nonetheless, this method was not originally taken into consideration during the satellite’s design process, so it is necessary to assess whether the GOSAT-1 satellite can technically support this approach. Note that there have been no cases of Japanese-built Earth observation satellites in low Earth orbit being actively decommissioned through controlled re-entry into the atmosphere.

(4) **Discussions with stakeholders**

As mentioned in section 1. (1), GOSAT-1 plays a crucial role in monitoring progress towards the targets of the Paris Agreement, making it essentially an international public good. It has received international acclaim, and it is hoped that it will remain in operation. Collaborative research is underway based on agreements with numerous organizations, including the National Aeronautics and Space Administration (NASA), the European Space Agency (ESA), National Centre for Space Studies (CNES), and German Aerospace Center (DLR). When considering the operation continuity evaluation criteria, it is essential to engage in sufficient discussion with stakeholders such as these and foster understanding about the importance of continuity in Earth observation and the establishment of sustainable practices in space utilization.

During discussions with stakeholders, it is important to carefully consider the following key points:

1. Connectable Earth observation:
- The necessity for international cooperation in addressing space debris issues.
2. Basis for operation continuity evaluation:

① Assessment of feasibility of transition from GOSAT-1 to GOSAT-2.

② Assessment of GOSAT-1's soundness and risks associated with continued operation.

③ Soundness of GOSAT-2 (considering its designed lifespan of 5 years).

3. Direction for future initiatives

(1) **GOSAT-1 measures**

Continuous monitoring of the status of GOSAT-1 is being carried out in accordance with the criteria outlined in 2 (2). As of now, it has been confirmed by JAXA that there is no immediate need for decommissioning using the methods mentioned in 2. (1) within the next one to two years, and it appears that the satellite can continue operating without issue. Even if the conditional reliability of the functionality required for decommissioning exceeds 90%, however, there is still a risk of GOSAT-1 suddenly turning into space debris due to unforeseen issues causing a loss of communication.

After determining whether a transition from GOSAT-1 to GOSAT-2 is possible, decommissioning will be carried out at an appropriate time while seeking the understanding of stakeholders.

Upon termination of GOSAT-1's operations, in addition to the disposal methods outlined in 2. (3), the possibility of utilizing the information for development of space debris monitoring and removal technology will be considered. For example, provided that there is a sufficient amount of fuel (propellant) and the satellite remains sound, it may be beneficial to use it as a test subject for space situational awareness, such as observing debris in orbit or collecting low Earth orbit data.

In this summary, the evaluation and consideration of GOSAT-1 conducted in accordance with the latest international standard for newly launched satellites (ISO-24113 (2019)), as well as examination of the active disposal of satellites after their missions end in order to prevent the creation of new space debris, could both be said to be new initiatives. In

addition to discussions and consensus-building with stakeholders, both domestically and internationally, decisions regarding the course of action to be taken will be made through consultations with NIES and JAXA, the co-implementers of the GOSAT project.

The information outlined in this summary and the experience gained through GOSAT-1 operations will be shared widely, both domestically and internationally, to serve as a reference for the initiatives of a variety of stakeholders, including private entities. It will also contribute to increasing the momentum of initiatives and deliberations on measures related to space debris prevention in Japan and overseas.

(2) **Measures for the near future**

The operation of GOSAT-2 will continue to be managed in the same way as GOSAT-1. As for the third GOSAT satellite, GOSAT-GW, which is being developed following the space debris mitigation measures for GOSAT-2, the validity of the design, including operation continuity evaluation, will be verified and, based on the current discussions held regarding GOSAT-1, and future deliberations will be held on what concrete considerations can be incorporated.

Looking ahead, the development of space debris removal and in-orbit services such as repairs and refueling is expected. Once these services become a reality, they could significantly contribute to reducing space debris generation by extending satellite lifespans and promoting the reuse and recycling of decommissioned satellites, and ensuring proper disposal. There are efforts by Japanese companies in this area, and it is hoped that the ministry will monitor developments in collaboration with relevant organizations, and through public-private partnerships, engage in international information sharing and the promotion of innovation.