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**Long-term Sustainability of Outer Space Activities**

# Long-term Sustainability of Outer Space Activities

The present conference room paper contains comments received by the Secretariat from the following member State of the Committee on the Peaceful Uses of Outer Space: Japan.

* A/AC.105/C.1/L.306.

**Japan conference room paper**
**to the "Terms of reference and methods of work of the Working Group on the Long-Term Sustainability of Outer Space Activities of the Scientific and Technical Subcommittee" (FUTURE A/AC.105/C.1/L.307)**

# The Technical Proposal of the Procedure to Support the Working Group Activities Defined in the ToR on the Long-term Sustainability of Outer Space Activities to Acquire Comprehensive Results

## I. Introduction

The terms of reference (ToR) and methods of work of the Working Group (WG) on the Long-term Sustainability of Outer Space Activities of the Scientific and Technical Subcommittee were submitted by the Chair of the WG and discussed at the informal WG meeting held at the last IAC. The ToR provides clear ideas of the fields of study and detailed topics to be dealt with and studied by the WG in the seven areas listed below.

Table 1 Seven Areas to be Studied in the ToR

| WBS Subjects in the ToR |
|---|
| (a) Sustainable space utilization supporting sustainable development on Earth |
| (b) Space debris |
| (c) Space weather |
| (d) Space operations |
| (e) Tools to support collaborative space situational awareness |
| (f) Regulatory regimes |
| (g) Guidance for new entrants in the space arena |

In the comments from Japan submitted last November, Japan proposed the comprehensive risk analysis approach, which includes comprehensive survey of threats, identification of risk factors, risk assessment, contingency planning, and developing the best practices to ensure an effective output. This paper shows the concept of the approach and an example of the study result. Japan hopes that this paper will contribute to the discussions in WG and developing the final report.

Since this paper concentrates on technical aspects, the subjects identified in (b), (c), (d), and (e) in Table 1 are the main areas of study.

No matter what approach will be taken, it is required to keep in mind the security of intelligence and of the information.

## II. Concept of the Approach

The general idea of the risk analysis approach, which is to acquire the best practices for potential threats, will be described in the following steps:

(1) STEP-1: Comprehensive Survey of Threats
Potential threats to space activities should be reviewed comprehensively.
(2) STEP-2: Identification of Risk Factors
The major risk factors to sustainability of the space activities should be identified for assessment.
(3) STEP-3: Risk Assessment
Risk assessment for each threat should be completed to determine the major risk.
(4) STEP-4: Contingency Planning

For each major risk, preventive measures, measures to detect the realization of risk, countermeasures for potential damage, and corrective actions for long sustainability should be surveyed.

(5) STEP-5: Best Practices

A proposal of the best practices, which include international cooperative work, will be developed for the final report.

# III. STEP-1: Comprehensive Survey of Threats

## 1. Threats to Space Activities

All the risk factors that potentially threaten space activities should be identified in this first step. Generally, the following factors will be considered risk factors from a technical aspect:

(1) Quality and reliability assurance in design, manufacturing, and operation

At one time, a malfunction of a spacecraft would have been thought to be a matter just for its owner. However, now, a spacecraft of terminated missions left in the crowded orbital region is thought to pose the risk of collision, and if this led to an accidental explosion, the effect would not be ignored. Therefore, quality and reliability are a matter of interest for stakeholders around the world. The following are undesirable examples:

a) excessive cost reduction,
b) lack of technological capacity,
c) neglect of quality and reliability control, and
d) workmanship errors during manufacturing and operation.

Some of the above subjects are solved by the national governments under the framework of the UN/COPUOS Debris Mitigation Guidelines. Others might be answered by the technical intelligence accumulated in the International Standard (ISO) and other standards.

(2) Induced environment during operation

From the launch phase to the disposal phase, spacecraft are exposed to mechanical and thermal environments, which are induced by their own activities. Mechanical environment means shocks, vibration during flight, and acoustic emission at lift-off and during flight. Thermal environment includes radiative cooling and solar heating due to the circulation around the Earth. Electro-magnetic interferences are another threat. Lack of design or operation technology to cope with these environments will cause malfunction or accidental break-up. Since these factors have nearly been solved technically, existing technical standards are assisting spacecraft manufacturers.

(3) Natural environment

Major efforts in space activities have been made to develop a technology that withstands the natural space environment. Existing space technology, such as radiation hardness design and specific parts designed for space use, are sustaining reliable space activities. To ensure safe operation under the unstable space climate caused by solar flare activities, monitoring, warning, and forecasting services of the space environment are essential.

Micrometeoroids are another natural risk factor that causes impact damage on the spacecraft with higher velocity than orbital debris.

(4) Man-made Orbital Objects

Deterioration in the orbital environment by orbital debris is a risk because

a) the number of objects is steadily increasing;
b) the risk of collision cannot be ignored, not only by large objects (larger than 10 cm for instance) observed from the ground but also by micro-objects (smaller than 1 mm), which have a higher probability of causing malfunctions in spacecraft than large objects;
c) the threat of micro-debris cannot be ignored, but its population is not yet sufficiently understood;
d) as described in the UN/COPUOS Debris Mitigation Guidelines, the major source of debris generation in the near future will be a collision among existing objects followed by a chain reaction of collisions. The issue of debris has not yet been solved, even after

agreement of the Mitigation Guidelines.

### 2. Influences on Space Activities

Influences by the above-mentioned threats will deteriorate the orbital environment or cause human casualties, which will invite hesitation or disagreement from society on whether to continue space activities. The following are examples of such influences:

(1) malfunction of spacecraft, which generates debris in the useful orbital regions, or a large number of fragments if it is caused to break-up,

(2) damage to the human body in space by radiation attack, or human casualties ~~during orbit~~ on the Earth by the objects that survived reentry

## IV. STEP-2: Identification of Risk Factors

The results of STEP-1 will remind the world's space-related organizations of the troubles they are facing when attempting to accomplish their mission, or will promote enough wariness to preserve their business environment. The following risk factors may be listed as examples:

(1) Quality and Reliability:
A spacecraft should be designed to endure the flight and its operational environment. Global standards should be developed to support design, manufacturing, and operation. This is being done by the International Standardizing Organization (ISO), as an example. [This item is already covered by the ToR with its sub-clause IV-15-(g).]

(2) Natural Environment (Solar Flares, Geospace Disturbances, Electromagnetic Environment, etc.):
Monitoring and warning services are available through the Regional Warning Centers of the ISES. Further discussions in UN are expected in collaboration with other related international space weather organizations. [This item is already covered by the ToR with its sub-clause IV-15-(c).].

(3) Fragmentation
Fragmentation of spacecraft and launch vehicle orbital stages are the worst factors in the deterioration of the orbital environment by scattering debris in orbit. Typically, one fragmentation generates hundreds of large debris of several centimeters in size, and hundreds of thousands of debris one centimeter in size. This kind of debris is occupying more than 50 percent of all space objects in total.
It is essential that the world be informed of occurrences of fragmentation by the responsible operators, and the orbital characteristics of each fragment are expected to be determined immediately by the nations that have sufficient observation facilities and technology to do so. [This item could be covered by the ToR with its sub-clause IV-15-(e).]

(4) Collision with Other Spacecraft and Debris
Recent fragmentations have increased the risk of collision. For successful collision avoidance maneuvers, information on orbit characteristics, contact points in operation organization, and status of the spacecraft (under operation or abandoned) are essential, and mutual coordination for avoidance maneuvers must be organized. These activities are expected to be supported by an international data centre, which is mentioned in sub-clause IV-15-(e) in the ToR, and common procedures for collision avoidance as proposed in sub-clause IV-15-(d) in the ToR.
A more critical situation, the chain reaction of collisions among debris, is a concern, as mentioned in STEP 1-1-(4)-d. Although this problem is difficult even to discuss in the international meeting, most scientists and governmental space agencies have started to estimate the future situation, and to find technical solutions to improve the environment.

(5) Collision with Micro-debris
A spacecraft is vulnerable even to micro-debris (millimeters in size). Even 0.2-0.3- mm debris could penetrate the structural panel of a spacecraft and cause damage, or cut the electric harness exposed to space. The problem is that reliable statistical data has not been developed for such small debris, and mass-effective protection measures have not been developed.

(6) Reentry Casualties
The international treaty requires sending notice, and compensating casualties if they occur.

However, to understand the risk of fallen objects before the realization of such a casualty, information on physical properties and contact points are expected to be shared.

## V. STEP-3: Risk Assessment

The risk factors should be assessed by their risk magnitude defined by probability and influences according to the international risk assessment standard. If the risk magnitude is assessed not to be ignored, a contingency plan should be studied in STEP-4. The following table shows the result of risk assessment for the six risk factors mentioned in STEP-2.

Table 2 Risk Assessment

| | Factors | Influence | Probability | Risk Magnitude |
|---|---|---|---|---|
| 1 | Quality & Reliability Assurance | Loss of function | Quality & Reliability differ depending on manufacture | **Risk : Various**<br>-Probability: Large<br>-Influence: Various<br>-Control level is varied |
| 2 | Natural Environment | Loss of mission | Several spacecraft per ten years have terminated mission | **Risk: Medium**<br>- Probability: Large<br>- Influence: Medium<br>- Action: Monitoring and notification |
| 3 | On-orbital Break-up | Collision, and Deterioration of environment | About 200 break-up events have been observed | **Risk: Large**<br>- Probability: Large<br>- Influence: Large<br>- Measures: Being promoted |
| 4 | Collision with large objects | Break-up, and Deterioration of environment | Satellite to satellite collision occurred once; the probability could increase | **Risk: Medium**<br>- Probability: Small<br>- Influence: Large<br>- Action: Insufficient |
| 5 | Collision with micro-debris | Loss of function | Failure rate is controlled to be less than 0.01 in some countries | **Risk: Medium**<br>- Probability: Large<br>- Influence: Medium<br>- Action: Insufficient |
| 6 | Impact of re-entering objects | Casualty on the ground | Number of casualties are controlled to be less than 0.0001 in some agencies | **Risk: Un-ignorable**<br>- Probability: Small<br>- Influence: Medium<br>- Action: Insufficient |

# VI. STEP-4: Contingency Planning

The basic procedure of contingency planning will consist of the following:

(a) **Preventive Measures**
Identify preventive measures. Modeling the current situation, estimate the future situation and develop a design and operation standards to become basic measures.

(b) **Detection of Threat**
Identify effective monitoring and warning systems. A monitoring system must detect accidental situations and send warnings for immediate action to minimize damage to spacecraft and the influence on the environment.
Spacecraft, launch vehicles, and ground facilities will be able to detect occurrences of threats. As examples, the critical parameters of ordinary spacecraft are monitored to detect symptoms that cause break-up, space weather is monitored to detect abnormal solar activities, space debris is monitored and its orbital characteristics determined, the reentry time of large objects is monitored, etc. Such monitoring enables immediate corrective actions.

(c) **Immediate Corrective Actions**
For each risk factor, specific functions to avoid the risks, recover from the damage, or minimize the influences should be designed and prepared.

(d) **Permanent Measures**
A fundamental solution to eliminate potential threats should be identified as a future goal.

Examples of contingency planning for the six subjects identified in Table 2 are proposed in the following tables (Table 3-1 to 3-6). White letters indicate subjects to be discussed intensively in the WG. Those subjects are summarized in the bottom row. Attention is expected to be paid to Tables 3-3 to 3-6.

Table 3-1 Contingency Plan and Subject to be Improved: **Quality and Reliability Assurance**

| Process | Measures | Practice, Situation, and Subject to be Improved |
|---|---|---|
| Preventive Measures | Design and Operation Measures | Developing international standards and distributing them globally, and encouraging quality control not only for the benefit of the owner but also for the orbital environment. |
| Detection of Threat | Monitoring | Encourage periodical monitoring of critical parameters. |
| Immediate Corrective Actions | Analysis and Planning of Actions | If recovery measures are not effective, disposal measures and break-up prevention measures will be taken. |
| Permanent Measures | Feedback to Design | Causes should be cleared, and permanent actions will be taken for following projects. |
| Subject to be Discussed in WG | | Encouragement of quality control. |

Table 3-2 Contingency Plan and Subject to be Improved: **Natural Environment**

| Process | Measures | Practice, Situation, and Subject to be Improved |
|---|---|---|
| Preventive Measures | Modeling | Basic weather models for the typical operational orbital region have been developed. The higher and lower regions of above region is being developed in NICT/Japan. |
| | Design and Operation Measures | Radiation hardness design and specific parts are being developed; also, other design measures have been taken. |
| Detection of Threat | Monitoring<br>Detection of Threat<br>Warning | Monitoring and warning services are available through the Regional Warning Centers of the ISES. Also discussion in ISWI (*International Space Weather Initiative)* and WMO (World Meteorological Organization) is necessary. |
| Immediate Corrective Actions | Analysis and Planning of Actions | Basically, each space operator has its own contingency plan. |
| | Risk Avoidance | The electric system will be tentatively shut off.<br>Space crew will hide behind structures. |
| Subject to be Discussed in WG | | (1) Further discussions in UN are expected in collaboration with other related international space weather organizations. |

Table 3-3 Contingency Plan and Subject to be Improved: **On-orbit Break-up**

| Process | Measures | Practice, Situation, and Subject to be Improved |
|---|---|---|
| Preventive Measures | Modeling | Population and distribution of fragments will be estimated through experiences. |
| Detection of Threat | Monitoring | Periodical monitoring of the health of the spacecraft. |
| | Detection of Threat | Immediate warning when detecting break-up by malfunction in operating satellites. |
| | Warning | Information on fragment distribution is expected to be provided as immediately as possible. |
| Immediate Corrective Actions | Analysis and Planning of Actions | Orbit characteristics of fragments should be registered and shared. (Contribution by nations that can do this is required.) |
| | Risk Avoidance | Put off new launches until the situation is cleared. |
| Permanent Measures | | Break-up prevention measures should be encouraged. Intentional destruction should be prohibited. |
| | | Remove large debris, which is a critical source of chain reaction of collision, from useful orbital regions. |
| Subject to be Discussed in WG | | (1) Immediate warning when detecting break-up by malfunction in operating satellites.<br>(2) Information on fragment distribution is expected to be provided as immediately as possible.<br>(3) Prevention of a chain reaction of collisions among large debris from useful orbit regions. |

Table 3-4 Contingency Plan and Subject to be Improved: **Collision with Large Objects**

| Process | Measures | Practice, Situation, and Subject to be Improved |
|---|---|---|
| Preventive Measures | Modeling | Orbital characteristics of debris (although limited number) are available. |
| | Design and Operation Measures | Conjunction assessment tools and avoidance procedures will be prepared.<br>Propellant for collision avoidance maneuvers will be prepared. |
| Detection of Threat | Detection of Threat | Conjunction assessment should be done to detect collision risk. |
| | Warning | In the case of a close approach to the operating spacecraft, a warning should be sent to the operator of the spacecraft to coordinate the collision avoidance procedure. |
| Immediate Corrective Actions | Risk Avoidance | **Registry of operators and contact information for coordination.** |
| | | In the case of a close approach to the operating spacecraft, mutual coordination to avoid risk should be organized. |
| Permanent Measures | Remove Large Objects from Useful Orbital Regions | Remove large debris, which pose a risk of collision, from useful orbital regions and a critical source of chain reaction of collision. |
| Subject to be Discussed in WG | | (1) Registry of operators and contact information. |

Table 3-5 Contingency Plan and Subject to be Improved: **Collision with Micro-debris and Meteoroids**

| Process | Measures | Practice, Situation, and Subject to be Improved |
|---|---|---|
| Preventive Measures | Modeling | Since population models of micro-debris (in sub millimeter size) have not been agreed upon among world experts, actual collision probability is not clear, and international cooperation is expected for a more precise statistical model. |
| | Design and Operation Measures | Protection shields are encouraged in design, but technology has not reached that level. |
| | | Sensor to detect collision is useful for failure analysis. |
| Detection of Threat | Monitoring | Direct monitoring from the ground is impossible. Onboard monitoring is partly available. |
| | Warning | Warning of break-up is useful. |
| Immediate Corrective Actions | N/A | N/A |
| Permanent Measures | | Prevention of break-up, prohibition of intentional destruction. |
| | | Encouragement of protection design. |
| Subject to be Discussed in WG | | (1) Encouragement of surveying micro-debris with international cooperation, and improvement of the debris models, especially those for micro-debris.<br>(2) Encouragement of protection design. |

Table 3-6 Contingency Plan and Subject to be Improved: **Ground Casualties Caused by Reentering Objects**

| Process | Measures | Practice, Situation, and Subject to be Improved |
|---|---|---|
| Preventive Measures | Survivability Analysis | Some agencies are developing survivability assessment tools. |
| | Design and Operation Measures | Controlled reentry into ocean area or remote area. |
| | | Encouragement to select materials for easy demise. |
| Detection of Threat | Monitoring | Technology to estimate reentry time and location will be improved. |
| | Detection of Threat | Information of physical properties of falling objects should be shared.<br>A contact point to learn the details of falling objects should be opened. |
| | Warning | Responsible organization should warn related nations of the situation. |
| Immediate Corrective Actions | Analysis and Planning of Actions | N/A |
| Permanent Measures | N/A | Encouragement of controlled r-entry for risk objects.<br>Develop components to be demised easily. |
| Subject to be Discussed in WG | | (1) Encouragement of a design considering reentry safety.<br>(2) Sharing information on high-risk objects for reentry. |

# VII. STEP-5: Best Practices and International Cooperation

Based on Tables 3-1 to 3-6, subjects to be discussed in the WG are defined in Table 4.

Table 4 Subjects to be Discussed, and relation with ToR/WBS

| Risk Factors | Subjects | Works in ToR |
|---|---|---|
| Quality and Reliability Assurance | Developing international standards and distributing them globally, and encouraging quality control not only for the benefit of the owner but also the orbital environment. | (g)-(i) |
| On-orbit Break-up | (1) Immediate warning when detecting break-up by malfunction in operating satellites. | New subject (1/7) |

| | | |
|---|---|---|
| | (2) Information on fragment distribution is expected to be provided as immediately as possible.<br>(3) Prevention of a chain reaction of mutual collisions among large debris from useful orbit regions is expected. | New subject (2/7)<br>New subject (3/7) |
| Collision with spacecraft or other large objects | (1) Registry of operators and contact information. | (e)-(iii) |
| Collision with micro-debris and meteoroids | (1) Encouragement of surveying micro-debris with international cooperation, and improving the debris models, especially those for micro-debris.<br>(2) Encouragement of protection design. | New subject (4/7)<br>New subject (5/7) |
| Reentered system impacting the Earth | (1) Encouraging a design considering reentry safety, and development of components for easy demise.<br>(2) Sharing information on high-risk reentering objects. | New subject (6/7)<br>New subject (7/7) |

The subjects identified in Table 4 can be categorized as shown in Figure 1. The WG may create common understanding and develop fundamental philosophy, methods or conceptual practices as best practices, but for further details other international organizations, such as ISO and IADC may be requested to develop best practices for these subjects, as well as for other agenda items in the STSC. (See Figure 2)

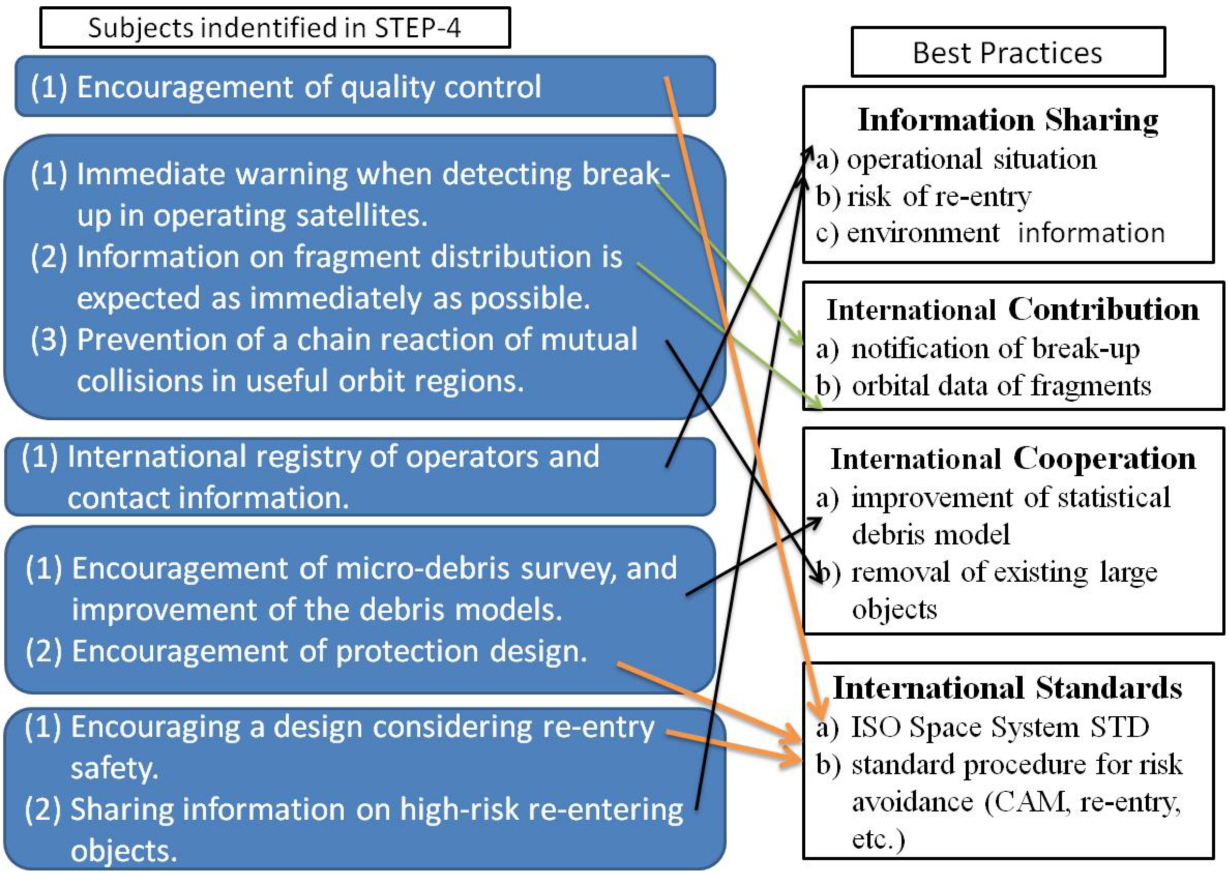


**Figure 1 Subjects and Candidates for Best Practices**

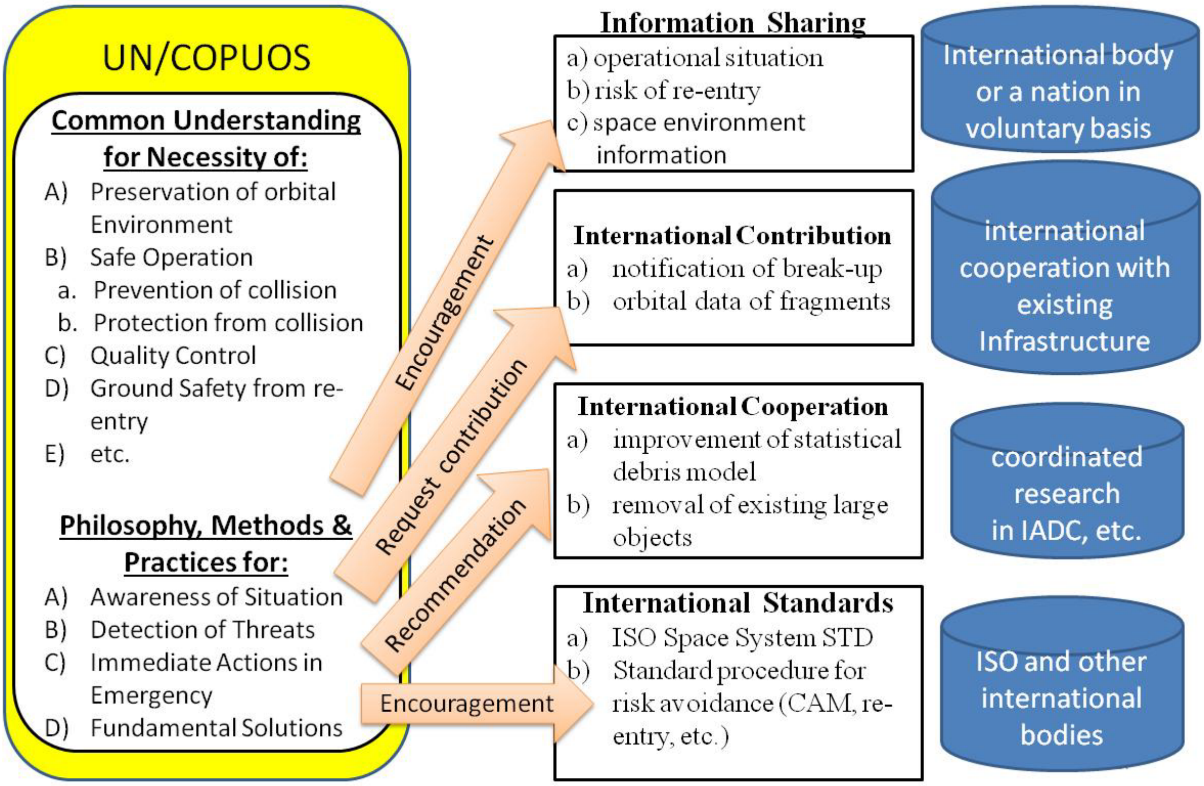


**Figure 2 Work Allocation & Sharing Among World Authorities to Develop & Encourage the Best Practices**

# VIII. Conclusion

A risk analysis and contingency planning as shown in the previous chapters will effectively induce what should be discussed in the WG. The following subjects, including seven new subjects, are indentified in this paper. Table 5 shows the final work breakdown structure (WBS) with additional subjects that Japan proposes as the result of typical risk assessment and contingency planning. As indicated in the column of "Remarks", seven subjects can be added to the works defined in ToR.

(1) Quality and Reliability Assurance
   a) Developing international standards and distributing them globally, and encouraging quality control not only for the benefit of the owner but also the orbital environment. [ToR-iv-15-g]

(2) Natural environment
   a) Monitoring and warning services are available through the Regional Warning Center (RWC) of the International Space Environment Service (ISES). Further international collaborations with other related international space weather organizations are expected. [ToR-iv-15-c]

(3) On-orbit Break-up
   a) Immediate warning when detecting break-up by malfunction in operating satellites. [**ToR-iv-15-e**](New subject-1/7)
   b) Information on fragment distribution is expected to be provided as immediately as possible. [**ToR-iv-15-e**]( New subject-2/7)
   c) Prevention of a chain reaction of mutual collisions among large debris from useful orbit regions is expected. [ToR-i5-13-b]( New subject-3/7)

(4) Collision with spacecraft or other large objects
   a) International, multinational, or national registry of operators and contact information. [ToR-iv-15-e]

(5) Collision with micro-debris and meteoroids
   a) Encouragement of surveying micro-debris with international cooperation, and improving the debris models, especially those for micro-debris. [**ToR-iv-15-b**]( New subject-4/7)

b) Encouragement of protection design. [**ToR-iv-15-g**]( New subject-5/7)

(6) Reentry Casualties

a) Encouragement of a design considering reentry safety, and development of specific components for easy demise. [**ToR-iv-15-b**]( New subject-6/7)

b) Sharing information on high-risk objects for reentry. [**ToR-iv-15-b**]( New subject-7/7)

The process introduced here will hopefully contribute to the discussion in WG and on generating the contents of a final report of the WG.

**Table 5 WBS in the ToR and Proposed Additional Works as Examples Induced from Tentative Risk Analysis (1/2)**

(Proposed additional subjects are in bold and underlined.)

| Title | Contents of Work | Remarks |
|---|---|---|
| (a) Sustainable space utilization supporting sustainable development on Earth | (i) The contribution of space science and technology to sustainable development on Earth | |
| | (ii) The concept of sustainable development extended to the domain of outer space | |
| | (iii) Technical capacity-building for developing countries | |
| | (iv) Equitable access to the limited resources of outer space | |
| (b) Space debris | (i) Measures to reduce the creation and proliferation of space debris<br>***1. Prevention of a chain reaction of mutual collisions among large debris from useful orbit regions (altitude: 800 km)** | Add(3/7) |
| | (ii) Collection, sharing, and dissemination of data on space objects<br>*1. Objects detectable from ground observation facilities<br>***2. Encouragement of surveying micro-debris in international cooperation, and improvement of debris models, especially those for micro-debris** | Add(4/7) |
| | (iii) Reentry<br>*1. Reentry notifications regarding substantial space objects<br>***2. Encouragement of a design considering reentry safety (easy to demise by selecting adequate materials, controlled reentry, etc.)**<br>***3. Sharing information on high-risk objects for reentry** | Add(6/7)<br>Add(7/7) |

**Table 5 WBS in the ToR and Proposed Additional Works as Examples Induced from Tentative Risk Analysis (2/2)**

| Title | Contents of Work | Remarks |
|---|---|---|
| (c) Space weather | (i) Collection, sharing, and dissemination of data | |
| | (ii) Sustaining global observation capability | |
| | (iii) Measures to mitigate the impact of space weather phenomena on operational space systems | |
| (d) Space operations | (i) Collision avoidance processes and procedures | |
| | (ii) Pre-launch and pre-maneuver notifications | |
| | (iii) Common standards, best practices, and guidelines | |
| (e) Tools to support collaborative space situational awareness | (i) International, multinational, or national registry of operators and contact information | |
| | (ii) International, multinational, or national data centers for the storage and exchange of information on space objects and operational information | |
| | (iii) Information-sharing procedures**.**<br>***1. Immediate warning on a voluntary basis when detecting break-up by malfunction in operating satellites.**<br>***2. Information on fragment distribution is expected to be provided as immediately as possible.** | Add(1/7)<br>Add(2/7) |
| (f) Regulatory regimes | (i) Adherence to existing treaties and principles on the peaceful uses of outer space | |
| | (ii) Regulating space activities of the Member State nations | |
| (g) Guidance for new entrants in the space arena | (i) Technical standards, best practices, and lessons learned for the successful development and operation of space systems, from the pre-launch phase to the end-of-life phase<br>*1. **Encouragement of protection design** | Add(5/7) |
| | (ii) Microsatellites and smaller satellites | |