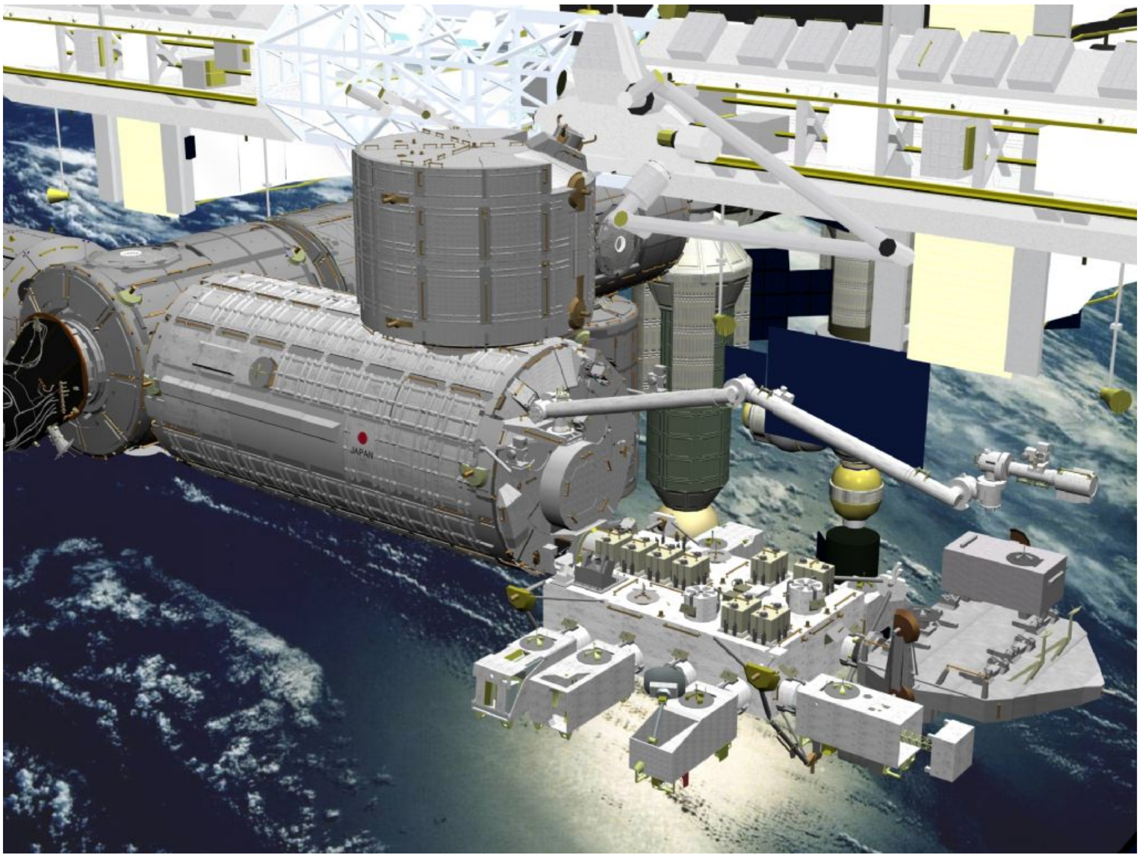
Planning Guide for Space Experiment Research



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Preface

Space environment, exemplified by microgravity on low-Earth orbit, has many unique merits and advantages for research, which cannot be realized on Earth. Achievements based on activities utilizing the space environment were summarized, compiled, and published in the

"Memoir of Japanese Space Experiments – Accomplishments and Lessons Learned", *JASMA* Vol. 22, Supplement 2005. That volume provides valuable information to scientists and engineers who would like to become involved in space experiments.

However, a summary of past achievements may not provide adequate information to potential participants in space environment research. Common-sense or routine on-the-ground research cannot simply be extrapolated into space: many preparatory tasks and precautions are necessary to achieve a scientific goal in space. Therefore, as a second attempt, the brochure "Planning Guide for Space Environment Research" was conceived and compiled in Japanese so that potential participants in future space experiments may understand well in advance what must be done from the submittal of the research theme to the actual flight execution of the experiment. That brochure was published in March 2007 by the Japan Space Forum.

This English brochure is the third version translated from the Japanese text. As with the Japanese text, the personnel of the Japan Space Forum were actively involved in preparing the manuscript, because their experience and know-how obtained from assistance and support tasks in terms of preparing and refining the space experiment plan and flight experiment operation are valuable information for this brochure. The inclusion of their experiences and lessons learned will, I believe, enhance the value of this brochure to the anticipated readers, either domestic or abroad.

The scope of space experiments can be divided roughly into two science disciplines, life science and materials science, this brochure addresses these two areas of research, considering many common facets of the two disciplines. For the sake of convenience to prospective readers, a colored page is inserted between the life science and materials science sections of this brochure, so that the readers interested in each discipline can easily access the intended contents. However, it is recommended that all readers look at the whole text, paying attention to what is not their area of expertise, and seriously endeavor to pioneer new fields of science.

The STS returned to flight in July 2006, and we have seen the continuous success of ISS assembly since then. The launch of JEM module “Kibo” is quickly nearing the final countdown; following that, we look forward to seeing the finishing touches on ISS construction. Once the construction is completed, the next stage will be the utilization of ISS-JEM to the fullest extent. I would like to call for the vigilance of all the people involved in the ISS-JEM utilization program to avoid inadequate or insufficient preparation.

It is my sincere hope that this brochure will serve as a proper guide not only for those who are working on the current space experiment program, but also for those who will plan and execute space experiments in the future.

Hiroo Inokuchi, Chairman of Board of Trustees, Japan Space Forum
Chief Scientist, Japan Aerospace Exploration Agency

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Introduction

Prior to this brochure, the "Planning Guide for Space Experiment Research: Memoir of Japanese Space Experiments-Accomplishments and Lessons Learned" was published in the form of Vol. 22 Supplement 2005 of the *Japan Society of Microgravity Application* (*JASMA*). The memoir is a compilation of almost all space experiments conducted by Japanese scientists and provides valuable information to scientists, engineers, and others who are considering becoming involved in space experiments.

This brochure elaborates primarily on the "Lessons Learned" portion of the memoir and is intended to provide further information so that readers may understand prerequisites to smooth and efficient space experiment planning. Thus, the authors of this brochure believe that its contents will serve as a guiding canon for anyone who is interested in space environment utilization for scientific and technological purposes.

The brochure consists of two parts, life science and materials science. Despite some similarity between life science and materials science in general terms, these two fields have evolved differently and obviously cannot be handled in the same way. Thus, they are described in two separate chapters. However, it is recommended that readers look at the entire brochure so as to enhance their level of preparedness for challenging interdisciplinary research in space.

Merits of Space Environment Utilization

The space environment of the International Space Station (ISS) orbit is characterized by microgravity, high vacuum, space radiation, and a wide field of view. All should be overcome by the time humans attempt to go and stay there, but some are definitely scientific parameters that await the scrutiny of scientists and engineers. Some particular aspects, such as the atomic oxygen-rich atmosphere and thermal condition discrepancy between the sun-lit and shaded surfaces of spacecraft, will challenge the hardware designer to develop far-advanced technology. The space environment at the altitude of ISS is summarized below.

Characteristics of Space Environment at the Altitude of ISS

Microgravity	10^{-6} to 10^{-4} *g*
Vacuum	Roughly 10^{-5} Pa+ (Creation of 10^{-11} Pa Possible)
Unique Atmospheric Composition	85% Atomic Oxygen
Space Radiation	Compound Environment of Various Space Radiation Sources
Wide Field of View	Theoretically 360 degrees
Solar Energy	1.4 kW/m^2
Thermal Management on Orbit	Heat Exchange Control in Vacuum by Radiation, Fluid Motion Control under Microgravity by Surface Tension, Interfacial Input, and Magnetic or Electrical Force

All phenomena on Earth are subjected to gravity, and apparently no one has questioned why they are observed that way. It was a big step in the space development activities of the past decades that scientists and engineers realized the need to observe what is masked by Earth's gravity. Presumably, criticality of the parameter gravity may differ in disciplines such as physics, chemistry, and biology; however, the gravity-dependent sciences in space that cannot be pursued rigorously on Earth will play a leading role in solving what cannot be solved on the ground.

Common sense tells us that water flows from high to low places on the ground, but this type of thinking does not apply in microgravity. A volume of water forms a spherical liquid ball that floats free in space. Fluid phenomena are quite sensitive to microgravity; thus, the topical problem of fluid dynamics and physics has been a major research subject in space since the 1970s. However, a number of unanswered questions remain, and repetition of experiments and long-duration experimentation on board the ISS will enhance the progress of science.

Weightlessness means that buoyancy, sedimentation, static pressure, and thermal convection are all negated. Thus, it becomes possible to observe the core of reaction, the solidification/aggregation/compounding process, leading to greater accuracy in physical parameter measurements, refined material composition, and crystal growth without disturbances.

As long as space activity continues to be a human endeavor, life science and space environment utilization will remain inseparable. Microgravity can be applied to the analysis of various life and biological problems. Cell cultivation and refinement/crystal growth of biomolecules have been studied under the disturbance-free environment, and are expected to result in a breakthrough for a number of disciplines.

To life born and developed on the ground, microgravity may seem to be an utterly unexpected condition. However, space experiments have revealed that life on Earth has a surprising ability to adapt to a new environment, indicating that human beings and the rest of the life on the ground possess various capabilities and a strong potential to evolve that past on-the-ground investigations have not yet disclosed.

As mentioned above, the space environment has immeasurable potential for utilization in both life and materials sciences. In the preparation for space experiments, life science and materials science differ greatly in terms of experiment samples, apparatus, devices or tools, and involvement of flight crew. These apparent differences highlight the influence of the concept design and planning of the space experiments and the implementation process. Therefore, this brochure consists of two parts: the first applies to life science, and the second applies to materials science. The two parts are independently composed, but they may share much basic information. For the sake of convenience of the reader interested in either of the two, the text is organized so that the reader may obtain the adequate or complete information/data base without looking at the whole brochure.

Part I Life Science

1-1 Introductory Remarks

One definite goal of life science is to make long space travel come true for ordinary citizens on Earth, yet extensive basic research on a variety of topics must be conducted before this dream becomes a reality.

At this moment, traveling into space is not easy, although it looks as if space travel by ordinary citizens is not merely a dream of the distant future, but will be possible soon. However, the space experiment, although it may appear to be easy to carry out, cannot be executed by the efforts of the researcher alone.

Considering the expenses, cost, and manpower involved in the space experiment, adequate and precise preparation on the ground is necessary to alleviate the risks associated with the flight program. This effort must involve the coordinated teamwork of the flight crew, scientists, engineers, managers, and government officials.

Requirements of experiments in space are manifold. The most important criteria for the science solicitation and selection process are that the research theme must involve proof of a scientifically significant hypothesis; it must involve proof that is possible only in a space experiment; and the research theme must foster a technological breakthrough.

Execution of a science mission on board the ISS may be regarded as field science, not as part of the laboratory sciences on the ground. Upon recognition as such, proper measures and precise preparations must be taken to reduce the possibility of failures or accidents.

The two factors that distinguish research in space from research on the ground are described below.

“Microgravity”

Microgravity in space is a major parameter in biological and medical research. Here caution needs to be exercised in identifying what is caused and what is not caused by gravity in biomedical processes. Some phenomena are explained similarly by physical or chemical principles, but the rest should be addressed by biomedical reasoning.

In the biological process, gravity information is converted into biosignals, and various responses appear in the course of signal transduction; therefore, it is impossible to describe the biological process by a mathematical formula or other numerical processes. The responses are totally different from those in physics. Nevertheless, it is important to eliminate ambiguity in defining the role of gravity when planning the experiment. The experiment plan should include the hypothesis to be proven. Being accustomed to working in gravity makes it difficult to switch to proper reasoning without gravity. Sometimes risks are associated with exercising our imagination (i.e. our imagination might fall short of our expectation), and we risk failure. Thus, it is necessary to examine the experiment plan many times and to repeatedly perform preliminary ground experiments to validate or verify space experiments.

“Engineering necessary for space experiments”

Even though the ISS is called an orbit laboratory, it is not possible for researchers to carry out biological experiments as freely as they do in a ground laboratory. The facilities and accommodations on board the ISS-JEM are qualitatively advanced over those of the Spacelab era, but many constraints are still evident. Thus, it is important to recognize the space experiment as quite different from its ground counterpart in its nature and in the implementation process. Space experimentation involves many conditions and situations that most researchers on the ground will never encounter or observe.

The total task flow of the medical or biological space experiment can be compared to the management of a stage performance. There, principal investigators (PIs) are not spectators but promoters who must make the stage performance a success. On-orbit experiment or launch of the mission that attracts the eye of the general public may be regarded as one act or one scene. When planning to make one stage performance a success, necessary tasks include planning the theme of the performance, selecting actors and actresses, preparing the playbooks, building large or small stage tools, refining the stage setting, and arranging the performance hall. Countless jobs must be carried out beyond the notice of spectators, and repeated practice and exercise are required to ensure a polished stage performance.

The final practice of flight operation and a dry run of the experiment processes prior to launch are like a dress rehearsal. Even though the actual space experiment on board the ISS-JEM may look enchanting, prior preparation activities and post-flight work actually absorb the energy of everyone involved. The totality of the preparatory tasks should be processed, aiming at the specific day of the launch. Success requires collaboration and work-sharing by many people who possess various capabilities and carry out numerous functions.

To pursue the scientific goal of the space experiment, proper application of engineering methods and technological skills in the implementation process is necessary to overcome a variety of obstacles and to mitigate the risks of failure.

1-2 Planning Scheme Leading to Success

As is well known in all disciplines, the specification of the experiment hardware (i.e. performance of the apparatus) and technologies in the operational stage is a major factor in the success of scientific research, especially in space environment utilization experiments. Even with an exceptional objective, it is impossible to achieve the goal without securing appropriate technologies.

1-2-1 Characteristics of the Space Experiment Proposal

In addition to scientific evaluation, technical evaluation is necessary. Technical evaluation to determine whether or not the proposed experiment can be flown as desired is unique to space experiments. Such a question is not an issue on the ground, because most experiments can be conducted on the ground. Unfortunately, that is not the case in space.

Even if the scientific merit looks extraordinary, it is possible that the experiment cannot be conducted for technical reasons (i.e., the space agency will not fly the experiment to orbit when they cannot accommodate it properly).

Such a situation may be avoided if caution is exercised in considering the technological side during the planning stage. Thus, during the process of theme selection, science evaluation and technical evaluation are equally important. Proposers must indicate the type of apparatus or tools they are going to use, and make a rough sketch of the execution steps, either manual or automatic.

1-2-2 Technical Evaluation on Feasibility (Realizability)

Technical evaluation addresses the uniqueness of the space experiment and mirrors its constraints. The purpose of this evaluation is to identify potential problems, explore the possibility of countering these problems, and assess the level of difficulty in countering these problems.

1) Experiment Requirements

The technical evaluation determines whether or not all the operational processes are doable (i.e. feasible to carry out).

Proposers are required to complete the experiment proposal form in terms of when, where, who, what, why, and how (5W1H). This description is termed “Experiment Requirements” and is intended to outline the details for the reviewer.

2) Uniqueness and Constraints as the Focus of Technical Evaluation

When a problem appears in the description, a certain number of points are deducted from the original budget, depending on criticality. When the total number of deducted points exceeds a specified level, the proposal is rejected. Thus, it is recommended that the proposer try to minimize the potential loss of points, although it is not necessary to try to achieve the 100% mark!

Comments on countering the problems will be fed back to the proposer. The proposer should work on those comments, once the theme is selected.

3) Uniqueness of the Space Experiment

The entire space experiment may be cast into a sequence of operations, and 5W1H should be delineated as required. Here, some comments are made to help the proposer be aware of the importance of completing the form accurately and thoroughly. The following comments are taken from the experiences and lessons learned from past space experiments, and hopefully will serve as an appropriate reference to potential proposers.

(1) WHEN: Schedule of flight and time slot of execution

Unlike ground experiment execution, it is not possible to fix the date of launching and carrying out the mission even ten years in advance because the space transportation system is subject to so much preparatory work prior to launch. No one can guarantee the date or time of departure from the launch pad far in advance. The operation of the space flight remains quite different from that of international and domestic airliners.

Nonetheless, the flight program operator wants the scientists to be ready at any time of the year, and the researchers should be able to prepare live samples at any time requested, even if the acquisition of live samples in wildlife seems seasonal and not possible throughout the year.

In principle, the schedule is always "to be determined" (TBD). The date of launch is usually announced one year ahead, but it is always possible to have 48-hour, one-week, or two-week delays. Researchers are required to prepare five or six times more samples than are needed in one experiment on the ground. Sometimes efforts will end up in total disaster because of a one-year postponement of launch, which heavily disrupts the daily, weekly, monthly, and annual timeline of businesses at the home universities or research institutions. It is necessary to have a large team consisting of many surrogates for lectures, ground preparations, and ground control operations.

The sequence from the ground to the initiation of the experiment is as follows.

- Completion of the final preparations tasks of live samples on the ground
- Delivery to the launch operator,
- Installation on the space transportation system (i.e., Space Shuttle or Soyuz)
- Delivery to the ISS
- Mounting on the proper experiment apparatus of the ISS
- Switching on.

This sequence takes a minimum of three days. Thus, a bio-phenomenon with a cycle of less than three days cannot be accommodated, and a capability to initiate the process after three days (e.g. maintaining the samples in lower temperatures throughout the transportation period) should be incorporated.

The three-month ISS visitation cycle is a dominant factor for researchers in choosing the experiment duration and the time length in which the effects of microgravity or space radiation can be detected. For example, if the experiment comes to a conclusion within one or two weeks, chemical fixation or refrigeration up to the time of recovery to the ground is recommended. In addition, it is necessary to verify the method in advance so that the fixed samples will not degrade during the storage period.

Live samples are constantly subject to change: they may look very active on one day but sleep on another day. However, impromptu adjustment of the handling sequence or procedures is not possible in space as it is on the ground. Some lead time to change is necessary. Thus, it is preferable to clarify the time margins of handling of each critical operation before the flight.

(2) WHERE: Location of the laboratory

Obviously, the proposer cannot intervene in the actual experiment operation, unless the proposer is a flight crew member. However, the researcher or proposer can monitor the progress of the flight experiment at the ground control center and can suggest changes in operational steps, but not much can be expected of ground activities. Consequently, the experiment plan should address a variety of paths throughout the experiment, and operational tasks should be as simple and automated as possible.

Procurement sites must be well-studied. Live samples and reagents may be purchased near the launch site (Kennedy Space Center), but obtaining the necessary items overseas is not as easy as it is domestically. Thus, caution should be exercised not to waste time carrying out routine errands.

When launch and recovery of samples are conducted in a foreign land, the samples go through packaging and transportation, necessitating application for quarantine at the airports, tax waver, exemption of X-ray inspection, and many other tasks. Those tasks may be completed by the support workers and will not bother the scientists, except for preparing precise requirements for the support workers.

(3) WHO

The flight crew includes an experiment operator on orbit. All flight crew members will be trained in experiment operation before the actual flight, but they are not experts on the subject. Thus, it is not appropriate to burden them with difficult or time-consuming training.

Responsibilities are delegated diversely to scientists, support engineers, ground crew, flight crew, and managerial personnel as appropriate. Nevertheless, the PI (i.e., proposer or scientist) is a major player in the flight mission.

(4) WHAT

The flight samples should be able to live in the anticipated instrument or apparatus. Because the available storage room on board the ISS-JEM is limited, types and number or volume should be carefully chosen so that the experiment results will be statistically significant.

Experiment instruments and apparatuses on board the ISS-JEM are listed in the Announcement of Opportunity (AO), and experiments requiring other instruments or apparatuses are not selected. This information is available on the JAXA website. Since it is not possible to mount the samples directly onto the apparatus, first it is necessary to prepare the container or canister for the sample. If the sample is in a fluid state, the container or canister should fully contain the fluid, since no free fluid surface is allowed in the experiment. An experiment-specific container or canister may be prepared either by the scientists or support workers, depending on the characteristics or requirements of the experiment.

A vessel for cultivating cells (i.e. the canister containing the sample cells) should be operational under microgravity. Obviously, it should be an enclosed container without a gas-liquid interface. The compatibility between the container wall and the samples must be verified. Sometimes the surface coating of the container’s internal wall can harm the live samples.

The ISS-JEM is a closed space as well as a microgravity laboratory. Thus, the leakage of reagent (e.g. formalin) can be devastating to the flight crew and the interior equipment. Reagents easily handled in the laboratory on the ground must be strictly controlled when utilized in space. It is a common practice to prepare a special container to prevent spilling-over of the working reagents, in an effort to pass regulations. Sometimes a proposed reagent cannot be used. In such a case, it is necessary to seek possible substitutes that could serve the same purpose.

Once on orbit, it will be too late to replenish supplies or replace missing items.. Therefore, it is necessary to list all items, big or small, to be utilized on orbit, and to make sure that they are complete and in perfect condition.

In every step of operation, it is necessary to specify the purpose of the operation, the sample that is to be picked up next, and the apparatus that is to be switched on or off. For example, the proposer may designate “Switch off A-1” and “Pick up sample of C-3.”

(5) WHY: Basis of experiment requirement: Scientific requirement

The reason that a procedure is to be performed in a certain way is termed the “scientific requirement.” The proposer should clarify this scientific requirement to ensure that operators and agency personnel understand adequately. Once the people involved understand the scientific requirement, they do their best to complete the tasks. When the requirement is not 100% satisfactory, the proposer is asked to reduce the requirement to the acceptable level without sacrificing the scientific significance of the mission. This is a negotiating process between the scientists and engineers.

(6) HOW

Here, 5W1H is to be summarized and cast into the practical implementation process. All engineering problems, however minor, must be approached from the technical point of view with the same level of enthusiasm as the scientific problems. Otherwise, the space experiment mission will not be successful. The tasks at this stage (i.e., the joint tasks after the theme is selected) are basically carried out by support workers. Nonetheless, while completing the proposal, the proposers must pay due attention to 5W1H from the beginning of the process.

1-3 Uniqueness and Constraints of the Space Experiments

When all the measures and schemes meet the experiment requirements, the experiment mission may possibly fly. The available options for methodologies, hardware, and software may seem quite limited. Thus, it is wise to design the experiment with the limitations and constraints in mind.

When the AO is released, it will contain information on the available experiment apparatus and factors that may affect feasibility . If the measures to meet the requirements are beyond the scope of the provisions, an entirely new apparatus, tool, device, or technology may be necessary. If it does not seem entirely possible to develop brand new facilities, the feasibility of the proposal is rated low, and eventually the proposal is likely to be rejected. Section 1-4-5 explains how the space mission facilities are to be developed. They require much time and manpower, and a substantial monetary investment.

1-3-1 Focus of the Technical Evaluation

Technical evaluation considers which experiment requirements impinge on the constraints.

1) Experiment requirements versus apparatus in space

The checkpoints include the following.

- Will the experiment be possible with the available apparatus?
- When a new apparatus is necessary, will it be possible to develop the hardware by the time of the flight experiment?
- Will it be possible to raise the funds to develop a new apparatus?

It is generally assumed that the hardware is already installed on orbit, and the proposers should understand those facilities well as they design the mission.

2) Experiment operational procedures

The checkpoints include the following.

- Are the requirements of the crew excessive?
- Is the operational time line described in detail?

Crew time and crew tasks

No crew member is professionally assigned to a specific piece of space experiment. The flight crew members spend most of their time maintaining the ISS; thus, they can spare only a few hours per week for experiment operations. Crew time is not dedicated to any single experiment, but to a number of experiments. Thus, the available hours are divided into minutes and are scattered throughout the week. Also, the flight crew cannot do anything related to the experiment on the day of shuttle docking to or undocking from the ISS.

Since the flight crew members are busy all day, it is advisable to ask them to carry out certain operational work within a window of a few hours. It is difficult for them to do a job at an exactly specified moment of the day or hour. They need a few hours' margin to process requirements of all kinds.

50% more time allocation required

Flight crew members train on experiment operations before a flight. Roughly speaking, it takes 50% longer to do a task on orbit than it does to do the same task on the ground. Work (performance) in space is not as efficient as that on the ground. Furthermore, it is generally not acceptable for a crewmember to work continuously on one experiment for more than 30 minutes.

Late access and early removal

Live samples should be prepared and handed to the launch operator 90 hours before the launch. Any requirement to handle the samples less than 90 hours in advance is called "late access." It is common practice for the operator to return the flight samples to the investigator within 24 hours after recovery or landing of the space transportation system. The requirement to receive the flight sample in less than 24 hours is called "early removal." These requirements could be satisfied theoretically, but sometimes severe restraints or restrictions prevent early removal.

Storage in a refrigerator and freezer

The space transportation system is not always equipped with a refrigerator or freezer. Experiments that require such facilities during launch and recovery will be possible only when the transportation system possess them. Obviously, the flight opportunity of such an experiment is limited.

Experiment duration

In the current operational planning, there is a ferry flight to the ISS every three months. The space shuttle or other transportation system is docked to the ISS for about two weeks.

An experiment requiring animals to live three weeks on orbit and then return to Earth alive is not possible due to the lack of an available recovery flight. In planning those experiments, the investigators should consider a substitute plan, such as euthanizing the animals and keeping them in the freezer.

Additional evaluated items are as follows.

- Are the resource requirements for mass, weight, volume, power, and storage at a lower temperature within the proper limits?
- Does the experiment have a negative effect on any other experiment carried out in the same time frame?

3) Environmental health and safety

Another consideration is whether any element in the proposed experiment may harm the surrounding environment or the flight crew.

1-4 Tasks prior to Execution

The first step in carrying out a space experiment is to apply for "Space Experiment Solicitation." Planning and designing the space experiment constitute the necessary preparatory tasks in the application process.

1-4-1 Announcement of Opportunity, Review, and Selection

The sequence is: AO issue, proposal submittal, science evaluation, technical evaluation, program evaluation, and candidate selection (Fig. 1-4-1).

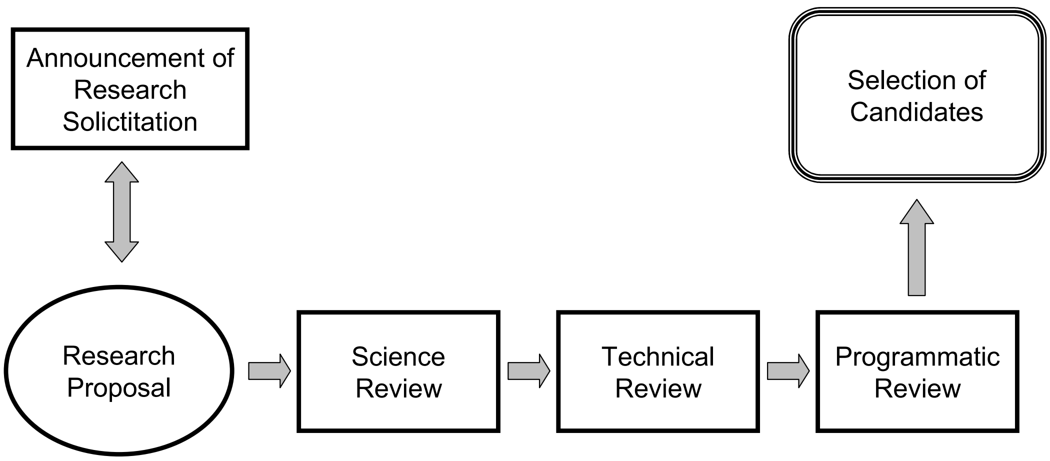

Fig. 1-4-1 Review Process from Solicitation to Selection

1) Announcement of Research Solicitation

Letters of announcement are sent to major universities and research institutions. The information is also posted on the homepages of JAXA, JSF, and associated academic or professional organizations. The solicitation is open for two months.

2) Science Review

The science review is conducted by setting up a science panel organized and managed by the responsible agency. Two or more specialists are assigned to look at the proposal document and return their evaluation results to the science panel. The science panel employs a grading system similar to that used in college and assigns a grade of A to D to each proposal. .

The science evaluation criteria are listed in Table 1-4-1.

Table 1-4-1 Scientific Evaluation Criteria

Significance	・ Does the study address an important problem? If the aims of the application are achieved, how will scientific knowledge or technology be enhanced? ・ What will be the effect of the study on the concepts, methods, or products that drive this field of science?
Approach	・ Are the conceptual framework, design, methods, and analyses adequately developed, coherently integrated, and appropriate to the aims of the project? ・ Is the proposed approach likely to yield the desired results? ・ Does the applicant acknowledge potential problem areas and consider alternative tactics?
Originality and Innovation	・ Are the aims original and innovative? ・ Does the project employ novel concepts, approaches, or methods? ・ Does the project challenge existing paradigms, or develop new methodologies or technologies?
Capability of Execution	・ Is the investigator appropriately trained and well-suited to carry out this work? ・ Is the proposed work appropriate to the experience level of the principal investigator and any co-investigators? ・ Is the evidence of the investigators' productivity satisfactory? ・ Does the scientific environment in which the work will be performed contribute to the probability of success? ・ Does the proposed experiment take advantage of unique features of the scientific environment or employ useful collaborative arrangements? ・ Does evidence of institutional support exist?

3) Technical Review

Proposals that pass the science review are evaluated in a technical review. The practical system of evaluation looks similar to that of the science review. A professional panel consists of members of a primarily engineering background (e.g., expertise in operation, hardware development, technology development, and multiple coordination).

The evaluation is conducted mechanically, and points are deducted for items that infringe on the contour of restrictions, restraints, and constraints. The number of points deducted is judged by the criticality of the situation. If the deducted points exceed a certain level, the proposal is rejected.

4) Program Review

Proposals that pass the science review and the technical review undergo a program review. The responsible agency decides which flight experiment proposal is to be selected. Primary evaluation points may be clarified at the time of the AO (e.g., strategic emphasis on a certain research area or desirable topics). In addition, evaluation depends on the budget of the flight program (i.e., how many science themes they can afford to fly).

5) Selection of Candidates

Through the above processes, some space experiment themes (i.e. potentially flyable themes) are selected as candidates.

1-4-2 Tasks after Candidate Selection

The tasks from definition and development phases to post-flight analysis span three to four years. These tasks include documentation of ground preparation and flight operation, preparatory experiments on the ground to meet safety requirements, post-flight analysis, and report submittal (Fig. 1-4-2).

Preparation involves two phases, the definition phase and the development phase. The two phases are slightly different in nature: the former is oriented to science content, and the latter to actual flight preparation tasks.

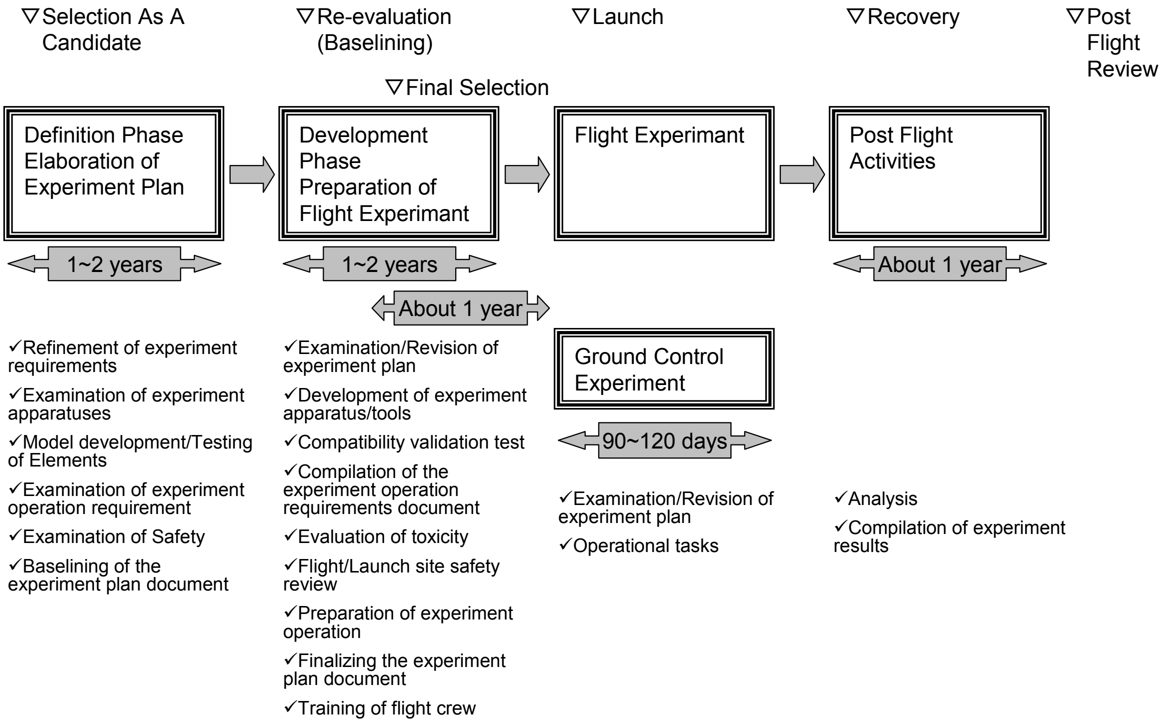

Fig. 1-4-2 Work Flow After Being Selected As A Candidate

1-4-3 Tasks of Proposers

Various tasks (Fig.1-4-2) such as elaboration of planning, preparation of flight experiments, flight operation, and post-flight analysis are shared by scientists and support workers. Work-sharing and joint tasks are summarized in Table 1-4-3. This table presents only general terms; each proposer should construct a specific table so that everyone involved in the experiment execution has a common understanding as to what each person's assignment is.

Table 1-4-3 Definition and Development Phase Tasks (Life Science)

Phases or Action		Investigators' Tasks	Joint Tasks	Support Workers' Tasks
	Decision of Experiment Contents	Clarification of A/Is posed through the selection process Identification of validation items and experiment condition Establishment of the validation/ verification processes	Examination of experiment apparatus/sample suitability versus experiment requirements	Provision of technical data and appropriate information
Definition Phase	Establishment of precise experiment plan for flight	Re-evaluation or optimization of experiment conditions for flight Trial manufacture of sample breadboard model. Validation of safety /maintainability of sample Material.	Examination of sample development process, applicable apparatus or devices, operational requirements. Drafting Experiment Plan Document	Provision of technical data and appropriate information
	Re-evaluation	Participation in Re-evaluation Review Preparation of the statement note to testify about the scientific background	Re-evaluation (Base-lining) Review	Compilation of Experiment Plan Document (initial version) Preparation of technical documents
Development Phase	Verification of Installability /Compatibility	Preparation of sample material Verification of sample compatibility Re-evaluation of Experiment Plan Document based upon compatibility verification test	Revision of Experiment Plan Document, Laboratory test execution to verify compatibility	Development of samples, devices, and tools. Verification of sample compatibility including toxicity examination Flight/Launch Site Safety Review Preparation of Operation Requirement Document
	Final selection	Compilation of the report on scientific background and its public announcement (presentation)	Final Selection Review	Final scheduling of flight experiment execution Compilation of technical report and presentation
	Preparation of Ground reference experiment	Preparation of sample material		Manufacture of samples
	Pre-flight preparation	Preparation of sample materials Mission-specific crew training Preparation of mission-specific ground support equipment	Finalizing Experiment Plan Document including the contingency plan	Manufacture of samples Compilation of Operation Plan Document Flight crew training Compilation of Operation Manual
Flight Experiment	Flight experiment execution	Monitoring telemetry data at the Operation Center or home office	Experiment Operation	Launch and recovery of samples Acquisition of experiment data
	Ground reference experiment	Data Analysis	Ground reference experiment execution	Provision of ground reference experiment apparatus
Post-Flight Activities	Post-Flight activities	Analysis and evaluation of experiment results Presentation of achievements at Flight Science Conference Provision of flight data to Data Archive Center (where all flight data are accumulated in JAXA)	Analysis and evaluation of experiment results Compilation of the mission report	Support of analysis and evaluation of experiment results Host and manage the post-flight science conference Support of Data Archive Center Host and manage the science evaluation board

Compatibility verification test: The test to demonstrate the function and performance of the apparatus under operation with predetermined experimental conditions and control parameters, using the real live specimen as planned.

Table 1-4-3 includes one column to describe the support group. However, the support group members may be engineers from an engineering company or hardware developing company, or a JAXA manager or other personnel. Regardless of status or position, all involved in the program are team members sharing the same objectives and mission. The total effort assembling all the tasks listed in Table 1-4-3 is termed “Experiment Integration.”

1-4-4 Tasks of Support workers

Support workers provide engineering assistance, such as collecting information on hardware and its operation, as well as overall managerial and clerical matters associated with planning and execution.

1-4-5 Experiment Instruments

1) Experiment Instruments and Apparatus to be Utilized on the ISS

Experiment instruments and apparatus on board the ISS are composed of the Multi-user Experiment Facility (MEF) and the Biological Experiment Unit (BEU). The MEF is manufactured and provided by JAXA (or other partner agency). The BEU does not contain live biological samples but containers or canisters to house bio-samples internally. It is equipped with biosensors and associated electronics. This BEU is usually installed in the MEF, but sometimes it is a complex independent experiment facility.

The MEF specifications are fixed, and nobody can change them. In contrast, the BEU can be employed in various applications as long as it can be used while mounted in the MEF. It may generally be designed or modified as the proposer wishes. Examples of MEFs and BEUs developed thus far by JAXA may be found at http://iss.sfo.jaxa.jp/kibo/kobomefc/

2) How Space Experiment Instruments and Apparatuses Are Developed

Usually, the space agency provides the experiment instruments and apparatuses, and the AO clearly indicates the types of apparatuses that will be available in the specified period on orbit. It is possible for scientists to develop and bring apparatus to the space agency; but in that case, development must be carried out in accordance with the pre-set regulated procedure of the space agency.

When instruments or apparatuses are under development, the scientists must follow the specific requirements on hardware performance, hopefully in terms of specified digits.

No matter who develops the hardware, the routinely adopted procedure is to follow the specifications of the providers of the satellites or launchers. The process starts with the Conceptual Design, then goes to the Preliminary Design, and finally arrives at the Critical Design. The following section explains what needs to be done throughout the three phases in sequence, so that scientists may understand how to develop their own specific hardware. The series of activities culminates with the design review that takes place at the end of each phase. A review board conducts an evaluation and decides whether or not the development tasks may proceed to the next stage.

Conceptual Design

The breadboard model (BBM) for the experiment instrument or apparatus, plus necessary peripherals, is developed and examined in this phase. It is essential to validate the proposed hypothesis, or at least part of hypothesis, by laboratory experiments or numerical simulations. The scientists and support group, including the hardware manufacturer, must come to a unanimous conclusion as to the type of hardware to be developed in terms of specific digits.

Preliminary Design

In the Preliminary Design phase, the engineering model (EM) is manufactured and its performance is examined and/or verified in the space-simulated environment of the ground laboratory. The purpose of this activity is to confirm that the instrument will work in space as expected.

Critical Design

The Critical Design phase is the final stage, which involves checking everything with the manufacturing proto flight model (PFM) and the flight model (FM). The PFM and the FM are identical, except for the fact that the PFM is for ground use and the FM is for flight. Recently, the PFM has rarely been manufactured due to budget concerns. Also, the reliability of space hardware has improved, so that it is not so crucial to look at exactly the same model on the ground to analyze problems on orbit, when malfunctions occur on the FM (while flying on orbit). Ways to fix the problem exist without using a PFM.

Design Reviews

The Design Review process, a unique practice in the space community at large, was introduced in the era of the Apollo Program by NASA. Usually, a review board is organized at conceptual, preliminary and critical design phases. This board typically consists of experts on various technical problems, engineers/senior members of hardware manufacturing companies, mission coordination contractors, and space agency personnel and managers, to name only a few.

The engineers, scientists, and others working on the project present their design before the review board. A Q and A session follows, along with general discussions. The review board then summarizes the reports/activities and comes to a conclusion. The meeting, which is called a workshop or forum, is more like a hearing than a presentation, and it allows for little variation as to how to organize this type of conference.

The Design Review is intended to improve the overall reliability of the project. It is unlikely that the people in charge of implementing and developing the project will give incorrect or false information to the review board. They are more prone to present problems, issues, and concerns. Thus, the review board meeting provides a great opportunity to engage the collective wisdom of everyone involved, resulting in higher reliability of the mission.

1-4-6 Preparing the Space Experiment Planning Document

Usually the scientists (proposers), engineers, and managers from all organizations involved work jointly on the Space Experiment Plan, which is never required in ground research. This document serves as a manifestation of the agreement of all people involved.

1) Framework of the document

As delineated many times, here the keywords are once again summarized.

①Purpose/Objective of the research, significance of experiment

②Working hypothesis

③Necessity or grounds for carrying out the experiment in space

④ Experiment facility, instrument or apparatus, biological experiment unit, device and tools, bio-samples or animals to be used, reagents

⑤Experiment operational procedures, monitoring, measurement of bio-samples Scrapping/transportation/storage plan

⑥Anticipated results or achievements, predominant effect on science or society

2) The composition of the document

The table of contents includes the following.

1) Principal Investigator and team, affiliations of team members and tasks
2) Experiment
2-1 Title of the Experiment
2-2 Objective of the Experiment
2-3 Description of the Experiment
The description includes the working hypothesis and its grounds, originality and new knowledge to be acquired in the experiment, references to past research related to the experiment, reasons for coming up with the experiment, overall scientific background of the experiment, anticipated influence or propagating nature expected from the results of the experiment, and the necessity of carrying out the experiment on board the ISS-JEM.
2-4 Description of on-orbit experiment Instruments, specimens, tools, operational steps
2-5 Special requirements for operation, if any
3) Instruments, Apparatuses, Specimens, subjects, tools, and devices
3-1 Instruments and Apparatuses
3-2 Specimens
3-3 Specimen holder or container
3-4 Devices or tools prepared by the proposer
3-5 Transportation and storage of specimens and/or reagents
4) Experiment Procedures
4-1 Operational steps
4-2 Measuring and observation techniques
4-3 Commanding uplink
4-5 Requirements of the crew

5) Ground Reference Experiment
5-1 Facilities, instruments or apparatus, location
5-2 Date, month, year
5-3 Operational procedures
5-4 Experiment conditions
6) Post-Flight Analysis
6-1 Monitoring and observation items
6-2 Data analysis and output
6-3 Expected results and their extension

Appendix 1 Current Topics on Biomedical Research and Human Space Technology Development

1. Past Circumstances and Present Status

Since the first space flight by Gagarin in 1959, 500 human beings have traveled in space, and those who have stayed in space more than one month now number 100. However, the space environment remains severe for humans and still raises many medical issues and problems.

Space medical research has two interrelated and inseparable facets, the health care of the flight crew and scientific medical investigation.

JAXA has eight commissioned astronauts and has participated in eight space flights. However, all missions have been short-term, and Japan has virtually no experience with long-term stays in space. Thus, JAXA is well behind other ISS partners in terms of medical research and development of medical devices, and our space activities thus far have been limited. We have flown a high-definition camera for medical examination on orbit and have obtained medical data when a Japanese astronaut flew. As part of our ground research, we have conducted bed-rest experiments, isolation experiments, and studies with an artificial gravity generator for humans.

Long-duration stays on board the ISS began in 2000. As of September 2007, the 15th increment (called expedition #15) crew is staying on the ISS. Astronauts from US, Russia, and Europe have already participated in a long-duration stay. These three partners are forerunners in medical research and the development of medical devices. Currently, the crew members on board the ISS are utilizing instruments and devices for medical treatment, experiment facilities for medical research, and physical training devices developed by the above-mentioned partners. However, such medical instruments and devices are not adequate for real treatment. Moreover, some such facilities are becoming aged and obsolete.

The medical research conducted on board the ISS up to present is summarized sequentially in the table of ISS Space Medicine Experiments.

ISS Space Medicine Experiments

Experiment Title	Principal Investigator	Research Field	Brief Summary *	Inc 1	Inc 2	Inc 3	Inc 4	Inc 5	Inc 6	Inc 7 2 crews	Inc 8	Inc 9	Inc 10	Inc 11	Inc 12	Inc 13
				00/10	01/03	01/08	01/12	02/06	02/11	03/04	03/10	04/04	04/10	05/04	05/10	06/03
Environmental- Monitoring	NASA JSC	Environment	Early evaluation of air, water and surface samples of ISS													
Nutritional-Status	Smith	Nutrition	Nutritional status assessment from dietary intake, body composition, and blood and urine													
Torso	Badhwar	Radiation	Radiation measurement using an anatomical model of a male head and torso													
DOSMAP	Reitz	Radiation	Radiation levels mapping													
BBND	Goka (NASDA)	Radiation	Neutron radiation detection													
Interactions	Kanas	Psychology	Questionnaires for crewmember and crew-ground interaction													
Subregional Bone	Lang	Bone	Bone density scan until one-year postflight after long-term space flight													
H-REFLEX	Watt	Nervous system, Muscle	Loss of locomotor function in microgravity and spinal cord excitability													
RENAL STONE	Whitson	renal stome	The efficacy of potassium citrate to renal stone formation													
PuFF	West	Respiratory	The effects of EVA and long-term exposure to microgravity on pulmonary function													
XENON1	Gabrielson	Peripheral circulation	Peripheral circulation measurement using													
EVARM	Thomson	Radiation	Characterized the radiation doses of astronauts during EVA (spacewalk)													
BIOPSY	Fitts	Muscle	Skeletal muscle degradation tests by biopsies, performance tests and MRIs													
Mobility	Bloomberg	Neurophysiology	Testing pre and postflight locomotor function, and to develop countermeasure for mitigating locomotor dysfunction													
EB virus	Stowe	Immunology	Evaluate human immune system by Epstein-Barr virus activity													
Midodrine	Meck	Cardio-vascular	Test of midodrine as a countermeasure against post-flight orthostatic hypotension													
FOOT	Cavanagh	Biomechanics	Foot / ground reaction forces during space													
Chromosome	Obe	Radiation	Crew lymphocytes examination													
HPA	Zolesi	Biomechanics	Hand posture analysis during grasping and reaching tasks in weightlessness													
Ultradound (ADUM)	Dulchavsky	Medical System	Ultrasound exams for diagnostic telemedicine													
Journals	Stuster	Psychology	Behavioral issues associated with isolation and confinement: review and analysis of ISS crew journals													
DAFT	Urban	Environment	Counts ultra-fine dust particles													
Latent-Virus	Pierson	Immunology	Latent virus reactivation associated with space flight from saliva samples													
Promethazine	Putcha	Motion sickness	Motion sickness medication by Promethazine													
ALTEA	Narici	Radiation, Nervous System	Diagnostic technologies to cosmic radiation, and impacts on the human central nervous and visual system													
Chromosome-2	Johannes	Radiation	Crew lymphocytes examination													
SWAB	Pierson	Environment	Biocharacterization from surface, water and air													

* The detail of each experiment is described at NASA homepage (http://hrf.jsc.nasa.gov)

2. Topics in space medicine research

a. JAXA medical research plan

The JAXA Space Biomedical Research Office is systematically carrying out research activities in an effort to mitigate the risks of a long-duration stay in space for Japanese astronauts. The risks are categorized into five sub-risks: physiological countermeasures, psychological support, cosmic radiation management, on-orbit medical treatment system, and inner vehicle environment. Assessment and analysis have been performed for those sub-risks, and we have extracted several important subjects with high priority to be pursued from 2005 to 2009. The subjects under study are summarized in Table "Current Status of JAXA Clinical Space Medicine Research."

Current status of JAXA clinical space medicine research (2005～2009)

Research Field	Top Priority	Current Status
Physiological Countermeasure	Prevention of bone loss and urinary stone	Collaboration with US team (for ISS long stay astronauts) for bisphosphonate administration (waiting volunteers)
	Countermeasure for muscle	Under development for small muscle training devices
Psychological Support	Psychological monitoring for the adaptation to isolation and human interaction	Two research projects for stress monitoring
	Cross-cultural Issue	Conducting in astronauts training
Cosmic Radiation	Personal dosimeter (advanced type)	Under development. Operational monitoring is conducting using current device (TLD & CR-39)
	Biodosimetry	Collaboration with Russia and National Institute of Radiological
Medical System	Medical data monitoring equipment	Preparing for flight medical equipment
	Autonomous diagnostic medical device	Under development
Environment	Gas monitoring and analyzing system (advanced type)	Research project for developing gas monitoring device

To conduct such research, JAXA is calling for collaboration with scientists or researchers outside JAXA, and is planning to out-source part of the research work to appropriate organizations. The scheme and schedule of these activities will be reviewed periodically, and feedback will be made accordingly.

b. Obstacles presented by experiments using human subjects

Experiments requiring human subjects confront many constraints. Like experiments without human subjects, they include restrictions on weight, volume, and power requirements of the facility as well as crew time. It is far from realistic to perform experiments with highly invasive requirements. The medical data of the crew during the launch period and immediately after the return are valuable, but few examinations have been made at those times because of the many tasks assigned to the crew. Consequently, it is difficult to collect significant data or samples for research use at those times. Medical data for medical operations are collected periodically prior to launch, during flight, and post-flight for monitoring the health status of the crew.

Research studies requiring crew subjects undergo reviews regarding their safety and scientific significance (merits). Thus, the few experiments that are selected are very limited. The process of pharmaceutical validation/verification from clinical trials (i.e. ground validation) is similar to its real clinical application (i.e. space experiment). For example, research proposals for establishing physiological countermeasures are validated by bed-rest experiments on the ground, simulating weightlessness in space, prior to flight experiments. Only hardware and software verified on the ground are brought to space. Proposals must also be evaluated from the ethical perspective. If subjects are crew members, the investigator must not only obtain consent from the crew to carry out the experiment, but also inform crew members of the experiment results at a very early stage. Since astronauts tend to dislike the idea of their data being assessed, many considerations are necessary to foresee probable consequences. Investigators should be aware that they may spend much time and effort, even if their requirement is simply to sample one drop of blood in a simple procedure, to obtain non-invasive physiological data, or to provide medical data obtained in the past.

3. Future plan

The progress of innovation in medical treatment devices is remarkable on the ground. These devices are becoming smaller and more automated with higher performance on a daily basis. Furthermore, telemedicine has developed dramatically. JAXA intends to pursue the possibility of developing methods for collecting medical data with unrestraining/wireless and noninvasive means, thus resolving many of the constraints associated with flight experiments and contributing to the development of space medicine.

JEM launch and assembly to the ISS is currently scheduled to start at the beginning of 2008, and Japanese astronauts will eventually participate in long-duration stays on board the ISS. JAXA long-range vision statements include human space flight activity and exploration on the Moon’s surface. To realize future missions, space medicine research activities must be promoted and emphasized.

Appendix 2 Information Sources

Although the history of space biology experiments is short compared to those of other categories in life and biological research areas, many references and publications on the subject are sufficient to initiate the conceptual study of the space experiment. Neglecting to analyze past experiments will result in "the re-invention of the wheel."

Judging from the fact that publications or journals dealing with the space experiments are not easily purchased or obtained, it is sometimes preferable to make direct contact with the scientists who were involved in past space experiments.

All reports published in academic journals are included in Medline. Also, the English abstract of Japanese publications can be retrieved. With retrieval through Medline, it is useful to use keywords like *gravity*, *microgravity*, *space*, *flight*, and *NASA*, in addition to professional/disciplinary terms, and then narrow down the topic to what is needed. Information on space experiments may also be retrieved from the following websites.

Space Experiment Information Sites (Life Sciences)

JAXA	
International Space Environment Utilization Research Database	http://idb.exst.jaxa.jp/
NASA	
Microgravity Research Database	http://edmp.grc.nasa.gov/idea_search.cfm
ISS Research Information Sites	http://exploration.nasa.gov/programs/station/
Life Science Database	http://lsda.jsc.nasa.gov/
ISS Medical Projects	http://hrf.jsc.nasa.gov/
ESA	
Space Experiment Database	http://spaceflight.esa.int/eea/
Academic Journals	
Japanese Society for Biological Sciences in Space, Journal	http://www.jstage.jst.go.jp/browse/bss/-char/ja/
American Society of Gravitational Space Biology, Journal	http://asgsb.indstate.edu/publications.html

Part II: Materials Science

2-1 Introductory Remarks

The first microgravity experiment by a Japanese researcher was conducted during the flight of the Apollo-Soyuz in 1973. Since that time, more than 120 experiments in the materials science field have been conducted through such flight programs as FMPT, IML-1 & 2, SFU, MSL-1, and TR-1 Sounding Rockets.

Lessons have been learned from the successes and failures of these experiments. They are summarized here and will hopefully serve as valuable guidance for experiment planning and performance of experiment facilities, to enable technologies and whatever else is deemed necessary from conceptual study to actual flight.

Unlike research on the ground, space experiments face severe constraints regarding repetition and budget. Therefore, ground preparation must be carried out perfectly, so that the possibility of space experiment failure is close to zero. This level of perfection can be achieved only by making use of other scientists' experience and knowledge.

Unfortunately, Japanese scientists have not enjoyed flight opportunities in the recent past because of ISS construction delays. The transmission of the experience and lessons learned to the newcomers is challenging. The JEM module is to be attached to the ISS next year (in 2008). According to the current schedule, the ISS-JEM will be fully operational very soon, and we will see the actual experiment execution shortly. This text is intended for mission operators, scientists of many disciplines, engineers, and agency personnel and managers, so that they can remain on track to achieve success by applying the information provided.

2-2 Roadmap to Space Experiments

This section primarily targets scientists who are writing space experiment proposals.

2-2-1 Task Flow from Proposal to Execution

As a space agency, JAXA encourages scientists and nurtures potential space experiment themes through the following three schemes.

1) Application for the ground research award by JAXA-JSF
2) Participation in science working group (SWG) activity in the specific discipline of the scientist/engineer. Ninety SWGs (more than 900 members) are currently actively discussing potential science experiments on board the ISS-JEM.
3) Application for the Space Partnership Program.

   Participants in the Space Open Laboratory Program are eligible to apply for this award.

   In addition to the above public award schemes, HASTIC, an NPO in Hokkaido, provides flight opportunities for sounding rockets on a commercial basis.

Once a proposal is accepted as a flight experiment candidate, the candidate undergoes a definition phase study and a development phase study spanning two to five years, depending on the progress of the necessary tasks. The definition phase study involves precise experiment planning, while the development phase study involves preparing the flight experiment operation. During the second study, a final decision is made regarding which candidates will actually fly. The flight experiment itself takes 90 to 120 days, and the post-flight analysis should be completed within one year after the flight samples (specimens) are returned to the scientists. The work flow is illustrated in Fig. 2-1-1 Work Flow From Being Selected As A Candidate To Post Flight Tasks.

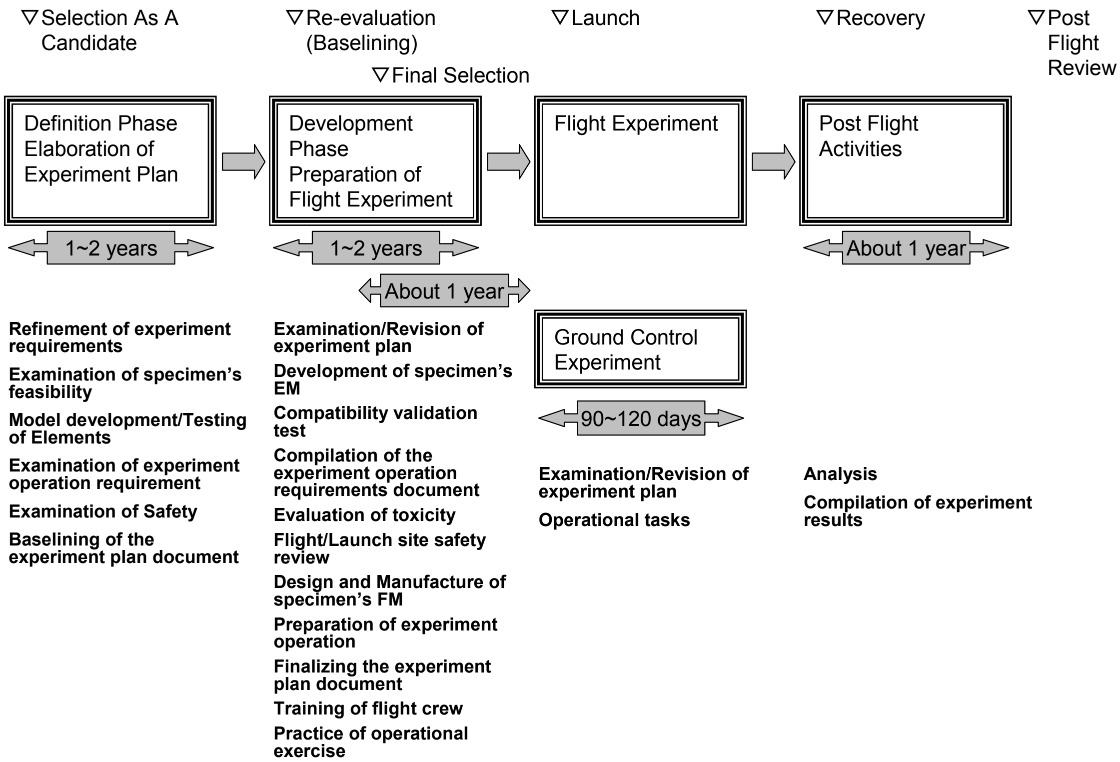

Fig. 2-1-1 Work Flow From Being Selected As A CandidateTo Post Flight Tasks

Experiment Requirements stipulate the number of specimen blocks, the amount of specimen bare material, the storage condition, and the concrete process to decide the experiment parameters. These requirements are summarized in the Experiment Planning Document.

Operation Requirements stipulate the precise operational procedures: transporting specimen blocks and sample materials to the launch site, mounting these items on the space transportation system, launching them to the ISS and installing them there, and recovering them to the ground. In the case of ground research, the scientists themselves usually become the operators, and it is not necessary to define the experiment requirements and operation requirements for real execution. In the case of flight experiments, the entire work package is divided into small chunks of work for personnel and workers. Thus, it is essential that all the people involved in the project share the same level of understanding about the experiment and operation requirements and fulfill their tasks to attain the common goal.

2-2-2 Tasks of Proposers

When completing the space experiment proposal forms, the proposer comes up with the basic concept of a working hypothesis for the space experiment, building the validation/verification model, validation/verification items, and validation/verification of tuning parameters. Still incomplete are the preparation and trial manufacture of specimen block and specimen materials, the performance validation test, the list of experiment parameters, and the data acquisition test for safety verification on board the ISS. These tasks must be done eventually through the definition and development phases. They are not the responsibility of the proposer alone; rather, they are shared by all the people involved. Task distribution is presented in Table 2-2-1 Tasks of Definition and Development Phases. The totality of these tasks is called Experiment Integration Work.

Tab.2-2-1 Tasks of Definition and Development Phases (Materials Science)

Phases/Action		Investigators' Tasks	Joint Tasks	Support Workers' Tasks
	Decision of Experiment Contents	Identification of validation items, hypothesis/validation models, and experiment parameters Establishment of the validation/ verification processes Clarification of effectiveness of microgravity (utilization of droptube/airplane experiments, acquisition of physical properties, numerical simulation) Validation of safety /maintainability of sample material	Examination of correspondence between experiment apparatus/samples versus experiment requirements	Provision of the technical data and appropriate information
Definition Phase	Establishment of precise experiment plan for flight	Re-evaluation/Optimization of experiment parameters for flight Trial manufacture of specimen's breadboard model ,	Examination of the feasibility of specimen development and operational requirements. Drafting Experiment Plan Document	Provision of the technical data and appropriate information
	Re-evaluation (Baselining) Selection of Flight Experiment Theme	Participation in Re-evaluation Review Preparation of the statement to establish scientific background	Re-evaluation (Baselining)Review	Compilation of Experiment Plan Document (initial version) Preparation of technical documents
Development Phase	Verification of Installability /Compatibility	Preparation/Compounding of sample material (bare specimen) Verification of specimen's Compatibility Re-evaluation of Experiment Plan Document based upon compatibility verification test	Revision of Experiment Plan Document Laboratory test execution to verify compatibility	Development of specimen, devices and tools Verification of specimen's compatibility, including toxicity examination Flight/Launch Site Safety Review Preparation of Operation Requirement Document
	Final selection	Compilation of the report on scientific background and its public announcement (presentation)	Final Selection Review	Final scheduling of flight experiment execution Compilation of Technical report and presentation
	Preparation of Ground reference experiment	Preparation/Compounding of sample material (bare specimen)		Manufacture of specimens
	Pre-flight preparation	Preparation/Compounding of sample materials Mission-specific crew training Preparation of mission-specific ground support equipment	Finalizing Experiment Plan Document, including the contingency plan	Manufacture of specimens Compilation of Operation Plan Document Flight crew training Compilation of Operation Manual
Flight Experiment	Flight experiment execution	Monitoring telemetry data at the Operation Center or home office	Experiment Operation	Launch and Recovery of specimens Acquisition of experiment data
	Ground reference experiment	Data Analysis	Ground reference experiment execution	Provision of ground reference experiment apparatus
Post-Flight Activities	Post-Flight activities	Analysis and evaluation of experiment result Presentation of achievements at Flight Science Conference Submission of the results to International conferences and academic journals Provision of flight data to Data Archive Center (where all the flight data are accumulated in JAXA)	Analysis and evaluation of experiment results Compilation of the mission report	Support of analysis and evaluation of experiment results Host and manage the post-flight science conference Support of Data Archive Center Host and manage the science evaluation board

Bare specimen (sample): The part that is to be installed in the container or the cartridge. This portion is to be prepared by the scientist, or principal investigator.

Compatibility verification test: The test to demonstrate the function and performance of the apparatus under operation with predetermined experiment conditions and control parameters, using the real specimen as planned.

2-2-3 Tasks of Support Workers

As is seen in the process of space experiment implementation tasks presented in Table 2-2-1, some tasks (e.g. evaluating the specimen's adaptability to the flight hardware and flight operation, and characterization of physical material properties by various tests to satisfy safety requirements on board the SS/JEM) may not be categorized as part of research for the scientists. Thus, technical assistance by support workers from space agencies and contract companies comes into play to alleviate the burden on the scientist (proposer) and to carry out the total flight mission more effectively.

For further clarification of the tasks of support workers, two block charts are presented in Figs. 2-2-1 and 2-2-2. Support workers include many players, not one company or one organization. They may be space agencies, engineering /coordination support companies, or hardware developers (manufacturers). This fact does not matter to the scientists, but it is advisable to know how many players will be involved. Figure 2-2-1 reveals the task distribution during the definition phase, for the purpose of refining the experimentation plan. Figure 2-2-2 indicates the task distribution during the development phase, for the purpose of preparing the flight experiment. The breakdown of these structures in diagrams is called "Experiment Integration."

The support workers work on optimization of a series of tasks, and hand the result to the flight operator. Therefore, they need to understand the contents of the experiment very well, cooperate with the scientists to overcome various obstacles, and propose a concrete experiment plan following the requirements of the scientists as much as possible.

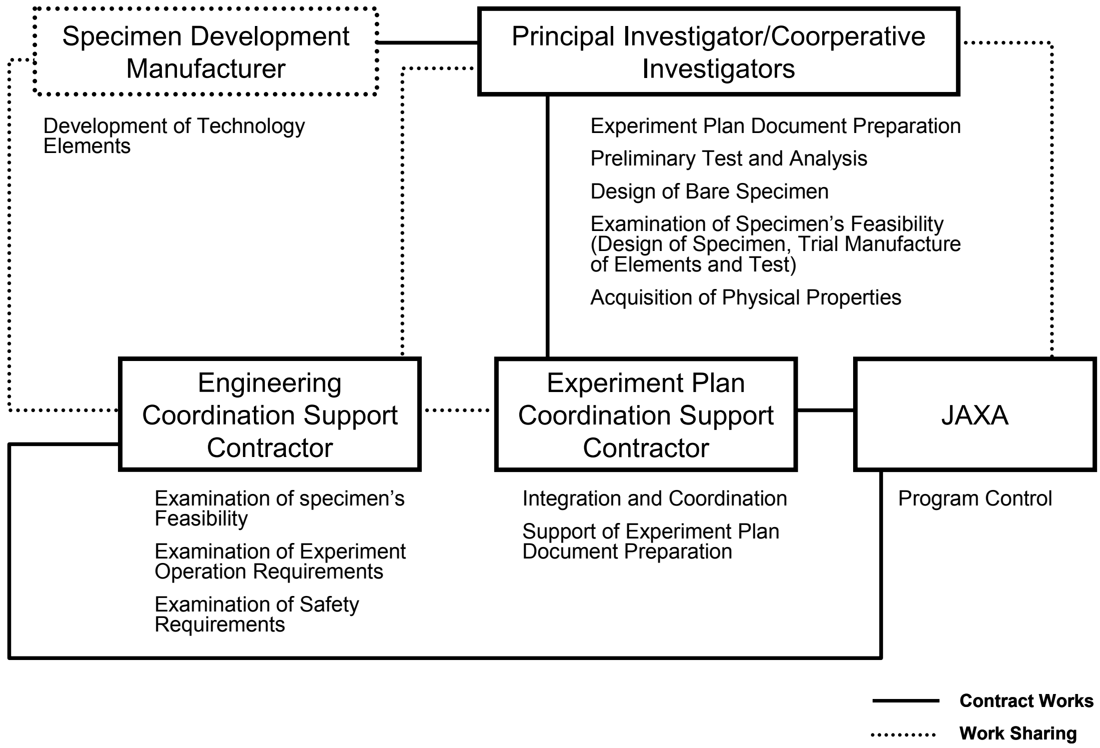

Fig. 2-2-1 Executive Organizations of Experiment Plan Integration in Definition Phase

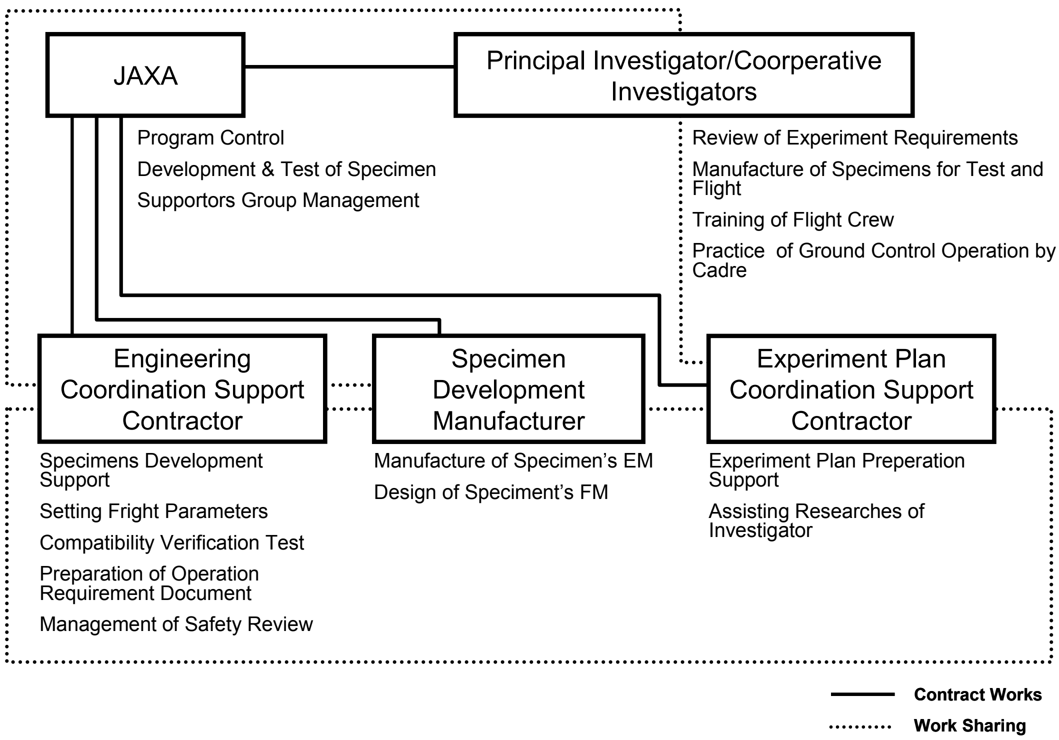

Fig. 2-2-2 Executive Organizations of Experiment Plan Integration in Development Phase

2-2-4 Reminders

(1) The experiment apparatus should be designed to meet safety requirements consisting of several tiers. The specific requirement is set depending on the specific risk. Scientists and engineers should be vigilant in rigorously predicting the level of risk, and developing ways to counter anticipated risks.

(2) Parameters for real flight experiments should be finalized during the earlier development phase of flight preparation. Thus, ground experiments should be carried out as planned, and flight experiment conditions should be fixed by the end of the definition phase. The ground experiment may be arranged, depending on the progress of the hardware development.

(3) Usually the specifications of the hardware (i.e., experiment apparatus) are determined beforehand, since the requirements for installing instruments on the ISS-JEM do not allow many choices of design. Thus, it is difficult to change the specifications, and the experimental plan must be adjustable to preset specifications. In addition, the number and type of data to be acquired, the acquisition processes, and the downlink or data media recovery should be optimized within the various constraints of flight operation.

(4) The schedule for preparation tasks, especially those spanning a few fiscal years, does not fit the normal sequence of researchers' monthly and annual rhythm in terms of the budget/schooling cycle. Thus, caution must be exercised to ensure that the biorhythm is not excessively disturbed by the space business in which the researcher becomes involved.

2-2-5 Preparing the Space Experiment Planning Document

1) Purpose of the Experiment Planning Document

It is required for all people involved (e.g. scientists, operators, engineering support personnel, and hardware manufacturers) to prepare the Experiment Planning Document and submit it to the responsible flight program office. Thus, preparation of this document calls for participation and cooperation of everyone involved. Presumably, this type of document may not be familiar to most scientists and proposers.

Such a document is never requested or compiled for ground research, and it features the unique aspects of space experiment research. All the necessary information, data, and articles/comments are to be included in this document. The space agency and the participating scientists and engineers involved in hardware manufacture and operation must agree on the contents of this document.

This Experiment Planning Document is the baseline document for all activities associated with the space experiment project, manifesting the unanimous consensus of all people working for the project.

2) Composition of the Experiment Planning Document

The contents list is as follows.

1) User Group (Organization)

Principal Investigator, Co-Investigators (names, positions, affiliations, sharing tasks)

2) Experiment Outline

2-1 Title of the experiment theme

2-2 Objectives of the experiment

2-3 General background

This section concretely describes the working hypothesis for setting the research objective/target, the rationale for creating the hypothesis (e.g. past experiments or observational facts), information on the research related to the proposal, the originality of the anticipated result of the proposed research, the impact on science and engineering at large, and the necessity for long-duration microgravity on board the ISS.

2-4 Outline of the experiment on orbit

2-5 Special comments on the experiment on orbit, if any

3) Experiment Apparatus, Tools, Devices, Specimens

3-1 Experiment Apparatus

3-2 Specimens

3-3 Specimen Block (often called Cartridge)

The specimen block, or cartridge, consists of the core specimen (bare sample material), ampoule, and canister or outside container of the ampoule in which the core specimen is charged. This section primarily presents the design chart or figure indicating the general layout and the operational functions of parts and devices.

3-4 Devices and Tools prepared by the Proposers.

3-5 Transportation/Storage Requirements of Specimens/Reagents

4) Experiment Processes

4-1 Sequence of operations

4-2 Sequence of operational conditions (such as temperature profile)

4-3 Measurement and observation methods

4-4 Command uplink

4-5 Requirements of the crew

5) Preparatory Ground Test with comparable flight model

5-1 Primary facility, instruments, and location

5-2 Schedule

5-3 Operation

5-4 Conditions

6) Post-Flight Analysis

6-1 Measurement and Observation Items

6-2 Data Analysis and Information Acquired

6-3 Results Expected

6-4 Analysis for Further Scrutiny

6-5 Conclusion

2-3 Technologies and Instruments for Space Experiments

Space experiment technologies and experiment facilities should be able to accomplish the objectives of the experiment. Nevertheless, the space experiment will face severe constraints in power, experiment time, size and volume of the specimen block, and safety. In addition, it is necessary to pay attention to space-environment-specific phenomena such as difficulty of removing bubbles, characteristic change of heat transfer, and manifestation of Marangoni flow. A variety of problems will not yet be resolved by the time of experiment execution. This section is intended for experiment proposers, facility developers, experiment support engineers, and others who are interested in space experiments.

2-3-1 Technologies for Space Experiments

(1) Accumulated space experiment technologies

First, space experiment technologies acquired through past space experiments are overviewed. We hope that these technologies will be thoroughly utilized and that new technologies will be created.

Some technological bases have been acquired and accumulated, thanks to past space experiments. Examples include evaluation of wettability, evaluation of micro-g on fluid, bubble translation, telescience, capillary pumping, evaluation of toxicity, numerical simulation, vibration control, in-situ observation, solution stirring/handling, utilization of parts/devices for civilian use, long-duration storage, and transportation of specimens. They are summarized in Table.2-3-1, with a brief description for each technical field.

Table 2-3-1 Space Experiment Technology Acquired Previously

Technology Field	Primary Contents
Wettability and reactivity between the material and container	Measurement of Wettability/Reactivity, Countermeasure to/Suppression of Reaction
Evaluation of Microgravity Effect on material processing	Characterization and Modeling of residual gravity, Countermeasure to g-jitter
High-Temperature Processing	High-Temperature Heating, Application to Space Experiments, Temperature Measurement
Bubble Translation/Evacuation in Fluid	Evacuation by applying the rotational magnetic field
Measurement and Control of Marangoni Flow	Precise measurement of the flow, its control by surface temperature and oxygen partial pressure
Telescience Technology	Testbed experiment, Experimental architecture and technical evaluation, Command signal transmission, Compensation of time-lag from command to execution
Capillary Pumping	Application of thermal input or internal pressure gradient within the loop
Safety Measures and Accumulation of the Data	Double and triple containment, Evaporation pressure data archive of toxic substances
Numerical Simulation of Physical Phenomena	Analytical software dealing with thermal convection/solidification combined process and unstable interface growth process
Thermal Analysis Simulation	Crucible Interior Temperature distribution analysis, Thermal convection analysis due to residual gravity, Crystal growth analysis
Stirring/Mixing of Samples	Efficient/effective mixing under microgravity
Vibration Control	Active/Passive vibration control (isolation and damping)
In-situ Observation	Two-wave interferometer, Real-time phase shift interferometer, high-speed camera
Solution Handling	Technique to handle the solution/fluid under microgravity
High Reliability	Quality assurance and development management similar to those seen in the launcher/satellite programs
Experiment Integration	Optimization and refinement of experiment planning process among all players: scientists, apparatus manufacturer, and agency personnel
Application of parts/devices for civilian use	Digital VTR, Video camera
Long-Time Sample Storage of Samples	Solution Growth (organic and inorganic), Fluid, Colloid
Transportation of Samples	Vibration environment control log, Temperature control log

(2) Uniqueness of space experiments

A unique aspect of the space experiment, the meagerness of all resources, compels us to consider how to maximize the science. This is not a scientific question, but an engineering one to be resolved by engineers.

On the ground, the experimenter can operate the facility, adjusting its performance as needed, and it is possible to repeat the experiment and analyze the results statistically to improve their total accuracy. However, in the case of a space experiment, operation by the crew or by the command from the ground involves various constraints, and it is better to have automated instruments. With the repetition of an experiment, operations that are easily accomplished on the ground (e.g. rinsing the devices) must be examined thoroughly and correctly prepared.

Countering many problems, the space experiment operation has established processing by experiment sequence. This concept implies clarification and quantification of the experiment process (i.e. determining the timing of the execution of the operation and the type of handling). This exercise enables the scientists to reevaluate their experiments and to understand the subjects more thoroughly.

For example, in the electric furnace experiment in the MSL-1 mission, the experiment was performed by monitoring, commanding, and changing the experiment conditions and operational steps from the ground, leading to higher operational accuracy. In addition, human-machine interface engineering was adopted for the layout of instruments and their operation. This approach is expected to nurture new technology widely applicable to the industry at large.

(3) Utilization of commercial products

Unlike commercial products on the ground, space systems have adopted very special parts and devices for their components because of the severe environmental requirements on orbit. However, some commercial parts and devices have recently been applied to satellites or rockets. They work as expected on orbit, if the mission duration is not long.

To satisfy the two requirements, top-level science accomplishment and cost reduction, commercial digital video devices are being converted for space use through their miniaturization, weight reduction, and increased resistance to the space environment. The NASDA sounding rocket program TR-1A has already adopted some commercial products.

In using commercial products, vibration resistance characteristics of print chips and connections in electronics is crucial; thus, they can be utilized after vibration/ shock tolerance is raised/verified and mounted in spacecraft/rockets as standard.

(4) Safety measures

Safety measures of the manned systems imposed major impacts and burdens both cost-wise and schedule-wise in the era of the FMPT (SL-J Mission). Since that time, all the outgas data and spacecraft maximum allowable concentrations (SMAC) standards have been accumulated in JAXA and NASA open data archives:
http://matdb1n.tksc.nasda.go.jp/otuline j.html
http://www1.jsc.nasa.gov/toxicology/

(5) Refinement and Optimization of space experiment planning (Experiment Integration)

With ground research, an experiment can be carried out on a trial-and-error basis; in contrast, the space experiment requiring excellent results with only one trial on orbit necessitates a quite different approach. A higher degree of accuracy and precision than that on the ground is obviously required.

For a higher probability of success, excessive requirements from the scientists must be relaxed. For a higher degree of accuracy, the experiment theory must be re-evaluated, or physical parameters must be measured once again.

Scientists, hardware developers/engineers, and operators (including the space agency in charge of the flight program) must sketch the big picture or control the total configuration of the experiment in terms of experiment procedure preparation/quantification and theory verification by the minimum amount of data. These three groups process joint tasks such as defining the experiment conditions and design specifications (called Experiment Integration).

This total coordination is sometimes processed in accordance with the performance tests of experiment facilities/instruments, and it requires tedious and time-consuming negotiation among three groups who have generally different views even on the same subject. Arriving at a precise and unanimous conclusion within the limited time span is necessary for the success of the experiment. In the earlier days of space experiments, many scientists contended that higher priority was placed on technology rather than on science; but later, discussions and mutual understanding among the three groups improved. A few problems still remain, and knowledge accumulated in the past needs to be transferred to subsequent generations.

2-3-2 Instruments for Space Experiments

Due to many constraints on volume, weight, power consumption, reliability and safety, vibration tolerance, and interface to spacecraft, it is unlikely or impossible to install ground hardware on spacecraft.

To meet the requests of the majority of users, JAXA provides multi-user facilities such as the Fluid Physics Experiment Facility (FPEF), the Solution and Crystal Observation Facility (SCOF), the Protein Crystallization Research Facility (PCRF), and the Gradient Heating Furnace (GHF). The Electrostatic Levitation Furnace (ELF) and the Multipurpose Rack will be developed by the second phase of ISS-JEM utilization. Their specifications are available in the JAXA brochure and on the following websites:

http://iss.sfo.jaxa.jp/kibo/kibomefc/index.html

http://idb.exst.jaxa.jp/

When the proposed experiment cannot be carried out by the multi-user facility provided by the space agencies, it is necessary to design and build a mission-specific facility. Usually, scientists are not able to build such a facility, so they negotiate with the space agency as to how to develop the desired hardware.

Since JAXA is now developing a general/multipurpose rack to house any instrument or apparatus, it is becoming easier for the scientists to propose an experiment-specific instrument/apparatus on board the ISS-JEM.

2-3-3 Development of Specimen Block

The term "specimen" has two meanings: the bare solid (seed material) made of certain chemical elements, and the (usually) cylindrical seed material charged in the ampoule or cell and finally set in the canister. This outside canister interfaces with the crucible, the innermost portion of the furnace to be utilized. In the space community, the second meaning (i.e. seed material set in the container) may generally be adopted and understood as such, unless otherwise indicated.

In this text, however, for the sake of clarity we use terminology in a more rigorous manner. Here, the term "specimen" refers to sample material or specimen substance, not the specimen block or cartridge. We have already adopted the terms "specimen block" and "cartridge" in Section 2-2-5. Sometimes it is possible to mount the ampoule or cell charged by the sample substance directly on the crucible, skipping the application of an outside canister, when double or triple containment is not necessary for safety reasons.

The scientist's role is to develop the seed material or experiment medium, and the specimen block. It is generally necessary to validate the technology to prepare the sample material and the technical feasibility of the container. Thus, it is necessary to build the engineering model (in some cases, up to the BBM) of the specimen block, satisfying the experiment requirements and maximizing the science. Adequate technology and information/data base should be transferred from the scientists to the manufacturer and operator, since the space agency procures the FM of the specimen block, and the space agency or the hardware developer can better handle flight safety. It is not easy for scientists to work on models not directly associated with science.

The scientist should try to help hardware developers and other support workers understand how to approach the scientifically significant experiment. In some cases, the scientists need to compromise their requirements of the size of the sample/specimen and the experiment conditions. If the support workers are adequately aware of the experiment contents, the constraints on the experiment may be relaxed and the experiment procedures revised.

2-3-4 Summary

Information from past space experiments is summarized in the form of a technical report, usually one report per experiment. This report is utilized in the facility development for the STS and the ISS, and accumulated in various databases. Nevertheless, the information (experiences or lessons learned) is mostly accumulated individually. Since an ISS-JEM project may last for a long time and face a generation change of scientists and engineers, technology transmission from the present to the future is critical for the space experiment to be successful.

2-4 Experiences and Lessons Learned from Space Experiments

Experiences and lessons learned can hardly be described in a clear format. Nevertheless, the major categories of collective wisdom are delineated in the following section.

2-4-1 During Preparation

1) 95-5 Rule

A mission consists of 95% ground experiment and 5% space experiment.

This statement has two meanings. The first suggests carrying out as many ground experiments as possible because the repetition of the experiment on orbit is severely restricted. Ground preparatory experiments involve the precise determination of experiment parameters, and the validation and verification of parameters by the facility FM.

The second meaning suggests scrutinizing the experiment, once again questioning whether or not the planned experiment is worth executing on orbit. For example, in the case of an experiment controlling convection, the convection velocity on the ground can be suppressed to the level of microgravity $10^{-3} – 10^{-4}g$ by providing a liquid column of 1mm diameter. In validating the theory, if a large diameter of the liquid (sample) column is not required, it is not necessary to try a space experiment at all.

2) Determining precise experiment parameters

In a space experiment, repetition is not as possible as it is on the ground. The repetition of ground experiments and the optimization of experiment conditions are necessary to achieve success in the first trial on orbit. In addition, the experiment conditions cannot be changed easily on orbit; thus, “the more ground experiments the better.” Change requires agreement with the operator in advance.

In the case of the FMPT crystal growth experiment, more than 100 experiments were carried out to determine the optimum conditions, such as the seeding condition to utilize the seed crystal. In-depth prior evaluation of the experiment conditions enabled us to see success and yielded many insights, such as the capability to preset the proper microgravity condition necessary for homogeneous crystal growth.

3) Ground experiment by the trial model (BBM)

In the early stage of the design phase, it is necessary to build a BBM of the facility, specimen block, and other components/devices, and to examine the performance of each component as well as the instruments combined. The higher the fidelity of those apparatus to the FM, the higher the accuracy and significance of the data. Since the ground test cannot substitute a 1g environment for a μg environment, tests using aircraft or drop-tubes are recommended to validate and confirm the design of the FM under μg.

4) Ground experiment by the flight model (FM)

Decisions regarding experiment parameters are based on the results of the ground experiment of the proposers. Obtaining the expected results is not 100% guaranteed when the preset parameters are applied to the FM. The slight difference between the BBM or the EM and the FM causes a “difference” in science. Ground models are manufactured without any operational constraints, while the FM is designed considering various restrictions of facilities on board the ISS-JEM. Thus, the ground test by the FM is necessary to obtain feedback on the FM design and to determine the precise parameters of on-orbit experiments.

5) Test as a means to discover “the unexpected”

In the development stage of a cartridge, when the container of the specimen material in which electric current was to be charged, the electric voltage did not rise during the test. Engineers found that the sample material had leaked out of the electrode, and supposedly made contact with the furnace. Thus, the electric current passed the leaked material and went through the furnace structure (i.e. a malfunction occurred).

A countermeasure was taken to stop this type of malfunction. First, the structure at the electrode was reinforced to reduce the possibility of leakage. Next, the cartridge was insulated around the electrode (i.e. isolated from electric current). Insulation prevented the passage of electricity to the apparatus, even if leakage occurred. Finally, insulation was extended to all portions of the cartridge, such as the mounting interface with the interior structure of the furnace.

This countermeasure was sufficient to make electric charge possible under the possible leakage of sample material. In the actual flight, leakage did not occur. Therefore, the preparatory action proved to be correct and adequate.

As this experience exemplifies, the ground test at the earlier stage of planning may be a good opportunity to avoid an unexpected event on orbit. However, in the actual development process of the facility, the performance of the facility is verified at the last moment after ample design validation is completed. It is difficult to obtain feedback from the verification test to create a better design, even if a problem does occur. To alleviate the associated risk, two approaches are proposed: to proceed from BBM, EM, PFM, and FM; or to carry out a thorough test from the BBM stage, when the EM and PFM are omitted.

6) Foundation of microgravity science

Microgravity science starts from designing the experiment hardware.

If water held in a beaker is heated in space, it will not stay in the container; instead, it will float in the air and become a large spherical bubble. Conducting an experiment that involves heating water in space requires coming up with a completely different experiment facility, unlike most ground experiment facilities. This is the starting point of microgravity science experiments.

It is necessary to exercise one’s imagination to design devices, while considering the evidence revealed by short-time μ-g experiments by aircraft, drop-tubes, or sounding rockets, to ensure that the idea/concept will work under microgravity.

Controlling a water bubble at a certain position in space first requires the confirmation of the method, its effectiveness and reliability, based on preparatory tests on the ground (e.g., aircraft, droptube, or sounding rocket).

Evidence data is necessary to ensure that the design of the hardware meets safety standards and restrictions. Otherwise, rework would be imposed at the last moment of the safety review, and the experiment contents might be drastically degraded.

A ground reference experiment under $1g$ is sometimes possible, but at other times it is not possible, depending on the experiment facility on orbit. For example, a large-diameter liquid column cannot be handled on the ground, but it is possible in space. If reference experiments are impossible on the ground, a quite different approach is required. Finding an alternate approach is part of microgravity science.

Originality in experimentation may lead to publication of the results in the academic journal of the appropriate discipline. Writing a paper sometimes impels the scientist to notice the lack of data or defects in the data, thus inspiring another idea to develop. Such a situation is beneficial not only for the scientist but also for the rest of the world. For example, in the days of the Apollo program, the savior of the Apollo 13 crew facing the accident was the trouble-shooting software created by a Ph.D. student, which had accidentally been filed at the NASA office. This praiseworthy story tells more than a dramatic novel. We propose a research system in Japan where all such Ph.D. theses are registered. Microgravity science is abundant in research subjects and topics.

In summary, experiences that still need explanation include the following:

①Merit and demerit of the cartridge where the heater is enclosed
②Fidelity of the thermal model in the early stage of design
③Check and review organization
④Development of optimized mission-specific specimen block
⑤Determination of the dimension of the specimen block, with anticipation that the process will be supported by proper validation
⑥Necessity of prior validation/verification of sample materials
⑦Many development items on a new experiment
⑧Configuration difference, even the slightest, that may lead to malfunction
⑨Rejecting stereotypic thinking
⑩Regarding the FM casually
⑪Deeper understanding of necessity as a shortcut to problem solution.

2-4-2 Failure attributed to Lack of Experience

Despite hard work on ground preparation, an unimaginable situation may occur in space, and failure may result. Some examples are described below.

1) Differences between flight (on orbit) and ground environments

Here, some practical examples of the differences between flight and ground environments will be described. In the liquid pillar (column) formation experiment, the temperature difference between the upper and lower disks was 32.5K for the ground experiment, but 46.6K for the microgravity experiment, even if the power supply to the apparatus remained the same for both. Periodic oscillatory flow during a 3sec period was observed on the ground, and non-periodic compound flow associated with temperature variation with several periods was observed under microgravity.

In the silicon solution experiment, the final temperature attained inside the molten silicon under microgravity flight conditions was 15 to 30 degrees higher than it was on the ground. Consequently, the temperature of the flight sample material was higher over all of the cartridge.

The following reasons for these phenomena were determined: suppression of thermal convection, differences in thermal environment due to argon gas flow variation, and heat imbalance (excessive input heat from the electric pump) due to a smaller amount of SiO_2 grown on the silicon surface and attached to the interior quartz tube wall.

Clearly, the factors described above indicate the differences between 1*g* environment and microgravity environment. They emphasize that an understanding of the phenomena in the idealistic sense could not be reflected in the proper setting of experiment conditions.

2) Difficulty in removing air bubbles

Since it is difficult to remove air bubbles under microgravity, their suppression is necessary. When dispersion alloys are made of powder material, gas bubbles evolve out of the material when the material becomes molten. Even if the amount of gas is small, the gas bubbles become very large because of high vacuum and microgravity, and stay inside the solidified substance after it has cooled down. Moreover, disturbance by gas bubbles inside the molten material causes larger grain separation than that by the gravity effect. Thus, a countermeasure to suppress the generation of gas bubbles is necessary for microgravity experiments.

At the time of the FMPT experiments, bubbles were suppressed by developing handling technology of experiment sample materials at a high temperature and under a vacuum, and procuring a pressurized high-temperature electric furnace.

In a TR-1A sounding rocket experiment, no pressurized high-temperature electric furnace was available; therefore, the sample material underwent a treatment of hydrogen/vacuum processing and high temperature, and the addition of titanium. Most ground experiment tasks were carried out to make sure that no gas bubbles would appear. Consequently, solution and solidification experiments of alloys and semiconductors in FMPT and TR-1A programs were successful.

3) Dominance of Marangoni convection under microgravity

Once, the experiment results could not be analyzed because the effect of Marangoni convection was dominant in a molten alloy dispersion experiment. The reason for this problem was that the temperature profile became more complex than on the ground, due to the apparent increase of mass transport under microgravity. Possible methods to suppress Marangoni flow in space are to suppress the formation of free surfaces by pressurizing the molten substance, to lessen the quasi-surface area by using a crucible with better wettability, and to decrease the temperature differences among components of dispersing materials in order to suppress the convection induced by the density gradient.

4) Residual gravity and gravity jitter

On the Space Shuttle and the ISS, gravity will not become zero, due to the existence of residual gravity. In addition to static gravity, the noise (g-jitter) of gravity consists of many frequencies. Thus, an experiment should not be designed assuming zero-gravity.

Failure in the earlier space experiments were mostly attributed to the fact that scientists did not pay much attention to microgravity, and thus they did not obtain the expected results.

5) Verifying hardware performance in microgravity

In the sounding rocket experiment, it was important to evaluate the performance of the facilities under microgravity. Thus, experiments by droptube and airplane were conducted to acquire the design data necessary to develop the flight hardware and to determine the experiment plan.

6) Failure of liquid column formation

One failure was due to the oscillation of the extruding liquid column at the initial phase of formation. This oscillation caused the column to contact part of the harness protruding from the heating disk. Thus, the liquid escaped (leaked) from the disk into the harness. This protruding portion of harness was not supposed to be there. However, it was recognized not as a potential hindrance to the experiment, but rather as a small shade when taking the infrared image pictures, even when observed during the ground test. A precise analysis and evaluation of the accident revealed that the problem could be resolved by extending the length of the neck to the depth of the disk from the base, and a recommendation was made for developing ISS hardware. Nevertheless, the experiment results produced new findings: because of the liquid leakage, the shape of the liquid column was not cylindrical but like a round saddle (i.e. the diameter of the column was largest at both disks and smaller at the center). Viewing from the observation camera in the direction of the disk axis revealed a ring-like halation around the center portion of the column. This halation moved around with the surface vibration of the column, and analysis of the camera image enabled us to quantify the surface vibration of the liquid column.

7) Movement of molten specimen in a quartz crucible

It was formerly considered that an object placed statically in the STS would not move around in microgravity. This assumption was not correct. As an example, a molten sphere was observed floating around and hitting the wall of the quartz crucible.

Some external force is needed to move the center of gravity of the molten sphere. The question was what this force was and where it originated. We examined the recorded g-jitter history, but no pulse of gravity had been recorded at that specific time. The answer to this question has not been obtained thus far.

2-4-3 Teamwork

1) Teamwork and group efforts for space experiments

A space experiment is a large project that requires cooperation among many specialists and professionals, and expertise is necessary. For example, a crystal growth experiment requires a theoretician, a specialist on numerical simulation of fluid dynamics, a specialist to measure physical properties, a specialist to analyze and evaluate the quality of the crystal, and space experiment engineers. Collaboration among those people is necessary.

2) Amalgamation of science and technology

The scientists should carry out as many ground experiments as they can, scrutinize the contents of the experiment, and prepare the Experiment Planning Document so that the experiment operator and facility manufacturer can understand the contents in depth. Additionally, people on the operation side and hardware developers must carry out their assignments flexibly so as to achieve the scientific objectives.

In determining experiment conditions, scientists must understand the characteristics of the hardware, and facility developers must understand the experiment objectives. It is not a negotiation in which one side gives way to another, but rather the creation of collective wisdom to achieve optimum experiment conditions. The science by the scientists and technology by the hardware developers then merge, leading to successful space experiments.

3) Coordination of operators, researchers, and hardware developers

The most important aspect in carrying out a space experiment is coordination among scientists, space agency personnel, hardware developers, and technical support workers. This coordination is intended to determine the proper experiment conditions with previously prepared facilities under numerous constraints, without degrading the scientific concept/objective. The continuation of coordination meetings with possible trial and error will bring about deep mutual understanding and credibility. In the case of the sounding rocket experiments, the Space Experiment Planning Document became increasingly more substantial as the project proceeded.

4) Networking with multidisciplinary specialists

Every time a difficulty arises (e.g., a broken cell in the middle of an experiment, a cell that does not fit the size of the cartridge, an impossible electric chemical measurement), it is necessary to find someone to fix the problem. No report may exist to help the experimenter find the right person (engineer) at the right time for assistance. Technology is usually not written in a report or a textbook; instead, it belongs to individuals. Thus, it is always advisable to maintain an association with specialists of all disciplines.

5) Debate and discussion in advance

The experiment coordination meeting of scientists and engineers of different disciplines involves discussions about many proposed items until ample mutual understanding is achieved; such a meeting is productive in that it brings out what the scientists may not have noticed.

An example is application of 10g during rocket launch. If gravity segregation occurs during the solidification process, it will not occur in the solution-solidification process under microgravity. In contrast, if gravity segregation occurs in the molten state, segregation is accelerated by the excessive launch gravity of 10g and a significantly segregated sample might be acquired. In this case, the sample material is in a molten state prior to the launch. As a result, we decided to carry out two experiments using two electric furnaces. In one furnace, the sample material became molten prior to the launch. In the other furnace, the sample material became molten after reaching the microgravity condition.

2-4-4 Importance of Numerical Simulation

Currently, it is possible to foresee what will happen in flight experiments, thanks to available software and high-speed computers. For example, the behavior of a fluid under microgravity can be predicted by simulation, to a certain extent. Needless to say, ground experiments are important. However, experiments conducted on the ground cannot be used to determine the experiment conditions in space.

It is helpful to consider the example of the FMPT experiment. In the crystal growth experiment, the position where the seed material was supposed to become molten was shifted 15mm along the higher-temperature portion of the sample in space. This discrepancy was due to the fact that convection was suppressed under microgravity (i.e. heat transport was suppressed). While on the ground, heat was obviously transmitted from the higher temperature portion to the lower temperature portion because of natural convection.

Under microgravity, the transfer of heat took place primarily through conduction. Understanding these results and conducting some preparatory numerical simulations in advance enable predicting the location and interfacial shape where the seed material will start to become molten.

2-4-5 Failure Attributed to Excessive Familiarization

1) Importance of not relying on past achievements

Sometimes the vector of the success gene disappears, and failure occurs. In the sounding rocket experiments, success was apparent with the fluid experiment forming the liquid column from flights 1 through 3, even though the diameter of the liquid seemed slightly smaller. However, when the diameter of the fluid column was increased for flights 4 and 6 with the heating disk made of glass, the liquid column did not form successfully.

The earlier success caused us to be too confident in the design of a similar facility later. It is necessary to be prepared to encounter difficulty and criticality when designing facilities of different sizes, especially larger ones.

2) Difficulty of modifying hardware

As mentioned previously, the fluid physics facility flown on sounding rocket flights 4 and 6 was a modified version of that flown on flights 1, 2, and 3. In general, modification is easier than designing a new device. However, sometimes modification is carried out by a different team, not the original team who developed the previous version. Thus, modification turns out to be more difficult than new development. Past achievement and success do not enable us to make changes freely unless we have adequate and proper reasons to change. It is necessary to minimize change/addition/time/cost/labor. It must be emphasized that the engineers modifying the hardware have to be more knowledgeable about their tasks than those designing new hardware.

3) The Importance of Having Someone In Charge

This section is a continuation of 1) and 2) above. The fluid physics facility structure and the heating disk for the fluid column formation device of flight 6 were developed independently by different personnel (engineers). The heating disk itself was verified by the aircraft experiment, and it was successful in flights 1, 2, and 3. Moreover, the problem on flight 4 was supposed to be fixed. Therefore, no one doubted the proper flight operation and success of flight 6. Everybody was prone to think that since it had been successful in the past, it would work adequately, and individuals tended to think that they should look at only what they themselves had modified. Consequently, no one was in charge at the critical moment.

4) Compatibility of flight cell (container of the specimen) to specimen

At one time, the flight sample of colloid was charged in the flight cell at the launch site, and the anticipated crystal growth was supposed to be observed right after the filling of the sample. However, it did not appear, and no desalination reaction by the ion exchange resin was observed.

The reason was determined later: air bubbles blocked the resin mesh, inhibiting the desalination reaction, since the wettability between the teflon mesh and sample solution was not appropriate. Unfortunately, the reason was not discovered at the launch site; the sample was repeatedly refilled and precious time was lost, prolonging the launch site tasks.

5) Manual processing to fill the cell with sample material

A certain task carried out in the laboratory without apparent consciousness, due to years of similar routine exercises, may be forgotten at a critical moment, even though those chores are crucial to keeping the material in proper condition. However, the environment at the launch site is different from that at the laboratory, and filling the sample material may sometimes fail.

6) Preparation of backup sample material

During the colloid experiment, much of the sample material was prepared to adjust the crystal growth velocity, but it became unusable.

Aggregation of the sample was enhanced due to the low efficiency of stirring (mixing), resulting in lower density than expected. Thus, it was impossible to measure the spectrum because the spectrum peak was outside the measurable range of the frequency (into the higher frequency region).

We could quickly refill the higher density sample material and proceed. In this particular situation, we were lucky to have backup samples.

2-4-6 Regard for even Classical (Low) Technology

1) Difficulty of Precise Drilling

In making the instruments and jigs, the structural members must be drilled precisely. For example, it requires high skill to drill a hole with a diameter of 1.5m and a depth of 19.5m, with a precision of $\pm 10\mu m$. Generally speaking, the mechanics and engineers of small or medium-sized companies tend to possess those skills. Once we ordered a large company, a manufacturer of sintered boron nitride, to drill the hole on the plate. They brought back the plate with a hole of 50μm at one end but a hole of a different size at the other end. The hole was tapered! They then showed us a document guaranteeing their work.

2) Experiment Materials

Since space experiments are expensive, scientists and support workers tend to prepare special items for the space experiments, in spite of the fact that they prepare homemade samples for the ground research. This difference will definitely cause trouble for space experiments. It is not advisable to prepare and procure special materials for the space experiment; instead, the same or similar material should be used in both experiments, with the space experiment serving as an extension or an extrapolation of the ground experiment.

2-4-7 How to Cope with a Long Waiting Time on the Ground

A space experiment is a project type of research activity that requires five to six years for preparation. It is carried out with the collaboration of scientists, engineers, and support workers. The most important factor in this activity is the confidence of the scientists in their research objectives. Scientists should continue asking questions objectively and trying to find answers; doing so raises their level of confidence.

On the MSL-1 flight, one mission came down without results, due to some trouble on board the STS. The scientist on that mission remained calm and waited until the re-flight of the mission, because he/she had confidence in its scientific significance.

2-4-8 Vigilance on Serendipity and Unexpected Happenings in Space

If everything goes as planned, all people working on a project will become bored. We must be vigilant in observing and analyzing what we did not expect.

An example of an unexpected happening in space is the spherical crystal of the semiconductor that appeared accidentally. In the crystal growth experiment of PbSnTe, in addition to the cylindrical crystal (the target crystal), a number of spherical crystals (11mm diameter) were unexpectedly found inside the carbon spring used to pressurize the molten substance. The dislocation density of the spherical crystals was of the magnitude $10^4/cm^2$, two digits lower than that of ground-grown crystals. Thus, the quality of the crystal became the new world record. News of this unexpected byproduct was noteworthy among those in the science community of that day.

In the experiment of InGaAs, crystal segregation was not realized. At that time, the relation between the g-jitter and segregation did not receive attention, but in later years this question became a topic of research and was studied extensively.

Appendix

Valuable Information Sites (Materials Sciences)

Database	
JAXA International Space Environment Utilization Research Database	http://idb.exst.jaxa.jp/
NASA Microgravity Science Research Database	http://edmp.grc.nasa.gov/idea_search.cfm
ESA Space Experiments Database	http://spaceflight.esa.int/eea/
Academic Societies and Organizations	
Japan Society of Microgravity Applications	http://www.jasma.info/
European Low Gravity Research Association	http://www.elgra.org/
Others	
Multi-users' Experiment Apparatus	http://iss.sfo.jaxa.jp/kibo/kibomefc/index.html
Safety	http://www1.jsc.nasa.gov/toxicology/
Outgas Data	http://matdb1n.tksc.nasda.go.jp/outline_j.html

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(1) H. Inokuchi, Editor, Memoir of Japanese Space Experiments -Accomplishments and Lessons Learned-, (Japanese text) The Japan Society of Microgravity Application, 22 Supplement, 2005.

(2) Executive Summary of " Memoir of Japanese Space Experiments - Accomplishments and Lessons Learned –"JAXA Brochure

Editorial Postscript

This brochure was developed directly from a brochure with the same contents but in Japanese, published by JSF in March 2007. When we wrote the Japanese text, we primarily followed the description pattern of the International AOs for medical/biological and physical/materials sciences, and presented the pivotal explanation.

Now, once again the description in Japanese has been translated into English, because this brochure is intended for international readers. Currently, JAXA is announcing that opportunities of ISS-JEM utilization will be extended to Asian scientists and technologists to enhance the existing ground collaborative endeavors with Asian countries. JAXA believes that joint space activities may strengthen the current friendly ties further in the future.

Even though space medicine is part of life science and should be included in the text as such, the space medicine research in space by Japanese experimenters has not yielded comprehensive results, and their achievements cannot be compared with those of life science and materials science described in Parts I and II. Thus, only an informative explanation is provided in the appendix of Part I so that readers may understand the current situation on board the ISS and the future plans of the JAXA space medicine research group.

The JEM module “Kibo” is scheduled to be launched and attached to the ISS very soon. Once Kibo is on orbit, its utilization will be possible for several years, possibly 10 years. This endeavor will definitely bring a new aspect and perspective to Japanese sciences at large, and will contribute much to national science and technology policy-making. It is hoped that this brochure will be widely circulated and read by not only the professionals but also the general public and policy-makers.

The former products in the Japanese text are well written. As a result, we had some difficulty translating the Japanese text into English because conveying precise nuances in the Japanese language often ends up as an approximation in English. Nevertheless, we believe that we did the best we could.

Last but not least, all authors express their gratitude to Ms. Satomi ISHI for taking time to tailor the entire script and to lay out the manuscript, tables, and figures in an orderly manner.

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