ISSN 0288-433X

THE INSTITUTE OF SPACE AND ASTRONAUTICAL SCIENCE REPORT SP NO. 16

The First Open Competition for the MUSES-C Asteroidal Sample Preliminary Examination Team

edited by

Ikuo KUSHIRO, Akira FUJIWARA, and Hajime YANO

March 2003

The Institute of Space and Astronautical Science, Sagamihara, Japan

ISAS REPORT SP No. 16, 2003

Published The Institute of Space and Astronautical Science (ISAS)
3-1-1 Yoshinodai, Sagamihara, Kanagawa 229-8510, Japan
Tel. +81-42-759-8009

Printed Tokyo Press CO., LTD.
2-27-12 Sakuragawa, Itabashi-ku, Tokyo 174-0075, Japan
Tel. +81-3-3932-9291

These reports are issued at irregular intervals.
All communications relating to these repoets should be addressed to the administration department, general affairs division, ISAS.

The Institute of Space and Astronautical Science
Report SP No. 16, March 2003

The First Open Competition for the MUSES-C Asteroidal Sample Preliminary Examination Team

Edited by

Ikuo Kushiro
Institute for Frontier Research on Earth Evolution

Akira Fujiwara and Hajime Yano
The Institute of Space and Astronautical Science

The Institute of Space and Astronautical Science
Sagamihara, Japan

Preface

In the last three decades after the U.S. Apollo and the former-USSR Luna missions to the Moon, sample return programs from other celestial bodies had not been conducted. However, meteoritic scientists have collected tens of thousands of meteorites from the Antarctic and hot deserts and cosmic dust samples from the low earth orbit, stratosphere, polar ices, and deep-sea sediments. Also the advancement of analytical instruments and techniques was greatly achieved, especially in the area of micro-analysis and non-destructive analysis. As for ground observations, a number of newly discovered asteroids is exponentially increasing within the last decade, mainly due to "spaceguard" activities, which search potentially hazardous Earth-crossing asteroids down to sub-km size and determines their orbits. Statistical studies of classification of meteorite/cosmic dust as well as those of asteroids are now possible.

Then, planetary science has entered the second golden age of the minor body exploration in the new millennium, following the International Halley Watch in 1980's. A list of completed or on-going minor body missions include: NEAR-Shoemaker mission for in-orbit investigation of the asteroid Eros, STARDUST mission for sample return from Comet Wild-2, Genesis mission for sample return of solar wind implantation, CONTOUR mission for multiple fly-bys of short period comets (but failed in space), and Rosetta mission for rendezvous and landing on a comet nucleus (originally planned for Comet Wirtanen but recently postponed the launch).

The ISAS's MUSES-C mission will be a Japanese entry to this list. Although it is defined as an engineering demonstration spacecraft, its ambitious goal to collect surface materials of an asteroid is totally unprecedented and may well become a giant leap for the advancement of astromaterial research. Compared with existing meteorite and cosmic dust collections, asteroidal samples that the MUSES-C will bring back to us in the summer of 2007 are so unique and precious that they come from the definitely known parent body which will be fully investigated in-situ and they are never interacted with the terrestrial environment. Although sample return from only one type of asteroids cannot close the case, the "ground truth" to be provided by the MUSES-C sample return is surely the first step to bridge between asteroid spectral types judged by ground observation and analytical results of astromaterials in laboratories.

As this is an endeavor for all the humankind, the returned samples should be distributed to as many qualified researchers as possible all over the world for maximizing its scientific output. Yet, such detailed analysis proposals must rely on general characteristics of the samples during the initial analysis phase. The MUSES-C Asteroidal Sample Preliminary Examination Team (MASPET) will consist of ISAS scientists, NASA and Australian Co-Is, and Japanese researchers from outsourcing institutions, most of who will be selected on the basis of open competitions in respective disciplines. The MASPET is responsible for characterizing general features of the bulk and some of major samples. They also must make acquired data available to the public after the first results published; then international scientists can request samples for detailed analyses accordingly.

The first competition was conducted in 2000-2001 and the MUSES-C Sample Advisory Committee endorsed the final recommendation in May 2002. A total of eleven applications from a large variety of analytical disciplines was received and peer-reviewed. Nine of them received two sets of unknown test samples to demonstrate their self-claimed analytical performance. Multiple international referees evaluated their reports and 6 of them were recognized as qualified to join the MASPET as of 2002.

This document is a compilation of some of their analysis reports, permitted to publish by respective applicants. Therefore, each report focuses on specific suitability for general characterization of the returned samples; yet neither new discoveries nor scientific achievements of the reports are their objectives of writing. Instead, the authors demonstrate how much their technical capabilities, analytical precision, and usefulness of the derived results for subsequent detailed analyses are worth being included in the MUSES-C initial analysis.

The competition will be repeated once more after the spacecraft launch and the final MASPET membership should be decided in the late 2005, after the spacecraft leaves the asteroid. This document may well serve the second round applicants in Japan as a reference of what levels of expertise are expected in the initial analysis phase, and any other researchers all over the world who are interested in applying for sample allocation during the detail analysis phase. This will also serve as a source book for ISAS to design an astromaterial curation and initial analysis facility.

March 2003

Ikuo KUSHIRO (IFREE, Japan)
Akira FUJIWARA (ISAS, Japan)
Hajime YANO (ISAS, Japan)

ISAS Report SP No. 16 The First Open Competition for the MUSES-C Asteroidal Sample Preliminary Examination Team

CONTENTS

The Institute of Space and Astronautical Science
Report SP No. 16, March 2003

The MUSES-C mission profile and the first MASPET competition procedure summary

By

Hajime YANO*, Michael E. ZOLENSKY†, Akira FUJIWARA*, and Ikuo KUSHIRO‡

(1 February 2003)

Abstract: ISAS's MUSES-C mission will be launched in May 2003 and attempt the world's first asteroid sample return. The target is 1998SF36, a sub-km, S-type asteroid. In order to maximize scientific output from recovered (mostly) powder samples, in June 2007, the samples should be distributed to as many qualified researchers upon proposals from all over the world. Yet, such detailed analysis proposals must rely on general characteristics of the samples studied by the initial analysis team, MASPET.

MASPET will consist of ISAS scientists, NASA and Australian Co-Is, and Japanese researchers from outsourcing institutions, most of who will be selected through the open competitions of mostly non-destructive, microanalysis techniques in respective disciplines needed during the initial analysis stage. They will work as one "all-Japan" team and are responsible for characterizing the general features of the bulk and some of major samples. They also must make acquired data available to the public, after the first results published within a year from the capsule touch-down, so that international scientists can refer them and request samples for suitable, detailed analyses accordingly.

The first competition was conducted in 2000-2001 and the MUSES-C Sample Advisory Committee endorsed the final recommendation in May 2002. A total of eleven applications from a large variety of analytical disciplines was received and peer-reviewed. Nine of them received two sets of unknown test samples to demonstrate their self-claimed analytical performance. Multiple international referees evaluated their reports and 6 of them were recognized as qualified to join the MASPET as of 2002. These "unknown" samples were the UNSM3529 fraction of Allende (CV3) and Valdinizza (L6). The competition will be repeated once more after the spacecraft launch and the final membership of the MASPET should be decided in the late 2005, right after the spacecraft leaves the asteroid.

1. MUSES-C MISSION PROFILE

The Institute of Space and Astronautical Science (ISAS) is responsible for all space science missions in Japan. In May 2003, ISAS will launch the World's first sample return mission from a near Earth asteroid (NEA), which is called with the code name "MUSES-C".

* Planetary Science Division, The Institute of Space and Astronautical Science, Kanagawa, JAPAN
† NASA Johnson Space Center, Houston, Texas, U.S.A.
‡ The Institute for Frontier Research on Earth Evolution, Tokyo, JAPAN

MUSES-C is defined as an engineering testing spacecraft for key technologies of future planetary exploration such as autonomous navigation, electric propulsion, surface sampling from minor bodies, and direct re-entry of return capsule to the Earth (Kawaguchi et al. 2000). It will be launched with the M-V-5 full-stage solid rocket from ISAS Kagoshima Space Center, rendezvous to the NEA "1998SF36" in the middle of 2005 for global mapping with the optical imaging camera with 8-color filter wheel (AMICA), the near-IR spectroscopy (0.85-2.1 micron) (NIRS), the X-ray fluorescence spectrometer (0.7-10 keV) (XRS), and the LIDAR for geological, mineralogical, chemical and topographical studies of the asteroid. Then, the spacecraft will descend to the asteroid surface and attempt "touch & go" sampling sequence at up to three different locations. Collected samples will be returned to the earth (the Woomera desert of Australia) by the re-entry capsule, in which keeps these samples vacuum-sealed, in June 2007.

2. MISSION TARGET PROPERTIES

The mission target body 1998SF36 was discovered in September 1998 by the LINEAR program. Through radar and multi-band optical observation campaigns in 2001, its orbital, physical and spectral characteristics were fully investigated (Binzel et al. 2001; Ostro et al. 2001; Kaasalainen et al., 2002). According to these results, the asteroid has the ellipticity = 0.280, perihelion distance = 0.953 AU, aphelion distance = 1.693 AU, orbital inclination = 1.726 deg., semi-major axis = 1.324 AU, retrograde rotational period = $\sim$12.15 hours, geometric albedo = 0.32 ± 0.04, absolute magnitude = +19.1, and $(490\pm100)\times(250\pm55)\times(180\pm50)$ m in size. Also visible and near-IR spectroscopy obtained during its 2001 apparition revealed it to fit the best with a red-sloped S(IV)-type spectrum having strong 1- and 2-micron absorption bands, analogous to ordinary LL chondrite olivine/pyroxene contents with possible space weathering effect (Sasaki et al. 2001). It is similar to the NEA Eros, which the NEAR Shoemaker spacecraft visited. The United States NRC and the COSPAR Planetary Protection Panel recently endorsed the space quarantine recommendation for 1998SF36 as follows: "No special containment and handling warranted beyond what is needed for scientific purposes (NRC Space Studies Board 1998)".

By assuming its bulk density similar to that of the LL chondrites, the surface gravity level of 1998SF36 may be in the order of 10 micro-G with its escape velocity = $\sim$20 cm/s. Recent in-situ studies by Galileo and NEAR Shoemaker spacecraft suggested that even relatively small asteroids preserve considerable amount of regolith on their surfaces (Veverka et al. 2001), although smaller asteroids are likely to hold thinner regolith layers due to its weaker gravity level.

3. SAMPLING SEQUESNCE

However it is still not possible to fully understand surface conditions of such minor bodies only from ground observation, prior to the launch of sample return spacecraft. Thus MUSES-C employs a sampling mechanism that suits for a diverse heterogeneity of target surfaces, from metal-silicate hard surfaces to regolith layers covered with fluffy microparticles. It is the impact sampling device consisted of projectors, a deployable "horn", cylindrical/ conical concentrator to receive and deflect ejected fragments, and a sample container or the "catcher", with separate rooms for each sampling, and a transfer mechanism to the capsule (Yano et al. 2002).

Once the sampling device touches the asteroidal surface with a tip of the horn, it starts to tilt and may hit its solar cell paddles and RCS thrusters of the spacecraft with local obstacles.

Therefore the timing is critical for RCS thrusts to ascent the spacecraft safely. By previous experimental and computational simulations of the touch-down sequence of the MUSES-C, it was concluded that the spacecraft must complete the touch-down detection, sampling and ascent firing within 1 second or so (Fig. 1) (Sawai et al. 2001).

During the sampling sequence, as soon as the end of the 1-m long horn, which extends out from the asteroid side of the spacecraft body, touches on the surface, a Ta metal projectile of 5-g mass is shot at a velocity of 300 m/s. Impact of the projectile produces surface ejecta, which are concentrated through the interior of the conical horn toward the catcher. The catcher is finally transferred into the reentry capsule and tightly sealed.

The expected amount of the samples from results of 1G and microgravity impact tests for both consolidated bed rocks and regolith simulants are around several hundred mg to several g per shot. A few grams of sample collection at each impact site are considered as a great success, thanks to current advancement of micro-analytical technology. However it should be noted that the majority of recovered samples were fine-grained (sub-mm size) particles, rather than large chips ($\gtrsim$several mm) of rocks. Because of slow impact fragmentation unlike hypervelocity impacts, significant shock alteration of minerals in the samples is not expected.

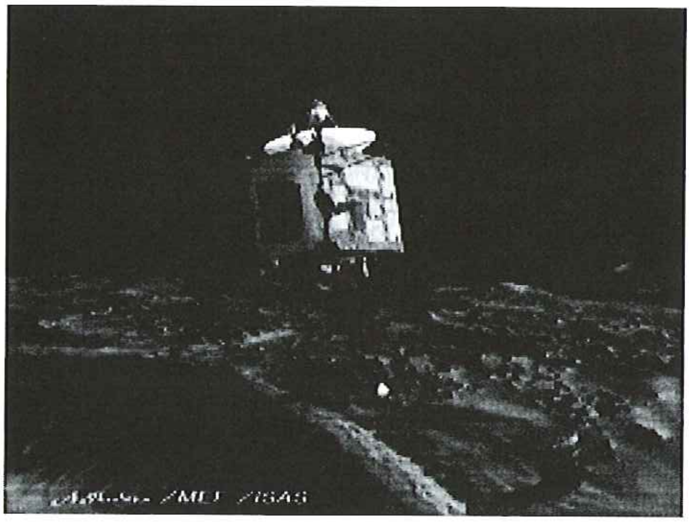

Fig. 1: The artist impression of MUSES-C descending to the asteroid surface for sampling (Courtesy: A. Ikeshita/ MEF /ISAS)

4. SAMPLE ANALYSES

After the safe recovery of samples sealed in the capsule in 2007, the curation work and initial analyses of these samples for general characterization will be carried out in Japan. However, unlike conventional meteorite and cosmic dust samples collected on the earth, curatorial work of astromaterials that have never interacted with the terrestrial environment before is not a trivial task. At present, the NASA Johnson Space Center (JSC) is the only institution in the world having such a facility and over 30 years of the service record for the Apollo lunar samples. JSC will continue serving as the curation facility for all the new sample return missions of NASA, including solar wind particles by the Genesis mission and cometary coma dust and interstellar dust samples by the STARDUST mission. Therefore it is important for Japan to create her first astromaterial curation facility with sample processing and preservation chambers in ISAS.

The initial analysis will investigate physical properties (e.g., mass, size distribution, morphology, color, transparency, etc.) and produce optical calibration data for the on-board instruments (AMICA, NIRS, LIDAR) from 100 mass % of bulk samples by non-destructive means. Then up to 15 mass % will be consumed to characterize the representatives of the 1998SF36 samples for more details and publish their results within one year after the capsule touch-down.

Given a sufficient amount of the samples (i.e, $\gtrsim$several 100 mg) is recovered, after the initial analysis period the announcement of opportunity (AO) for detailed analyses of another 15 mass % of the samples will be released to qualified scientists all over the world. The other 15 mass % will be used for competitive AO only open to Japanese scientists while the other 10 mass % will be permanently transferred to NASA. The rest will be preserved for future use (Fig. 2).

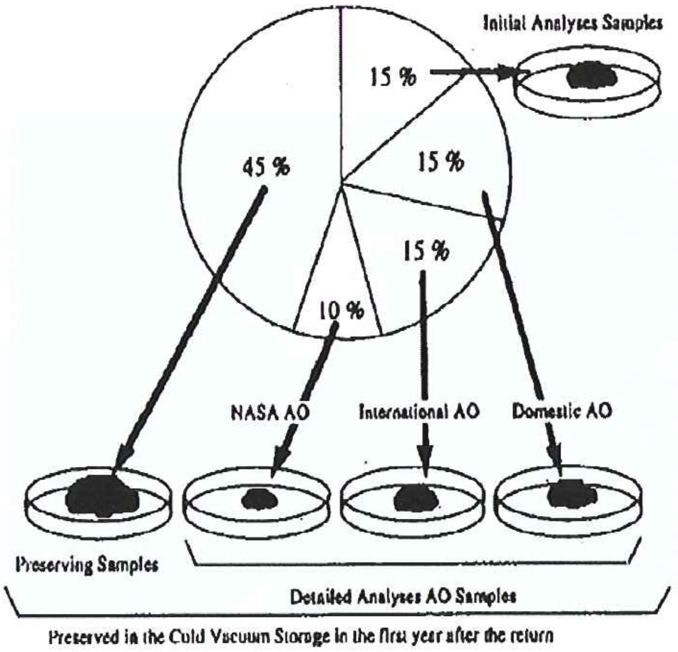

Fig. 2: MUSES-C sample division plan

5. THE FIRST MASPET COMPETITION

A group of scientists who will conduct the initial analyses of the MUSES-C samples is referred as the "MUSES-C Asteroidal Sample Preliminary Examination Team (MASPET)". As described above, impact sampling experiments expect the MUSES-C samples to be more similar to micrometeorites (i.e., powder samples) than large pieces of meteorites (i.e., chips). Confident exercise of non-destructive, micro-analyses whenever possible are vital. However, it is impractical to conduct all analytical disciplines only at ISAS while there are the world-class researchers with respective analytical techniques available in Japan. Instead, ISAS invites, on the competitive basis, several key "outsourcing" facilities and groups as the MASPET members, who will jointly work this initial analysis phase with ISAS (Fig. 3). Due to the international collaboration agreed by ISAS, NASA and the Australian Academy of Science, the MASPET members are also joined by two American scientists who will be selected through the NASA announcement and an Australian scientist. All of them will stay in Japan during the initial analysis. Thus the MASPET members must be very co-operative to each other as one team and may well need to analyze a very same microparticle by more than one technique.

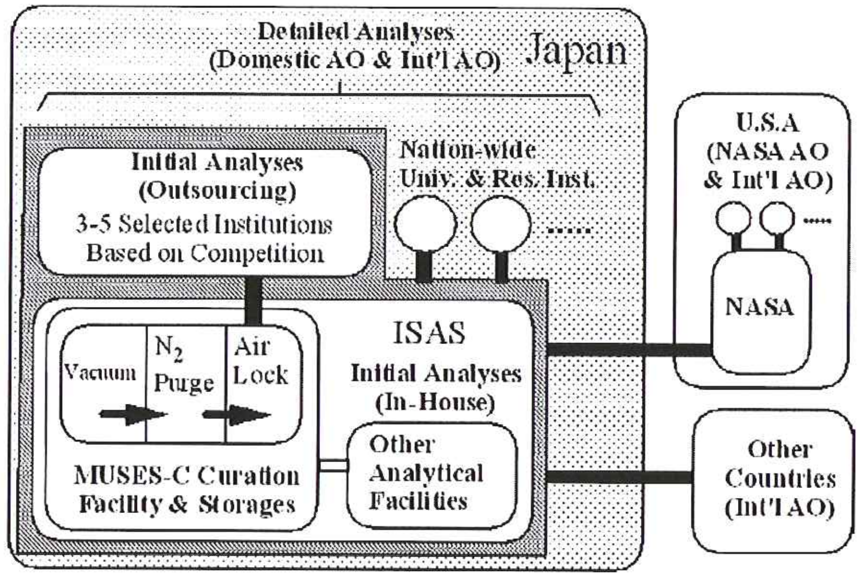

Fig. 3: MUSES-C sample analysis flow

In last several years, ISAS has formed the Sample Analysis Advisory Committee, chaired by one of the authors (IK), consisting of top astromaterial scientists in Japan, and received their feedbacks and recommendations to reflect spacecraft design, mission operation and sample curation plans. Since 1999, the MASPET competition scheme had been carefully planned and prepared by this committee. Then in the spring of 2000, ISAS welcomed domestic applications to the first round competition to demonstrate how much each micro-analytical technique (with the emphasis on non-destructive methods) of potential outsourcing groups is suitable for the MASPET analysis. Applicants were requested to propose analytical techniques on the open competition basis. The evaluation committee was also led by IK within the Sample Analysis Advisory Committee; this was the very first kind of an open competition for astromaterial sample analysis ever held in Japan.

6. EVALUATION PROCESSES

The details of the evaluation procedure are as follows. First, each proposal was reviewed by two domestic referees. This round was only to make sure that proposals were feasible and scientifically sound for the initial and general analysis but not for the detailed analysis. The contents of proposal must include how much mass of samples is required as the minimum in order to demonstrate the highest possible precision they can achieve and the shortest duration to conduct such an analysis at respective facilities in Japan. Therefore, the evaluation of each analysis report was focused on specific suitability for general characterization of the returned samples, as an integral part of the MUSES-C initial analysis activities. Neither new discoveries nor scientific achievements of the report were goals of this competition. Instead, the proponents must demonstrate how much their technical capabilities, analytical precision, and usefulness of the derived results for subsequent detailed analyses are worth being included in the MUSES-C initial analysis. Eleven groups applied from all over Japan and nine of them were passed this stage. The applications included (but not restricted to) the following techniques: (1) selected isotopic measurements, (2) ion probe (including SHRIMP), (3) carbonates, (4) organics & carbon isotopes, (5) major & trace elements, (6) micro-tomography, (7) mineralogy & petrology, (8) noble gas, (9) nuclear activation, and (10) residual magnetism.

At the second stage, two types of "unknown" asteroidal sample analogs (meteoritic samples that no applicant knew what they were in advance) were confidentially supplied by the Smithsonian Institution, thanks to E. Jarosewich, and prepared by the authors (MEZ and HY) with an anonymous volunteer researcher, implementing requests on sample handling tools, containers, contamination controls, etc., of each proposal as much as we could. Then in the summer of 2000, we handled the samples to subdivide for each of self-claimed amount of samples (the maximum of 100 mg each), with the JSC Apollo program Al foils and glass vials at the ISAS and the National Institute of Polar Research clean rooms (class 100).

After conducting respective analyses, the applicants were asked to write a report in English within in self-claimed duration (the maximum of 6 months) (i.e., by February 2001), in order to be peer-reviewed by two or more international referees. Those referees ranked the submitted reports with recommendations by the fall 2001 and return the results to the evaluation committee. After the completion of all the peer reviews, the evaluation committee compiled evaluations and recommended the finalists of this round competition to the Sample Analysis Advisory Committee. Finally in May 2002, the Advisory Committee endorsed the recommendation and six out of the nine finalists were recognized as being qualified to join the MASPET as of the year 2002.

7. TEST SAMPLES

In the whole period of the competition, the applicants were not informed what the two asteroidal analog samples they analyzed, while the referees were given the basic data of the samples for evaluation of the reports. These samples were powders of Allende/USNM3529 (CV3) (Clarke et al. 1971; Jarosewich et al. 1987) and Valdinizza (L6) (Levi-Donati & Jarosewich 1971; Jarosewich 1990). They were carefully chosen to test various aspects of micro-analysis capabilities in different techniques, including organics and carbonates. Some applicants specifically requested chip samples. Yet the primary focus of this competition was to evaluate the applicants' capability for handling and analyses of sub-mm samples, as expected from the impact tests, for the initial analysis service. It was also technically difficult to equally homogenize each sample and sub-divide them in all the size fractions (especially at larger ends). Thus some applicants filed an additional report for the analysis of larger pieces of the other samples prepared by themselves (e.g., chip pieces of a meteorite), after consulting the evaluation committee.

One of the two test samples was the USNM 3529 fraction of Allende, a well-studied CV3 carbonaceous chondrite, of which details are largely available in various journals and books (e.g., see the references mentioned above). Its standards were first prepared by wet chemical means, and cannot be duplicated now (because there are no longer wet chemists left analyzing these meteorites). Also it is important to note that the USNM 3529 sample is known to have the highest neutron effects among the Allende pieces by Cressy (1972); it has a 5-6 Myr exposure age as a whole, and its shielding depth was estimated to be ~100 g/cm^2 (Nishiizumi 2001).

Another sample was powders of Valdinizza, an unobvious L6 ordinary chondrite, which was well homogenized at the Smithsonian and then handled with aluminum foils designed for the NASA lunar samples. The meteorite was a fall witnessed in 1903 (July 12, 1000hrs) at 44°52' N, 9°9' E near Pavia, Lombardy, Italy. Two stones of 872.5 g and 131.5 g were recovered and included olivine-hypersthenes with 20.83 % total iron (see http://utenti.tripod.it/Meteoriteman/ and http://www.meteoritesales.com/met_v.htm). Based on noble gas measurements by Hintenberger et al. (1965), the meteorite contains a $^{22}Ne/^{21}Ne$ ratio of 1.068 and has an exposure age of 7 Myr. Although the exposure age is shorter than 20 Myr, neutron effects can be expected since it has a low $^{22}Ne/^{21}Ne$ ratio, which indicates high shielding conditions (Nishiizumi 2001).

8. FUTURE PLAN

Although the first competition made the six domestic teams recognized as being qualified to join the MASPET as of 2002, the MUSES-C is still to be launched and there will be 4 years of time gap between this competition and the beginning of the actual MASPET initial analysis. Analytical instruments, techniques, and professional personnel may advance greatly in next several years. Therefore, while the recognition of qualification through the first competition significantly counts, we shall repeat this competition one more time (planned to announce in the late 2003) in order to collect the best experts in the whole range of different analytical techniques at the time of the sample return. Then the final selection of the MASPET members will be made after the completion of in-situ measurements and sampling of 1998SF36 by the MUSES-C spacecraft (planned to leave the asteroid in November 2005).

ACKNOWLEDGMENTS

The authors are the most grateful to E. Jarosewich of the Smithsonian Institution for kindly allocating us the precious test samples for this competition. We also thank an anonymous volunteer researcher for helping the sample preparation and more than three dozens of anonymous, domestic and international referees for carefully evaluating the applications and their analysis reports. All the members of the MUSES-C Sample Advisory Committee are appreciated for their candid opinions and suggestions to make this competition successful. The ISAS MUSES-C mission staffs are supportive to the whole processes of this activity. T. Yajima of ISAS is also appreciated for her support on administrative work of the competition. Lastly, the authors thank all the applicants for participating on this unique opportunity and sharing their expertise and invaluable time with the MUSES-C project.

REFERENCES

Binzel, R.P. et al., 2001, MUSES-C target asteroid 1998 SF36: A reddened ordinary chondrite, Meteoritics & Planetary Science, 36.

Clarke, R.S. et al., 1971, The Allende, Mexico, Meteorite Shower, Smithsonian Institution Press.

Jarosewich, E., 1990, Chemical analyses of meteorites: A compilation of stony and iron meteorite analyses, Meteoritics, 25, 323-337.

Jarosewich, E. et al., 1987, The Allende Meteorite Reference Sample, Smithsonian Institution Press.

Kaasalainen, M. et al., 2002, Proc. Asteroids, Comets and Meteors 2002, ESA SP-500.

Kawaguchi, J. et al., 2000, Readiness of the MUSES-C project and the spacecraft flight model status, Prof. Int. Conf. of Space Technology & Science, 22, 2000-o-3-06v.

Levi-Donati, G.R. and Jarosewich, E., 1971, The Valdinizza meteorite: Mineralogy, chemistry and microtextures, Meteoritics, 6, No.1, 1-14.

Nishiizumi, K., 2001, private communication, University of California at Berkeley, U.S.A.

NRC Space Studies Board, 1998, Evaluating the Biological Potential in Samples Returned from Planetary Satellites and Small Solar System Bodies, National Academy Press.

Ostro, S.J., 2001, Radar observations of asteroids, Abst. Asteroids 2001, (http://www.astropa.unipa.it/Asteroids2001/Abstracts/Talks/ostro.doc).

Sasaki, S. et al., 2001, Production of iron Nan particles by laser irradiation in a simulation of lunar-like space weathering, Nature, 410, 555-557.

Sawai, S. et al., 2001, MUSES-C touch-down test by robotics simulator, Proc. 2000 ISAS 10th Workshop on Astrodynamics Flight Mechanics, 286-291.

Veverka, J. et al., 2001, Imaging of small scale features on 433 Eros from NEAR: Evidence for a deep regolith, Science, Vol. 292, 484-488.

Yano, H. et al., 2002, Asteroidal surface sampling by the MUSES-C spacecraft, Proc. Asteroids, Comets and Meteors 2002, ESA SP-500, 103-106.

REPORTS ALREADY PUBLISHED

SP 1 (March 1983)
Proceedings of the Symposium on Mechanics for Space Flight.

SP 2 (March 1984)
Proceedings of the Symposium on Mechanics for Space Flight.

SP 3 (March 1985)
Proceedings of the Symposium on Mechanics for Space Flight.

SP 4 (March 1986)
Proceedings of the Symposium on Mechanics for Space Flight.

SP 5 (March 1987)
Proceedings of the Symposium on Mechanics for Space Flight.

SP 6 (March 1988)
Proceedings of the Symposium on Mechanics for Space Flight.

SP 7 (November 1988)
An Aerodynamic in Relation to an Aeroassisted Drbit Transfer Vehicle.

SP 8 (December 1988)
Utilization of Laser Technology in Space.

SP 9 (March 1989)
Proceeding of the Symposium on Mechanics for Space Flight.

SP 10 (September 1989)
High Energy Particle Experiment for The Geotail Mission —GEOTAIL HEP—

SP 11 (March 1990)
Proceedings of the Workshop on Space Debris May 11, 1989 at ISAS Conference Hall

SP 12 (March 1990)
Proceedings of the Symposium on Mechanics for Space Flight 1989

SP 13 (March 1991)
Proceedings of the Symposium on Mechanics for Space Flight 1990

SP 14 (December 2000)
Mid-and Far-Infrared Astronomy and Future Space Missions

SP 15 (March 2003)
Proceedings of the 2002 International Science Symposium on the Leonid Meteor Storms