Space Biology Research Development

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and
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Final Technical Report

TABLE OF CONTENTS

I. Abstract 2
II. Project Description 3
III. Work Carried Out During Year 1 5
IV. Work Carried Out During Year 2 5
V. Work Carried Out During Year 3 6
VI. Work Carried Out During Year 4 6
VII. Concluding Remarks 7

Attachments:
1. Papers and Reports Nov. 1, 1985 - March 31, 1993 8
2. Advances in Space Biology and Medicine, contents vols. 1, 2, and 3 14

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I. ABSTRACT

The purpose of the SETI Institute is to conduct and promote research and related activities regarding the search for extraterrestrial life, particularly intelligent life. Such research encompasses the broad discipline of "Life in the Universe", including all scientific and technological aspects of astronomy and the planetary sciences, chemical evolution, the origin of life, biological evolution and cultural evolution.

The primary purpose of project NCC 2-614 has been to provide funding for the Principal Investigator to collaborate with the personnel of the SETI Institute and the NASA-Ames Research Center in order to plan and develop space biology research on and in connection with Space Station "Freedom", to promote cooperation with the international partners in the Space Station, and to conduct a study on the use of biosensors in space biology research and life support system operation, and to promote space biology research through the initiation of an annual publication "Advances in Space Biology and Medicine".

The Principal Investigator, Dr. Sjoerd L. Bonting, former professor & chairman, Department of Biochemistry, University of Nijmegen, Nijmegen, the Netherlands, has conducted the scientific and technical studies required for this purpose. He has worked in this capacity from November 1, 1985 till March 31, 1993, the last four years supported by the grant NCC 2-614. During this period he has become intimately acquainted with the life sciences programs of NASA and its international partners for Space Station "Freedom". He has written in this period a large number of papers and reports (see Attachment 1), many of which have had an impact on the planning and development of the Space Station life sciences facilities and program.

The role of NASA technical monitor during the tenure of this grant has been executed by Roger D. Arno, Deputy Chief, Biological Research Projects Office (Code SFL), NASA-Ames Research Center, in coordination with John W. Hines, Manager, Sensors 2000 Program (Code EES) for the biosensors work.
II. PROJECT DESCRIPTION

Space Biology Research Development

Space biology research plays a crucial role in the study of extraterrestrial life, both as fundamental research and as applied research.

Fundamental space biology research must provide information about prebiotic and early biological evolution as it may have taken place on other planets and other sites in the universe:
- Analysis (microscopic, biochemical, cultivation) of particles, collected in a Cosmic Dust Collector, can provide information about origin and transfer of biomolecules and primitive life forms;
- Soil samples, returned by unmanned and manned missions from Mars, Saturn's moon Titan, dark asteroids, and dark material on the surfaces of icy satellites of Uranus and Saturn should be studied for evidence of earlier, primitive life on these bodies;
- Growth of carbonaceous and icy grains from the interstellar gas phase should be studied in a Gas-Grain Growth Facility, to provide insight in the continuity of cosmic evolution from interstellar gas to solar nebula, stars and planets;
- Radiation exposure studies are needed to provide more insight in the effect of cosmic radiation, esp., HZE particle radiation, on biomolecules and primitive life forms on celestial bodies;
- Space biology studies will provide understanding of the effect of Earth gravity on the development and evolution of living organisms, their cells and physiological systems (human, animal, plant, and cell studies).

Applied space biology research is essential for qualifying man for long-term space missions. Questions must be answered, which are posed by the plans for extended duration missions on the Space Station (180 days and more), for a manned Lunar Base (1 year), for manned missions to Mars (1 to 3 years), and for an orbiting manufacturing Space Colony (up to 30 years):
- How long can man maintain health and productivity in 0-G, 0.17 G (Moon), 0.39 G (Mars), and with daily alternation between 0-G and 1 G (rotating Space Colony with manufacturing facility in hub), with and without countermeasures?
- What countermeasures are effective and possible?
- Is artificial gravity necessary?
- How can humans be protected against cosmic radiation during long-term space missions, particularly those beyond the Van Allen belt (Moon, Mars, Space Colony)?
- What kind of CELSS system will permit long-term human stay on Moon, Mars, and in an orbiting Space Colony?
- What forms of health care must be provided in Space Station, Moon and Mars bases and Space Colony; how will they have to be adapted from those used on Earth?

There is no clear separation between fundamental and applied space biology research, either in content, techniques or facilities. Applied research, to be efficient and successful, must rest on a solid basis of fundamental knowledge and understanding. In space biology research, our basic understanding is still very limited, and in many cases non-existent. For example, how can we hope to develop truly effective countermeasures against bone demineralization and muscle atrophy in low gravity, as long as we do not have a fundamental understanding of the mechanisms involved? Human studies to date have yielded not much more than the phenomenology of these processes. For example, recent cell studies and subsequent animal experiments, not aimed at studying these processes, have shown a large decrease in growth hormone secretion by the somatotrophic cells of the pituitary gland exposed to microgravity, both in vitro and in vivo. Since both bone demineralization and muscle atrophy seem to be due, at least in large part, to a
slowing down of synthetic processes, rather than to an accelerated breakdown, there is reason to believe that lowering of the growth hormone level in the blood may play an important role in both processes. This would obviously have consequences for electing the proper countermeasures: physical exercise would not be expected to protect against a secretion defect in the somatotrophic cells. A similar case can be made for the development of a biological CELSS system. Much more knowledge of the fundamental aspects of growth and behavior of plants and algae in microgravity is required before we can design, build and operate an effective and reliable CELSS system.

Not only do fundamental and applied research have to go hand in hand in an effective and scientifically valid space biology research program, but such a program must also encompass all subdisciplines: human, animal, plant and cell biology, exobiology and radiation biology. Fortunately, these subdisciplines have a common need for many facilities and instruments, which can thus be shared. Examples are: refrigerators, freezers, glove boxes, workbenches, biological and biochemical analytical equipment, and centrifuges. However, this requires careful planning and integration of many different research projects. In addition, the fact that the international partners in the Space Station program have very similar space biology interests, makes it highly desirable to cooperate in projects and to share research facilities, thus avoiding wasteful overlap in activities and reducing volume, power and crew time.

Since it is highly unlikely that such a broad and extensive program can be accomplished with the limited life sciences resources and duration of Phase-1 of Space Station Freedom, there will be a need for an extended space biology program with a considerable extension of facilities and resources in a later Phase-2.

The purpose of the work covered by this grant was to develop and define science rationale, methodology, facility and equipment requirements, experimental techniques, and mission sequence. This was to include such activities as writing program and project plans, defining equipment requirements and specifications, payload planning and mission analysis, experiment definition and description, defining space and ground operations, defining research resource requirements (volume, power, crew time, logistics). All this was to be done in good cooperation with the international partners and with the scientific community.

In addition, longer-term work was to be directed to provide opportunities for the SETI Microwave Observing Program in space, in case the ground-based system should fail to find the signals sought. This may involve basing a telescope on a Polar Platform of the Phase-2 Space Station, or basing it on the far side of the Moon, or on a platform in high Earth orbit. Attention was also to be directed to the definition, design and integration in the Space Station, Phase-2 payload of other exobiology facilities, particularly Cosmic Dust Collector, Gas-Grain Facility and Sample Quarantine Facility.

In year 1 the activities were primarily directed to the further definition and development of the large variable gravity centrifuge project, which includes the centrifuge, animal and plant habitats, a habitat holding facility, the glove box, and a cage cleaning device. This has also involved study of international cooperation between the Space Station partners in preparing and using facilities for space biology research on Space Station Freedom.

In year 2 the activities involved a study of habitats for past, present and future animal research in space, an ongoing study of potential biosensors for space biology research, and the writing and editing of reviews on all aspects of space biology research.

In year 3 the activities involved studies of cooperative use of the life sciences facilities planned for Space Station Freedom, continuing studies of potential biosensors for space biology research, and the writing and editing of reviews on all aspects of space biology research.
In year 4 the work was concentrated on the study of potential biosensors for space biology research and life support systems, and the writing and editing of reviews on all aspects of space biology research. In addition, a study of plant experiments and plant habitats planned for Space Station Freedom was undertaken.

III. WORK CARRIED OUT DURING YEAR 1

During the first year of this project 18 papers and reports were prepared (Attachment 1, nos. 45 - 62). During the preceding three years of my work for NASA-Ames Research Center (under separate funding) 44 papers and reports were prepared (Attachment 1, nos. 1 - 44).

A study of cryofixation in space was made (no. 45) with recommendations for the most suitable technique to be used for this purpose on Space Station Freedom (SSF).

The study on evolution of the life sciences program and facilities for SSF, Phase 2 (nos. 46, 47) was refined, and this material was presented at the meeting of the European Low Gravity Research Association, Toulouse (report, no. 48), the University of Nijmegen, the Netherlands, and at the ICES meeting in San Diego (no. 56).

During a lecture tour in Japan (report, no. 58) presentations were made at the Japan Space Utilization Promotion Center in Tokyo on animal research facilities on SSF, Phase 1, and on the evolution of life sciences research on SSF, Phase 2, at Nagoya University on animal research facilities on SSF, Phase 1, at the Kawasaki Space Technology Research Laboratory, Kobe, on animal research facilities on SSF, Phase 1, and on the evolution of life sciences research on SSF, Phase 2, at the Mitsubishi Takasago Research and Development Center, Himeji, on the evolution of life sciences research on SSF, Phase 2, at Kyoto University on the solar power satellite system. This was followed by attendance at the 9th IFSUSS meeting at the Japan Space Research Center, Sagamihara (report, no. 59).

Brief reports were written on the highlights of the SSSAAS meetings in League City, TX, and Santa Barbara, CA (nos. 51, 52). In addition, reports on Mars exploration and settlement (no. 49) and the Russian space program (no. 50) were prepared.

In keeping NASA workers up-to-date on the activities of ESA, reports on ESA publications (nos. 53, 55, 57, 60) and on the final report of the Columbus utilization systems study (no. 54) were produced.

During the year an invitation to become the editor of a new annual series, "Advances in Space Biology and Medicine", to be published by JAI Press, Inc., Greenwich, CT, was accepted. Twelve contributions from prominent experts in the USA, the Soviet Union, Europe and Japan were obtained for the first volume, published in 1991.

A major survey study of animal habitats used on previous space missions of the USA and the Soviet Union, and those to be used on future space missions of the USA and Japan was carried out (62).

IV. WORK CARRIED OUT DURING YEAR 2

An additional 18 papers and reports were produced during Year 2 of this project (Attachment 1, nos. 63-80).

For the Biological Research Project Office the extensive survey of animal habitats used in past, present and future space biology research, with a discussion of standards of animal care to be supplied, was completed (no. 62). At the COSPAR Meeting, The Hague, the Netherlands, a poster on the animal research facility for Space Station Freedom was presented (no. 64). A paper on the same subject was presented at the International Conference on Environmental Systems, Williamsburg, VA (no. 65).

In keeping NASA personnel up-to-date on the activities and developments in ESA, a report on relevant ESA publications in 1990 was written (no. 67).

At the request of John Hines, manager "Sensors 2000" program, and with the approval of Roger Arno, an ongoing study of biosensors with potential application in manned and unmanned
space biology research was undertaken (nos. 61, 63, 66, 72, 73). The Gordon Conference on Bioanalytical Sensors (no. 63) and the 5th International Diffuse Reflectance Conference (no. 66) were attended. At the Biosensors Symposium, Enschede, the Netherlands a paper was presented on the needs for biosensors in space biology research (no. 72). A report on developments in this field in the Netherlands was produced (no. 73).

As editor of the new annual series "Advances in Space Biology and Medicine", JAI Press, Inc., Greenwich, CT (no. 68), eight contributions were edited, and a ninth one (no. 70) and the Introduction (no. 69) for the first volume were written. Attachment 2 shows the contents of vol.1.

At the request of Ken Souza, Space Flight Program Division, and with the approval of Roger Arno, a series of reviews on six aspects of space biology research were prepared (nos. 74-79). These were edited into a draft chapter on "New Insights in Space Biology" (no. 80), which is to be published in a joint US-USSR multi-volume handbook on "Foundations of Space Biology and Medicine", successor to a 1975 publication under the same title.

V. WORK CARRIED OUT DURING YEAR 3

During year 3 attention was focused on three activities. For the Biological Research Project Office a study on the joint use of life sciences facilities by the international partners on Space Station Freedom was prepared (no. 88, 92). A statement on the use of the proposed ASI Life Science Mini Laboratory for housing the 2.5 m centrifuge was produced (83). In addition, NASA personnel were kept up-to-date on the activities and developments in ESA by the writing of several reports on relevant ESA publications and activities (nos. 84-87, 95, 96). In June 1991 the Man in Space Symposium of the International Astronautical Federation, Cologne, Germany was attended.

For the "Sensors 2000" program (John W. Hines, manager) the study of biosensors with potential application in manned and unmanned space biology research was continued. Invited papers on the need for such sensors in spaceflight were presented at the American Chemical Society meeting, Atlanta (no. 81), and at the Third Gordon Conference on Bioanalytical Sensors, Newport, R.I. (no. 91). Reports on these meetings were prepared (no. 82, 93). The Biosensors Symposium, Zeist, the Netherlands was attended (no. 90). The use of chemical sensors in monitoring recycled water quality was studied and the Fort Detrick, MD and Naval Research Laboratories were visited for this purpose (no. 89, 98, 100).

The work as editor of the new annual series "Advances in Space Biology and Medicine", JAI Press, Inc., Greenwich, CT was continued. The first volume appeared in November 1991 (nos. 68, 69, 70). The chapters for vol. 2 were edited, and the contents of this volume are shown in Attachment 2.

VI. WORK CARRIED OUT DURING YEAR 4

The primary emphasis during the final year of the grant was on the completion of the study of biosensors for application in manned and unmanned space biology research and in life support systems in the context of the 'Sensors 2000' program, managed by John W. Hines. The Second World Congress on Biosensors, Geneva, Switzerland, June 1992 and the ICES meeting, Seattle, July, 1992 were attended (105). At the latter meeting a paper was presented (103). Three papers on the application of chemical sensors in space biology research and in life support system monitoring were published (94, 104, 110). Several laboratories were visited where important developmental work on biosensors is carried out: the Lawrence Livermore National Laboratory (fiber-optic sensors) (102), the Naval Research Laboratory (evanescent wave optical fiber sensors), the TNO Institute, Zeist, the Netherlands (SPR sensors, enzyme sensors), and the MESA Institute, University of Twente, the Netherlands (electrochemical sensor systems on ISFET basis). On the basis of all information thus gathered two critical studies were written, one on evanescent wave optical fiber sensors (107) and one on ISFET sensor systems (111). In a series of three seminars at Ames Research Center (Feb. 11, 18, and
25, 1993) the various types of chemical sensors now existing were reviewed and proposals for a selection strategy and some recommendations were formulated. The material presented in these seminars has been consolidated in a final report (113).

In support of the work of the Biological Research Project Office (Roger D. Arno, Deputy Chief) the task to investigate, analyze, and document possibilities for cooperative use of life sciences facilities on Space Station Freedom with the international partners was continued. In particular, a critical study of all plant experiments planned for the Space Station and the various habitats proposed for these experiments was made with recommendations on the types of habitats minimally needed (106).

The work as editor of "Advances in Space Biology and Medicine" was continued, and a chapter on biosensors was contributed to vol. 2 (110). This volume appeared in November 1992 (108, 109). The contributions for vol. 3, which is dedicated to an ESA study on the effects of long-term isolation and confinement, were edited (112). The contents are shown in Attachment 2. This volume is expected to appear in November 1993. Editing of vol. 4 is in progress.

VII. CONCLUDING REMARKS

The four-year period of this grant covers the last part of my association with NASA-Ames Research Center, which lasted nearly eight years. During the first part of this period my work was financed through a grant of Dr. Richard E. Grindeland administered by the University of Santa Clara. I owe him gratitude for generously allowing me to work on the preparation of the life sciences facilities and experimentation for Space Station Freedom under the supervision of Roger D. Arno, Deputy Chief, Biological Research Projects Office (Code SFL).

It is a privilege to have been associated with the development of this large scale project with such great potential benefit for space biology research and for the future of manned space missions. It has also been a challenge to deal with the full panorama of space biological research and the engineering aspects associated with it. I have probably learned more new things during this period than during the preceding 35 years of my scientific career. Thus it has been a very stimulating way to conclude my 43-year activities as a scientist.

My association with NASA-Ames Research Center has resulted in 113 papers and reports, 68 during the tenure of this grant. Of these papers and reports18 - including two books edited and contributed to - have been published. In the process I have become familiar with the art of word processing, which has given me great satisfaction and has greatly facilitated the production of the many papers and reports resulting from my studies and activities. It is my hope that this work has been useful to the efforts of NASA-Ames Research Center now and in the future.

For the great amount of freedom I have been given in the execution of my tasks I am very much indebted to Roger D. Arno. His help and that of many others at Ames Research Center has been indispensable for the work carried out. I am also most grateful to Tom Pierson, director of the SETI Institute, and his staff for their constant help and for the use of their office facilities during the tenure of this grant. Finally, I wish to express my appreciation for the opportunity received through this grant to attend many meetings and to visit many institutes and laboratories in the USA and abroad.
Sjoerd L. Bonting, Ph.D.

Papers and Reports Nov.1, 1985 - March 31, 1993

5. Leven zonder Zwaartekracht, Biologisch Onderzoek in de Ruimte (Life without Gravity, Biological Research in Space), Natuur en Techniek vol.54, nr.8, 630-639, August 1986.
17. ESA Biochemical and Biological Analysis Facility, February 1987, 4pp.


27. ESA Life Sciences Program for the Man-Tended Free Flyer (MTFF), Nov. 4, 1987, 26pp.


30. ESA's Biotechnology Research Facility, Jan. 18, 1988, 10p.


50. Russian Space Program, June 1, 1989, 2 pp.


72. Biosensoren voor de Bemande Ruimtevaart (Biosensors for Manned Spaceflight), Optical Transducer Symposium, November 14-16, 1990, University of Twente, Enschede, the Netherlands, 18 pp.


Attachment 2.

ADVANCES IN SPACE BIOLOGY AND MEDICINE

Editor: Sjoerd L. Bonting, Sunnyvale, CA, USA
Publisher: JAI Press, Greenwich, CT, USA

Contents vol. 1, 1991

1. A.I. Grigoryev, Moscow Effects of Prolonged Space Flights on the Human Body
2. E. Holton & S. Arnaud, Moffett Field, CA, USA Skeletal Responses to Spaceflight
3. J. Miquel, Alicante, Spain & K. Souza, Moffett Field, CA, USA Gravity Effects on Reproduction, Development and Aging
4. S. Watanabe, Nagoya, Japan Neurovestibular Physiology in Fish
5. A.H. Brown, Philadelphia, USA Gravity Perception and Circumnutation in Plants
6. A. Merkys & R. Laurinavicius, Vilnius, Lithuania Development of Higher Plants under Altered Gravitational Conditions
7. A. Cogoli & F.K. Gmunder, Zurich, Switzerland Gravity Effects on Single Cells
8. L. DeLucas & C.E. Bugg, Huntsville, AL, USA Protein Crystal Growth in Space

Contents vol. 2, 1992

1. A.I. Grigoryev & A.D. Egorov, Moscow Mechanisms of the Effects of Weightlessness on the Human Body
2. A.I. Grigoryev & A.D. Egorov, Moscow Adaptation of Main Human Body Systems during and after Spaceflights
3. D. Philpott et al., Moffett Field, CA Ultrastructural and Cellular Changes in Myocardial Deconditioning
4. G. Gharib, Lyon, France Fluid and Electrolyte Regulation in Space
5. H.G. Hinghofer-Szalkay & Eva M. Koenig Human Nutritional under Extraterrestrial Conditions
6. A.D. Krikorian et al, Stony Brook, NY, USA Effects of Spaceflight on Growth and Cell Division in Higher Plants
Contents vol. 3. 1993
European Isolation and Confinement Study

1. J. Collet
   The First European Simulation of a Long Duration Manned Space Mission

2. V. Gushin et al.
   Soviet psychophysiological investigations of simulated isolation

3. A.W. Holland
   NASA investigations with isolated and confined environments

4. H. Ursin
   ISEMSI: a space psychology experiment

5. R.J. Vaernes et al.
   General description of ISEMSI

6. T. Bergan et al.
   Group functioning and communication

7. C. Tafforin
   Ethological analysis of spatial behavior

8. R.J. Vaernes et al.
   Workload and stress

9. R.J. Vaernes et al.
   Mental performance

10. G.R.J. Hockey & M. Wiethoff
    Cognitive fatigue in complex decision-making

11. G. Rizzoliati & A. Peru
    Attention

12. I. Tobler & A.A. Borbély
    Twenty-four hour rhythm of rest/activity and sleep/wakefulness

13. H.C. Gunga et al.
    Water and salt turnover

14. A. Maillet et al.
    Blood pressure, volume regulating hormones and electrolytes

15. A. Guell et al.
    Lower body negative pressure tests

16. D.A. Schmitt & L. Schaffar
    Immune function

17. M. Novara
    Additional experiments