NASA-CR-192830

Space Biology Research Development

Sjoerd L. Bonting, Ph.D.
Principal Investigator

Cooperative Agreement NCC 2-614
between
National Aeronautics and Space Administration - Ames Research Center
Moffett Field, CA 94035
and
SETI Institute
2035 Landings Drive, Mountain View, CA 94043

April 1, 1989 - March 31, 1993

Final Technical Report

TABLE OF CONTENTS

Future address of Principal Investigator: 12 Specreyse, 7471 TH Goor, the Netherlands (tel./fax: 31-5470-60947).
Selected reports and papers available from: Roger D. Arno, Deputy Chief, Biological Research Projects Office (Code SFL), NASA-Ames Research Center 244-19, Moffett Field, CA 94035; books from publisher.

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 counter-measures: 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 indispensible 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.

Attachment 1.

Sjoerd L. Bonting, Ph.D.

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

1. Report on ARC Conference "Space Station Human Factors: Research Review", December 1985, 6pp.
2. A Joint NASA-ESA Life Sciences Research Program on the Space Station: Feasibility and Advantages, January 1986, 51pp.
3. Trip Report of Visit to ESA Headquarters, Paris and ESTEC, Noordwijk, January 1986, 3pp.
4. Need, Utilization and Configuration of a Large Multi-G Centrifuge on the Space Station, July 1986, 24pp.
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.
6. Life Science Project Plan, September 1986, 30pp.
7. Comments on D.Keefe telemail Sept.4, 1986 about CETF Activity, September 1986, 1p.
8. ESA Studies of Space Station Facilities and G-Levels, September 1986, 1p.
9. ESA Activities, September 1986, 1p.
10. ESA Columbus Studies, September 1986, 2p.
11. Large Multi-G Centrifuge and Related Issues, paper presented at International Space Station Science Meeting, Ottawa, October 1986, 23pp.
12. Report on 4th International Space Station Science Meeting, Ottawa, October 1986, 18pp.
13. ESA - European Users' Requirements Analysis, WP-1000, Midterm Presentation, October 1986, 24pp.
14. ESA Module and Facilities, October 1986, 4pp.
15. Need, Utilization and Configuration of a Large Multi-G Centrifuge on the Space Station, in: Biological Sciences in Space 1986, Proceedings of the 1986 International Symposium on Biological Sciences in Space, Nagoya, Japan, November 10-12, 1986, eds. S.Watanabe, G.Mitarai, S.Mori, MYU Research, Tokyo, 1987, p.297-305.
16. Report on Joint NASA-ESA Life Sciences Program Working Group Meeting, Washington D.C., January 1987, 12pp.
17. ESA Biochemical and Biological Analysis Facility, February 1987, 4pp.

18. Crew Activities on Space Station, Report of ESA Columbus Crew Activities Working Group, February 1987, 3pp.

19. ESA Gravitational Biology Facility, Febrary 1987, 24pp.

20. Japanese Space Station Life Sciences Program, March 1987, 26pp.

21. Report on 5th International Space Station Science Meeting, Inuyama, Japan, April 1987, 22pp.

22. with Roger D. Arno: Program and Hardware Aspects of International Cooperation in Life Sciences on the Space Station, June 1987, 22pp.

23. Discussions at NASA Headquarters of paper "Program and Hardware Aspects of International Cooperation in Life Sciences on the Space Station", June 1987, 3pp.

24. Relevant Papers in ESA Bulletin, nr. 50, May 1987, 1p.

25. Report on Third European Symposium on Life Sciences in Space, Graz, Austria, September 1987, 7pp.

26. with Roger D. Arno and Steven D. Corbin: Animal Research on the Space Station, in: Proceedings Third European Symposium on Life Sciences Research in Space, Graz, Austria, 14-18 Sept.1987, ESA SP-271, Dec. 1987, p.361-365.

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

28. Report on 6th International Forum for Science Use of the Space Station, La Jolla, Nov.18-20, 1987, 6pp.

29. ESA Bulletin, November 1987, Summaries of Relevant Articles, Jan.15, 1988, 2p.

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

31. Space Station Microgravity Requirements and Disturbances, Jan. 22, 1988, 11p.

32. The Microgravity User Support Center at DFVLR, Cologne, W. Germany, March 1988, 3pp.

33. Report on 7th International Forum for Science Use of the Space Station, Versailles, France, May 15-18, 1988, 13pp.

34. Report on Space Station Science and Applications Advisory Subcommittee Workshop, Hyannis, MA, June 20-24, 1988, 12pp.

35. Some Suggestions for the international Joint Utilization Study, July 6, 1988, 2pp.

36. with Roger D. Arno, Jenny S. Kishiyama and Catherine C. Johnson: Bioisolation on the Space Station, 18th Intersociety Conference on Environmental Systems, San Francisco, July 11-13, 1988, SAE Paper 881050, 6pp., ISES Transactions 1989.

37. Evolution of Life Sciences Research on Space Station, A Review of Reports and Studies for Relevant Items, September 30, 1988, 32pp.

38. Evolution of Life Sciences Research on Space Station: A Long-Term Program for Life Sciences Research in Space and its Facility Implications, November 28, !988, 44pp.

39. Report on 8th International Forum for Science Use of the Space Station, Toronto, Canada, December 13-15, 1988, 11pp.

40. Nuclear Magnetic Resonance on Space Station, December 23, 1988, 11pp.

41. George A. Gerencser, John F. White, Diedrich Gradman, and Sjoerd L. Bonting: Is There a Cl-Pump?, Amer. J. Physiol. 255, R677-692, 1988.

42. Suggestions for the JSUS Working Meeting Washington, D.C., Jan.23-24, 1989, January 19, 1989, 4pp.

43. ESA Life Sciences Activities, February 7, 1989, 2pp.

44. Microgravity News from ESA, vol.1, nr.2, Nov. 1988, Summary of relevant items, February 9, 1989, 2pp.

45. Cryofixation in Space, March 7, 1989, 18 pp.

46. The Solar Power Satellite Scenario, March 20, 1989, 14 pp.

47. Evolution of Space Station: Life Sciences Program and Facilities, April 27, 1989, 11 pp.

48. Report on the Joint Meeting of the European Low Gravity Research Association and the Japanese Societies for Biological Sciences in Space, Toulouse, France, March 29-31, 1989, May 9, 1989, 15pp.

49. Mars Exploration and Settlement, May 27, 1989, 4 pp.

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

51. Highlights of the SSSAAS Meeting, League City, TX, October 13-14, 1988, May 30, 1989, 2 pp.

52. Highlights of the SSSAAS Meeting, Santa Barbara, CA, January 4-5, 1989, June 2, 1989, 2 pp.

53. ESA Publications 1988, May 31, 1989, 4 pp.

54. European Users' Requirements Analysis, Columbus Utilization Systems Study, Phase B2X, Executive Summary and Final Report, DFVLR-ESA, Cologne, FRG, June 1988, 53 and 225 pp., June 3, 1989, 4 pp.

55. Reaching for the Skies, ESA's Quarterly Publication on Space Transportation Systems, August 7, 1989, 1p.

56. Evolution of Space Station: Life Sciences Program and Facilities, 19th Intersociety Conference on Environmental Systems, San Diego, California, July 24-26, 1989, SAE Technical Paper Series no. 891474, 11 pp., ISES Transactions 1990.

57. ESA Publications 1989, October 2, 1989, 3 pp.

58. Travel Report Japan, October 4-20, 1989, 8 pp.

59. Report on 9th International Forum for Science Use of the Space Station, Sagamihara, Japan, October 17-19, 1989, October 31, 1989, 17pp.

60. Life Sciences Research in Space, ESA Publication SP-1105, July 1989, November 9, 1989, 3 pp.

61. Biosensors, December 5, 1989, 17 pp.

62. Habitats for Animal Research in Space, February 23, 1990, 102 pp.

63. Bioanalytical Sensors, Report on Gordon Research Conference, March 12-16, 1990, Ventura, California, April 2, 1990, 23 pp.

64. Animal Research Facility for Space Station Freedom, COSPAR Meeting, The Hague, the Netherlands, June 25-27, 1990, Advances in Space Research, 12(1):253-257, 1992.

65. with Roger D. Arno and Jenny S. Kishiyama: Facilities for Animal Research on Space Station Freedom, 20th International Conference on Environmental Systems, July 9-12, 1990, Williamsburg, VA, SAE Technical Paper Series no. 901303, 22 pp., ISES Transactions 1991.

66. Infrared Spectroscopy for Biosensor Applications, September 6, 1990, 19 pp.

67. ESA Publications 1990, October 15, 1990, 9 pp.

68. Editor, Advances in Space Biology and Medicine, vol. 1, 1991, JAI Press, Greenwich, CT, November 1991, 335 pp.

69. Introduction, Advances in Space Biology and Medicine, vol. 1, 1991, JAI Press, Greenwich, CT, November 1991, p. xi-xii.

70. with Roger D. Arno and Jenny S. Kishiyama: Facilities for Animal Research in Space, in: Advances in Space Biology and Medicine, vol. 1, 1991, JAI Press, Greenwich, CT, November 1991, p. 279-325.

71. Biosensor Overview, October 30, 1990, 45 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.

73. Biosensor Symposium, University of Twente, Enschede, the Netherlands, November 14-16, 1990, Report December 18, 1990, 19 pp.

74. Gravity Effects on Single Cells, October 13, 1990, 16 pp.

75. Gravity Effects on Human and Animal Development, October 29, 1990, 22 pp.

76. Gravity Effects on Bone, January 1, 1991, 32 pp.

77. Gravity Effects on Plants, January 5, 1991, 32 pp.

78. Gravity Effects on the Hematological System, January 11, 1991, 11 pp.

79. Gravity Effects on Muscle, January 12, 1991, 10 pp.

80. New Insights in Space Biology, January 14, 1991, 127 pp.

81. Needs for Biosensors in Space Biology Research, paper at Symposium on Commercial Opportunities for Development of Biosensors, American Chemical Society meeting, Atlanta, April 15, 1991, 13 pp.

82. Report on the Symposium on Commercial Opportunities for Development of Biosensors, American Chemical Society meeting, Atlanta, April 15, 1991, 2 pp.

83. ASI Life Science Mini Laboratory, May 14, 1991, 1 p.

84. ESA Activities and Developments 1989-1991, May 17, 1991, 3 pp.

85. ESA Publicity 1990-1991, May 18, 1991, 3 pp.

86. ESA Journals 1990-1991, May 20, 1991, 2 pp.

87. Overview of Life Science Facilities Developed by ESA, May 20, 1991, 2 pp.

88. Life Sciences Hardware Sharing on Space Station Freedom, May 22, 1991, 9 pp.

89. Sensors for Monitoring Recycled Water Quality during Long-Term Space Missions, May 31, 1991, 6 pp.

90. Biosensor Symposium, Zeist, the Netherlands, June 5, 1991, 13 pp.

91. Needs for Biosensors in Space Biology Research, paper at Gordon Research Conference on Bioanalytical Sensors, Newport, R.I., July 22-26, 1991, 13 pp.

92. Life Sciences Hardware Sharing on Space Station Freedom, August 19, 1991, 15 pp.

93. Bioanalytical Sensors, Report on the Gordon Research Conference, Newport, R.I., July 22-26, 1991, August 23, 1991, 16 pp.

94. Needs for Biosensors in Space Biology Research, in: *Biosensor Design and Application*, eds. Paul R. Mathewson and John W. Finley, ACS Symposium Series 511, 1992, p. 174-183.

95. ESA Life Sciences Activities (from a report of the ESA Life Sciences Working Group meeting, March 1991), September 14, 1991, 2 pp.

96. ESA Publications 1991, September 18, 1991, 2 pp.

97. Biosensors for Space Applications, September 9, 1991, 12 pp. (draft)

98. Sensors for Monitoring Recycled Water Quality during Long-Term Space Missions, Report of Visits to USAMRIID, Ft. Detrick, Frederick, MD and Naval Research Laboratory, Washington, D.C., September 30-October 2, 1991, October 4, 1991, 5 pp.

99. ESA Publications 1991, Cont'd., October 9, 1991, 2 pp.

100. Sensors for Monitoring Recycled Water Quality during Long-Term Space Missions, October 15, 1991, 11 pp.

101. Biosensor Symposium, Enschede, the Netherlands, December 11, 1991, Report February 8, 1992, 10 pp.

102. Fiber-Optic Sensors Developed at Lawrence Livermore National Laboratory, July 5, 1992, 9 pp.

103. Chemical Sensors for Space Applications, 22nd International Conference on Environmental Systems, July 13-16, 1992, Seattle, WA, SAE Technical Paper Series no. 921392, 13 pp.

104. Utilization of Biosensors and Chemical Sensors for Space Applications, *Biosensors & Bioelectronics* 7, 531-544, 1992.

105. Chemical Sensors at ICES, Seattle 1992, August 25, 1992, 4 pp.

106. Plant Studies and Habitats on Space Station Freedom, October 19, 1992, 6 pp.

107. Optical Sensors: Advantages, Disadvantages, Limitations, October 5, 1992, revised November 5, 1992, 9 pp.

108. Editor, Advances in Space Biology and Medicine, vol. 2, 1992, JAI Press, Greenwich, CT, November 1992, 304 pp.

109. Introduction, Advances in Space Biology and Medicine, vol. 2, 1992, JAI Press, Greenwich, CT, November 1992, p. ix-x.

110. Chemical Sensors for Space Applications, in: *Advances in Space Biology and Medicine*, ed. Sjoerd L. Bonting, vol. 2, 1992, JAI Press, Greenwich, CT, 1992, p. 263-293.

111. Electrochemical Sensors: Advantages, Disadvantages, Limitations, December 26, 1992, 11 pp.

112. Introduction, Advances in Space Biology and Medicine, vol. 3, 1993, JAI Press, Greenwich, CT, 2 pp., in press.

113. Chemical Sensors for Space Applications, Final Report with Recommendations, March 2 1993, 76 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

Contents vol. 2, 1992

<u>Contents vol. 3, 1993</u>

European Isolation and Confinement Study