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SUMMARY REPORT - INTERAGENCY AGREEMENT NO. DE-A102-79CH10025

ASSESSMENT OF THE EFFECTS OF THE ZERO GRAVITY ENVIRONMENT ON THE HEALTH AND SAFETY OF SPACE WORKERS

Date: February 18, 1980

ABSTRACT

NASA Life Sciences personnel, in conjunction with The Boeing Company, conducted a review of currently available information relating to adverse effects to the health and safety that SPS space workers may experience. Currently available information on the responses of humans to space flight is somewhat limited and was obtained under conditions which are grossly different from conditions to be experienced by future space workers. The limitations in information and differences in conditions have been considered in the assessment of potential health and safety hazards to the SPS space workers. The study did not disclose any adverse effects that would result in long term deviations to the medical or physiological health of space workers so long as proper preventive or ameleorating actions were taken.

A comprehensive report of study results summarizing the documented effects of the space environment experienced in previous manned space flights or in related ground-based studies has been submitted under separate cover. The report presents a plan for acquiring additional information for assuring that all possible adverse effects have been identified and that means of ameleoration are developed.

This study highlighted the need for several actions to be taken prior to sending large numbers of people into space. These include:

- *A continued research into the mechanisms involved in such physiological responses as calcium loss, muscle loss, cardiovascular deconditioning, changes in fluid and electrolyte distribution.*

- *A major design and development effort to improve life support and protective systems, habitability and health care systems.*

- *Extensive research into the psychological/sociological aspects of maintaining large numbers of workers in a space industry.*

- *Development of operational approaches which utilize results of the above to assure that career space workers and their families remain dedicated to the program.*

I. INTRODUCTION

This report and a full detailed report have been prepared in response to a letter request from Dr. Margaret R. White of the Lawrence Berkeley Laboratory dated March 5, 1979 and an interagency agreement DOE IA #DE-A102-79CH10025 between NASA Johnson Space Center and the Department of Energy (DOE). These reports present the results of a study performed by personnel within the NASA/JSC Life Sciences organization in conjunction with elements of The Boeing Company. In preparing these reports, an effort has been made to respond to the letter and intent of the Statement of Work (SOW) included in the interagency agreement.

It is understood that the information requested by the DOE is to support the "go or no-go" decision on the Satellite Power System (SPS) to be made in June 1980.

A. OBJECTIVE

The objective of the study was to assess the effects of all currently known deviations from normal of medical/physiological/biochemical parameters which appear to be due to zero gravity environment[(1)] and to acceleration and deceleration experienced in the reference SPS design on space workers. Study results are based on current knowledge and the current SPS Reference System Report, DOE/ER-0023, October 1978. These results include:

a. Identification of possible health or safety effects on space workers - either immediate or delayed - due to the zero gravity environment and to acceleration and deceleration,

b. Estimation of the probability that an individual will be adversely affected,

c. Description of the possible consequence to work efficiency in persons adversely affected, and

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(1) Although the SOW specified that only "the zero gravity environment and accelerations will be considered", NASA has taken the liberty of including potentially adverse effects caused by other stresses of working in the space environment. This was done to provide the DOE with relevant information which might otherwise have been excluded from consideration.

d. Description of the possible/probable consequences to immediate and future health of individuals exposed to this environment.

Another objective of this study was to prepare a research plan which addresses the uncertainties in the knowledge regarding the health and safety effects of the SPS space workers. This plan, if carried out, should make future assessments more reliable and will help to eliminate or ameliorate adverse health effects.

B. BACKGROUND

NASA has drawn heavily on the biomedical results of the Skylab missions with Apollo Soyuz Test Program (ASTP) updates for its source of current knowledge of the effects of weightlessness and acceleration/deceleration. To a lesser extent we have used biomedical results of all prior manned missions flown by the United States as well as the groundbased experimentation done in conjunction with these flight programs. Reports of studies performed by the Soviet Union have been used to a rather limited extent because of the frequent lack of a credible source or sufficient supporting data.

It is recognized that the sources of current knowledge are programs which subjected crewmembers to situations and conditions which are not fully representative of the situations and conditions that future SPS space workers will encounter. NASA and Boeing personnel assigned to this study have made a determined effort to identify and define the nature and influence of these differences in formulating their prediction of adverse effects. Factors involved comparing past and future missions are shown in Figure 1. Some of the major differences in the program requirements relating to the SPS space workers vs. the astronaut crews are shown in Figure 2.

FACTORS INVOLVED IN COMPARING PAST AND FUTURE MISSIONS

CREW(SPACE WORKERS)
- TYPE OF PERSONNEL
- PREPARATION AND TRAINING
- PRE, IN, POST FLIGHT ACTIVITIES
- REGIMENTATION AND DISCIPLINE
- ETC.

MISSION FLIGHT PARAMETERS
- ORBITS
- ACCELERATIONS
- SOLAR ACTIVITY PERIODS
- ETC.

HABITAT
- ENVIRONMENTS
- SHIELDING
- RECREATION AND REST
- FOOD AND NUTRITION
- PRIVACY
- ETC.

CAREER*
- TOTAL TIME IN SPACE
- CUMULATIVE PSYCHOLOGICAL/ PHYSIOLOGICAL EFFECTS
- JOB FATIGUE
- SPACE TIME/GROUND TIME

*NOTES: DURING A 5-YEAR CAREER WITH A 90 DAY UP/90 DAY DOWN A PERSON MAY SUFFER FROM SPACE ENVIRONMENT EFFECTS FOR 4 TO 5 MONTHS OUT OF EACH 6 MONTHS, RESULTING IN A CAREER SITUATION OF BEING IN A DEVIATE PHYSICAL CONDITION FOR 3½ TO 4 YEARS OF THE 5 YEAR TOTAL.

AFTER THE 84 DAY SKYLAB MISSION, TWO CREWMEN HAD NOT REGAINED HEEL BONE CALCIUM BY DAY 95 POSTFLIGHT.

FIGURE 1

MAJOR DIFFERENCES IN PROGRAM REQUIREMENTS RELATING TO THE SPACE WORKERS VS. ASTRONAUT CREWS

1. THE TYPE OF PERSONNEL SELECTED:

SPACE WORKERS		SKYLAB ASTRONAUTS
• MALE-FEMALE	VS.	• ALL MALE
• BROAD AGE RANGE	VS.	• LIMITED RANGE
• PHYSICALLY BASICALLY UNSCREENED	VS.	• PHYSICALLY SCREENED AND DEVELOPED
• LARGE CREWS	VS.	• 3 MAN CREW

2. THE EXTENT AND TYPE OF CREW PREPARATION FOR SPACE DUTIES:

SPACE WORKERS
- SHORTER PREPARATION TIME AND TRAINING, LIMITED PRIMARILY TO JOB RELATED ACTIVITY, WITH MINIMUM SPACECRAFT PHYSICS & SYSTEMS, HABITABILITY, ETC.

SKYLAB ASTRONAUTS
- SEVERAL YEARS OF BROADBASED EDUCATION AND TRAINING IN ALL ASPECTS OF MISSION ACTIVITIES WITH EXTENSIVE EDUCATION IN FUNDAMENTALS OF ALL SCIENCES INVOLVED IN PROGRAM.

3. THE NATURE OF THE MISSION ACTIVITY ASSIGNMENTS AND THE FREQUENCY AND DURATION OF FLIGHT TIME/GROUND TIME:

SPACE WORKERS
- BROAD VARIETY OF SPECIALIZED MANUAL, CLERICAL, STAFF SKILLS (WITH MINIMUM PROFESSIONAL ENGINEERING AND SCIENTIFIC SKILLS).
- WORK AT PEAK EFFICIENCY FOR MAXIMUM SAFE PERIOD DURING MISSION. RETURN TO SPACE IN SHORTEST SAFE AND PRACTICAL TIME.

SKYLAB ASTRONAUTS
- EACH CREW MEMBER CAPABLE OF ALL SCIENTIFIC, TECHNICAL AND MANAGEMENT REQUIREMENTS.
- WORK AT HIGHLY MOTIVATING JOBS AT CAREFULLY SCHEDULED TIME LINES BASED ON METABOLIC AND EXPERIMENT REQUIREMENTS, MISSION DURATION BASED ON CREWS' CONDITION (CAREFULLY MONITORED). RETURN TO SPACE NOT A PRESSING ITEM.

FIGURE 2

II. APPROACH

The approach used by NASA in performing this study was to assign highly qualified scientists in the various life sciences discipline areas to identify and define the possible environmental effects on the SPS space workers. The Boeing Company was selected to coordinate, compile and document the study results. NASA and Boeing participants drew extensively on documented research experience and available expertise from prior manned space flight programs.

Sources of information included:

- Documented biomedical results of Skylab and other manned space missions (USSR data was used to a limited extent, because of frequent lack of credible source or supporting data).
- Documented results of related ground-based biomedical research.
- Results of ground-based testing used to verify design and operational approaches.
- Information from other programs involving isolated crew habitation and confined quarters (Arctic and Antarctic activities, off-shore oil operations, underseas (Tektite), submarine duty, etc.).
- Direct contact with designated NASA or contractor expert consultants.
- Feedback from review meetings and comments on submitted reports.
- Internal Boeing expertise and technical reference sources.

The data base from these sources is quite comprehensive and included:

- Results of three major manned spaceflight programs (Apollo, Skylab and Apollo/Soyuz).
- Extensive ground-based and flight research in the major body systems (predominantly male humans as subjects).
- Experience gained from development of systems designed for supporting space flight. These systems related to health care, life support and protection, and environment and biological monitoring.
- Results of extensive ground-based development and demonstration testing. The testing validated systems design and operational approaches and provided crew training and familiarization opportunities.

III. DISCUSSION/RESULTS

A. STATUS

This study was completed early in January 1980 and a draft of the final report was distributed for NASA review on January 18. NASA review comments were incorporated and a final draft was submitted to DOE on February 18. The report was identified as Final Report - Interagency Agreement No. DE-A102-79CH10025, "Assesment of the Effects of the Zero Gravity Environment on the Health and Safety of Space Workers" January 31, 1980. The report presents a comprehensive review of the effects of the space environment on man, methods of preventing or ameleorating these effects, and a plan for acquiring additional information useful in predicting and counteracting adverse effects. This 15 page summary report describes in brief form the study accomplishments.

B. KEY FINDINGS

A review of available information on previous manned space flights has revealed no physiological responses to the space flight environments considered in this study that would jeopardize the health and safety of SPS space workers.

In this study weightlessness, acceleration/deceleration and certain other space environment factors were considered. Since the weightlessness of space flight has been available for scientific investigation only since the early 1960's, NASA has concentrated the major part of its biomedical research efforts in the study of the human's physiological response to this unique environment.

PHYSIOLOGICAL EFFECTS

Weightlessness is known to affect several physiological systems including cardiovascular, vestibular, fluid and electrolyte control, other hormonal, and musculoskeletal. Many of the changes that occur are not fully apparent until return to the one-g environment.

Gravitational forces have been present in the evolutionary development of every species of land animal and plant. To enable man and other animals to acquire and maintain posture and bodily orientation in normal gravity, the central nervous system interprets and integrates visual, kinesthetic, vestibular, and statokinetic signals to produce the "appropriate" gravity-dependent sensorimotor response. Both the system of complex receptors within the body and the learned central nervous system interpretations are tuned to the terrestrial weight/force relationship. Further, the cardiovascular systems of man and of other animals have evolved anatomical structures and physiological mechanisms (e.g., carotid sinus reflex) to deal successfully with changes of orientation with respect to gravitational forces.

In essence, the "stress" of zero-g is the removal of gravitational forces to which the organism has adapted through evolutionary time and for which the body is genetically programmed to respond. Adaptation to the zero-g environment involves disuse or modified use of these structures and mechanisms. Rapid and complete adaptation to a zero-g environment is desirable for enhanced performance during space flight. However, the degree of adaptation during zero-g exposure may affect the severity of problems encountered upon return and re-adaptation to the one-g environment.

C. RESULTS

Zero-g effects in some major physiological areas are summarized in the following paragraphs.

Gross-Level Effects

1. Antigravity muscles lose mass, probably comprised of fluid surrounding the muscle fibers and protein from the muscle fibers themselves. Other skeletal muscles appear not to exhibit these losses, or at least not to the same degree. There is a small, reversible loss of strength and ability to perform work at maximal levels.

2. Skeletal integrity is compromised by slow losses of the protein matrix of bone as well as of bone mineral, leading toward osteoporosis. Recovery is known to require a protracted period of time.

3. There is a fluid shift, particularly from the lower body to the head and upper torso, with some fluid loss, primarily from the blood plasma and interstitial fluid of the leg musculature. The fluid shift to the upper regions results in the engorgement of veins, puffiness of distensible regions of the face and neck, sinus and oropharyngeal congestion and possibly may contribute to the development of untoward vestibular responses including nausea and vomiting.

4. Cardiovascular adaptability or competence (orthostatic tolerance) is compromised as reflected by increased pulse rate and decreased blood pressure during stress tests (including LBNP) and erect standing in normogravity following space exposure.

Less Important Effects

Less obvious changes that may be secondary or tertiary level effects include:

1. A tendency to incur skin infections; this may be a result of cellular or humoral immunity or defense system depression, inadequacy of provisions for maintaining hygiene, increased trauma to the skin, or other cause(s).

2. A loss of red cell mass, probably related to depression of hemopoietic capabilities.

3. Changes in neuro-endocrine activity as measured in blood and urine, with special reference to electrolyte and water balance, electrolyte and plasma volume losses.

4. Physical injury produced by a too-confining space garment after the subject has experienced elongation in null gravity.

5. An indication of compromised bioenergetic control in that maximal work capability is reduced and the calibratable responses among energy output, heart rate and oxygen uptake lose their quantitative interdependence.

The organ systems and functions recognized as sensitive to the changes to and from weightlessness are the musculoskeletal system, the hemopoietic system, the cardiovascular system, the immune system, the endocrine system (secondarily) and bioenergetic control.

Organ systems that have suffered minimal or no functional changes during space exposure include reproductive, digestive, respiratory (in zero acceleration), lymphatic, nervous (especially psychomotor, behavior, judgement, problem-solving ability), sensory (except vestibular), and excretory.

D. INFERENCES

The effects of null gravity in the various physiological systems of man are significant inasmuch as they impose distinct threats to work performance and safety. In planning and preparing for future flights, the potential impact of these effects must be assessed for each space venture, because mission success and safety in the presence of these adverse effects will depend upon what is required and who is required to do it. Thus, these physiological changes take on greater significance when work loads are greater, task demands are more versatile, flight durations are lengthened or intermittent, or increased g exposures are introduced, all of which are likely to characterize flight requirements of the future. Similarly, with the inclusion of more specialized personnel of both sexes and broader age groups as members of flight crews, greater susceptibility to these changes and less ability to sustain them may be anticipated.

PERFORMANCE FACTORS

A number of factors have been identified which may adversely affect the performance of space workers whether at a space work station, during extravehicular activity (EVA), or upon return to Earth.

At the Work Station

1. Absence of gravity as a stabilizing force rendering legs virtually useless both as (a) means of locomotion, and (b) means of support and stabilization.

2. Transient vestibular upset in probably 30% of subjects for 1 to 5 days.

3. Inherent manipulative neuromuscular mechanisms which depend upon gravity may be inappropriate.

Extravehicular

4. Subject must be provided with an ambient atmosphere and temperature compatible with life and comfort, as well as urine and waste collection capability for use during prolonged activities.

5. Life support equipment as currently designed (a) frequently restricts movement, (b) increases energy costs of most movements, and (c) may restrict maximum physiological workload because of limited cooling capacity. The absence of gravity for stabilization and locomotion adds to the complexity of EVA activities.

Return to One-g

6. Although not a direct part of weightless operations, with repeat flights, especially of short duration and/or quick turn around, the following should be considered:

   a. 30% of subjects will probably be affected by vestibular upsets for 1 to 4 days thus reducing the useful time available on short missions.

   b. The cardiovascular deconditioning of null gravity may result in orthostatic intolerance on return to one-g after even relatively short missions and loss of muscle mass/tone may sharply reduce one-g abilities possibly resulting in some degree of incapacitation after missions of more than 3-4 weeks. Bone demineralization may present problems in one-g after longer missions. Most of the preceding undesirable effects can be reduced or eliminated by appropriate inflight countermeasures.

COUNTERMEASURES

1. Improved design of suitable work stations, stabilization devices and tools/equipment will be the principal countermeasure for item 1b. A great deal of additional information is required particularly in the area of anthropometric and work/energy costs analysis in weightlessness.

2. Improved hand holds, lines and other devices/vehicles for intravehicular and extravehicular locomotion will be required (items 1a and b).

3. Vestibular disturbances peculiar to zero-g are still not understood and countermeasures cannot be developed until the definitive research has been done. The selection of individuals known to be insensitive to such disturbances and the allowance for lost schedule time in a percentage of unknown subjects appears to be only rational approach available at present.

5. Continued development of life support systems with increased efficiency will be required in item 4. A series of anthropometric and efficiency studies of suited individuals must be accomplished in one-g and weightlessness.

6. The effects of weightless deconditioning (item 6b) can probably be minimized on return to one-g by suitable diet and exercise regimens which suitably load both cardiovascular and musculoskeletal systems. Treadmills and other devices are available but should be improved through continuing one-g and weightless studies. New approaches should be attempted to minimize the bone demineralization problem. Combined LBNP (lower body negative pressure) and electrolyte (NaCl) replacement just prior to return to one-g, should aid materially in reducing post-flight orthostatic intolerance.

E. REGIONS TO BE EXPLORED

The SPS program is a "whole new ball game" for the scientists and engineers who must assure the health and safety of space workers. The large number and variety of types of people, the variety of tasks, the length of stay time vs. ground time, span of career, and exposure to LEO and GEO environments will require new design and operational approaches for life support and protective systems, habitability systems and health care systems.

The operational modes and environments will introduce psychological and sociological situations which may impact the workers as well as their families and Earth-based associates. These considerations introduce new areas of research for NASA and DOE.

It is anticipated that NASA's involvement with the proposed SOC program will provide sufficient insight into the nature of these problems so that a timely recognition of development needs will result.

IV. GENERAL SUMMARY AND CONCLUSIONS

One crucial question must be addressed before committing to building and operating a Satellite Power System (SPS), and that is whether human workers can live safely and work efficiently in space, and if so, how long can they stay? What kind of effective work schedule can they maintain? And what is the total number and frequency of missions to plan as a career, in either LEO or GEO, without undue risk of life shortening or persistent disability?

NASA has gone a long way toward answering these questions. As part of the preparation to go to the moon (Apollo Program), NASA carefully explored the capability of astronauts to cope safely with the stresses associated with performing a vast battery of flight related tasks. During the Mercury and Gemini missions we learned that man could withstand the launch and reentry stresses, could perform complex mental and physical tasks for periods of up to 14 days, and could readapt to the Earth's gravity without adversely altering normal body functions. During Apollo we further expanded our knowledge and confidence in man's ability to safely and effectively perform complex tasks in the lunar and space environments and readily adapt to these changing environments. During Skylab NASA extensively explored man's ability to live and work in space through exhaustive biomedical experiments and by monitoring the inflight opration of several major health/life support subsystems.

Inflight research experiments were designed to contribute to the understanding of the functioning of major body systems. Body systems and functions studied included the cardiovascular, cardiopulmonary, musculoskeletal, hematologic, vestibular, renal, metabolic, neurological and endocrine systems. Few systems were not affected; the majority showed adaptive changes, and there were indications of progressive changes (bone demineralization and muscular atrophy) that in the long term could limit stay times unless corrected.

In Skylab, major emphasis was placed on the evaluation of health support subsystems, including food, waste management, personal hygiene, and inflight medical support. The data base thus acquired lends itself to informed planning for future long-duration missions.

The combined results of the medical experiments and the operational medical subsystems evaluations through stay-time of 84 days provided a high degree of confidence in the ability of man to work and live safely in a space environment for periods which may exceed 120 days, and the Soviets have extended this period to 6 months.

Although most adverse effects experienced during space flight soon disappeared upon return to the Earth's environment, there remains a definite concern for the long term effects upon an SPS space worker who would spend half his time in space for a five-year career period. The proposed 90-day up/90-day down cycle, coupled with the fact that many of the effects of weightlessness may persist throughout the flight period and that recovery from these effects may occupy much of the terrestrial stay, warrents serious scrutiny. These circumstances may keep the SPS workers in a subnormal physical condition or state of flux for 60 to 100 percent of their five-year career, while they are adapting sequentially to cyclical Earth/space conditions. Further studies will be necessary before these "career" effects can be properly evaluated and appropriate stay-time versus recuperation time can be determined.

Based on this study, the consensus of opinion is that there is no substantial evidence to indicate that unpreventable or non-corrective adverse effects will be experienced by SPS space workers. It is further believed that, although additional potentially adverse effects may be identified prior to the early SPS missions, counteracting or ameliorating approaches can be developed in the same time span and adverse effects to the health and safety of SPS workers can be avoided or minimized.

This position should not be construed as implying that there are no concerns for the safety and health of the SPS space workers. It is based on the supposition that NASA/DOE will conduct adequate research and development to recognize potential threats and provide countermeasures to protect the workers. It further presumes that the workers will be selected, trained, and motivated to make proper use of equipment and approaches designed to make their careers in space both healthy and safe.

Several aspects of this study deserve consideration if the conclusions presented in this study are to be viewed in proper perspective.

1. The "current knowledge" used as a basis for conclusions was derived from manned flights in which the type and condition of the crew and the mission conditions relating to the exposure of the crew to adverse effects of the space environment were grossly different from those anticipated for future SPS space workers.

2. The final definition of the role that man will play and the details of his living and working condition will evolve during the next 15 to 20 years as we gain additional experience through such precursor programs as the Space Transportation System (STS) development and operations programs and the Space Operations Center (SOC) development and operations programs.

3. The NASA Life Sciences and Crew Systems organizations will gain an abundance of test data relating to the physiological/psychological stresses to be experienced by the SPS crews and their families and are confident that the means to ameliorate or prevent any adverse effects due to these stresses will be developed. This information can be made available to the DOE at appropriate intervals during the development phases of the SPS program.

4. Although certain biomedical problems are known to exist and additional problems can be expected when large numbers of people make a career of working in space, our scientists and technical experts believe that these problems will be resolved and that humans will be able to live and work effectively in space with no unusual compromise to their health, safety, or general well-being.

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